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ENVIRONMENTAL CHARGING OF SPACECRAFT SURFACES - TESTS OF THERMAL CONTROL MATERIALS FOR USE ON THE GLOBAL POSITIONING SYSTEM FLIGHT SPACE VEHICLE - PART 1: SPECIMENS 1 TO 5

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16. Abstract

The NASA/USAF program on the Environmental Charging of Spacecraft Surfaces consists, in part, of experimental efforts directed toward evaluating the response of materials to the environmental charged particle flux. Samples of thermal blankets and second surface mirrors of the type to be used on the Global Positioning System Flight Space Vehicle have been tested to determine their response to electron flux. The primary result observed was that the ground connection of the metal layers of the blanket, as made by the baseline grounding technique using serrated washers and grommets, deteriorated with time at test. The discharges observed on the blankets were the "glow" type, not the "lightning strike" observed on past specimens. Testing was performed at ambient laboratory temperatures.

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Environmental Charging of Spacecraft Surfaces - Tests of Thermal Control Materials for Use on the Global Positioning System Flight Space Vehicle - Part I: Specimens 1 to 5

N. John Stevens, Vernon W. Klinect, Frank D. Berkopec

INTRODUCTION

Several geosynchronous satellites have reported anomalous activity near the local midnight region of the satellite orbits. Concurrent measurements have revealed transient particle fluxes of higher than expected energies in the local evening and midnight sectors of the orbit. Subsequent work has shown correlation between solar substorms and the anomalous behavior of spacecraft. Simple models of the mechanism for spacecraft charging and discharging have been postulated; some engineering fixes have been incorporated in recent satellites. Anomalies persist, however.

A satellite immersed in an ambient plasma will come into electrical equilibrium with that plasma by developing the surface charges necessary to reduce the net current between the satellite and the plasma to zero. The net current consists of contributions from the environmental flux, secondary and backscattered electrons and ions, and photoelectrons from illuminated areas. A satellite with parts in the sun and parts in the shade can be expected to be differentially charged. When adjacent parts are differentially charged such that voltage stress is great enough, breakdown of charged dielectric material occurs. This discharge emits electromagnetic pulses. These electromagnetic pulses are the most likely cause of satellite anomalous activity. Other results of discharges are the degradation of thermal control surfaces, surface contamination, and unwanted fields.

As a result of these problems the NASA and the Air Force initiated a joint research and technology program on the environmental charging of spacecraft surfaces that consists of analytical and experimental efforts directed to ultimately result in a spacecraft charging design and test monograph. The analytical effort is being conducted to model the environment and to investigate the charging and discharging mechanisms. The experimental effort is being conducted to evaluate the response of materials to the environmental charged particle flux. Specific experimental efforts conducted as part of this program include the testing described in this report. This report presents the results of environmental charging tests performed on test specimens of thermal control multilayer insulation blankets and second surface mirrors of the type to be used on the Global Positioning System Flight Space Vehicles. The specimens were supplied by the Rockwell International Corporation and the testing was performed in response to a request by the Rockwell International Corporation through the Air Force.

Test data consists of the magnitude of test specimen leakage current with the test specimen in a representative electron environment and a count of the discharges (of a certain magnitude) that occur on the specimen. The electron environment is deemed to be both the most severe and the most informative environment to pursue. The discharges are discriminated as described in the Appendix.

The Global Positioning System Flight Space Vehicles will be nominally in a 10,989 nautical mile orbit with an inclination of 63 degrees. While environmental charging of spacecraft surfaces has been specifically identified at geosynchronous orbit, the possibility exists that the phenomena can be encountered at lower orbits. The environment at lower orbits is sufficiently unknown to justify the testing reported herein.

APPARATUS AND PROCEDURE

Specimens Tested

Specimen 1. - This is multilayer insulation with a .0127 cm (5 mil) aluminized Kapton outer sheet, Kapton surface facing outward, and 15 layers of 0.00064 cm (1/4 mil) single aluminized Mylar. Grounding is achieved with grommeted, serrated washers making contact with the conductive (metallic) side of each layer. A single ground wire is attached to a terminal lug on the same grommet as the washers. The specimen is 30 cm by 30 cm (12 by 12 inches).

Specimen 2. - This specimen is identical to Specimen 1 except that the outer sheet is aluminized Teflon.

Specimen 3. - This specimen differs from Specimen 1 only in the grounding method. A 0.00064 cm (1/4 mil) aluminum foil strap is taped to the conductive side of each layer. These straps are electrically connected to ground.

Specimen 4. - This specimen is identical to Specimen 3 except the outer layer is aluminized Teflon.

Specimen 5. - This specimen consists of 16 fused silica second surface mirrors bonded to a 10 cm by 10 cm (4.06 inches by 4.06 inches) sheet of aluminum 0.15 cm (.06 inches) thick. Each mirror is 2.54 ±0.0076 cm by 2.54 ±.0076 cm (1 ±.003 by 1 ±.003 inches) and 0.02 cm (.008 inches) thick.

Facility

The facility, instrumentation, and test procedure are described in Appendix 1 of this report. Testing was performed at ambient temperatures.

Electron Beam Calibration

The electron beam at the specimen location was mapped with a five probe rake. This rake consisted of five current probes spaced horizontally 15.2 cm (6 inches) apart with the center probe centered on the sample. The rake was moved vertically through the beam. Current readings were taken every 7.6 cm (3 in.) from 38.1 cm (15 inches) above specimen center to 38.1 cm (15 inches) below specimen center.

Contour plots of current density at the nominal specimen plane were made from the data obtained. These are based on linear interpolation between the data points and show beam contours at the test conditions. A typical current density contour plot is shown in Figure 1.

Resistance Measurements

In addition to the measurements described in the appendix of this report, the resistance of each multilayer insulation blanket was measured from the ground attachment point to a point on the aluminum surface of the outermost blanket. These measurements were made before and after each test sequence.

RESULTS

The data from these tests are of two types: that which is taken when no discharges are occurring, and that which is taken when they are occurring.

When no discharges occur, the specimen current is obtained as a function of time, and in general the specimen current reaches a steady-state leakage current. A representative value of leakage current was chosen from each test and converted to current per unit area of specimen. This is presented in Table 1. The individual plots of specimen current as a function of time for various beam voltages are presented in Figures 2, 3, and 5 for Specimen1, Figures 7 and 8 for Specimen 2, Figures 10 and 11 for Specimen 3, Figures 13 and 14 for Specimen 4, and Figures 16, 17, and 18 for Specimen 5.

The data obtained when discharges are occurring is the number of discharges per unit time. This is plotted both cumulatively and directly. The individual plots of discharge activity are presented as the cumulative number of discharges per unit time in Figure 4 for Specimen 1, Figure 9 for Specimen 2, Figure 12 for Specimen 3, Figure 15 for Specimen 4, and Figure 19 for Specimen 5. The plots of discharges per unit time are presented in Figure 6 for the Specimen 1 life test, Figures 20 and 21 for Specimens 1 through 5 for the 1 nA/cm^2 current density and Figures 22 and 23 for Specimens 1 through 5 for the 10 nA/cm^2 current density.

Table 2 presents the resistance measured between the aluminized surfaces of the outer blanket layer and the ground connection of the sample.

DISCUSSION

Visual Observations of Testing

Multilayer Blankets. - The multilayer blankets were observed when discharges occurred. The only discharges observed were "glow" type discharges. This was true at both current densities and at all beam voltages at which discharges occurred. There were no "pinpoint" discharges or "lightning strikes" as have been observed on other specimens. On some occasions there seemed to be a concentration of the "glow" at the thread on the border of the sample.

Second Surface Mirror. - At the 1 nA/cm^2 current density the specimen did not begin having countable discharges until the 18kV beam voltage was reached. "Pinpoint" discharges were observed in the lines between the mirror segments.

At the 10 nA/cm^2 current density, the counted discharges began at 14kV. Both "pinpoint" and "lightning strike" type discharges were observed. These took place both in the lines between the mirror segments and on the faces of the mirrors. Some of these seemed to be preferential sites in that discharges repeatedly took place at these locations.

Grounding Techniques

There was change with time of the resistance to ground of the conductive surface of the outer sheet of the thermal blanket specimens using the serrated washer grounding system. Table 2 shows that the serrated washer system degraded in both specimens; the connection in specimen 2 ultimately opened.

There was no apparent change in the resistance to ground of the multiple ground strap system.

Leakage Current

Individual plots of leakage current data show the general trends of polymeric films in the NASA-LeRC test chamber simulation of the electron environment. The plots in Figure 2 are typical. The initial charging of the specimens by the incident beam occurs in several minutes; shorter charging times are observed with higher flux. Steady-state leakage current is usually attained in minutes but tests are continued to 20 minutes to insure that a steady state is observed and sufficient data is obtained.

Discharges

Table 1 presents leakage current data for the values of electron beam voltage for which no discharges were encountered. It can be seen that for the multilayer insulation blankets, specimens 1, 2, 3 and 4 discharges did not begin to occur until 10kV had been exceeded at both the 1 nA/cm^2 and 10 nA/cm^2 current densities. This is in agreement with past experience. The second surface mirror specimen did not experience discharges until 16kV had been exceeded at 1 nA/cm^2 and until 12kV had been exceeded at 10 nA/cm^2. This is in agreement with past experience. Individual plots of discharge count data show typical and not unexpected trends: increasing discharge counts with increasing beam voltage and increasing beam current.

CONCLUDING REMARKS

Environmental charging tests have been performed on samples of thermal control materials for the Global Positioning System Flight Space Vehicles. These tests have shown the environmental charging - induced discharges to be of the "glow" type, not the "lightning" type observed on past specimens (this data is obtained by visual observation). The primary result obtained was that the ground connection of the metal layers of the blanket, as made by the baseline grommet/serrated washer technique, deteriorated with time at test.

AUTHORS' STATEMENT

Current practice in the field of spacecraft thermal control involves use of specific materials. Trade names and similar identifications cannot be replaced by adequately descriptive generic terms. Trade names, therefore, have been used in this report. Thus, reference has been made to Kapton, Teflon, and Mylar, plastic films produced by the E. I. duPont deNemours & Co., Inc.

Table 1. - Summary of Specimen Leakage Current per Unit Specimen Area

Specimen	Incident Current Density (nA/cm^2)	Specimen Leakage Current Density (nA/cm^2) Beam Voltage (kV)							
		5	8	10	12	14	16	18	20
Specimen 1, Kapton/Mylar MLI **	1.0	0.43	0.33	0.32	*				
	10	1.8	1.6	21					
Specimen 2, Teflon/Mylar MLI	1.0	0.22	0.28	0.25					
	10	1.5	1.0	1.1					
Specimen 3, Kapton/Mylar MLI	1.0	0.31	0.35	0.31					
	10	1.7	1.8	1.9					
Specimen 4, Teflon/Mylar MLI	1.0	0.26	0.24	0.24					
	10	2.1	0.95	0.92					
Specimen 5, Second Surface Mirrors	1.0	0.52	0.52	0.50	0.45	0.42	0.46		
	10	2.4	2.0	1.7	2.3				

* Each absence of data is due to specimen discharging. The frequency of discharging prevented the measurement of steady state leakage current.

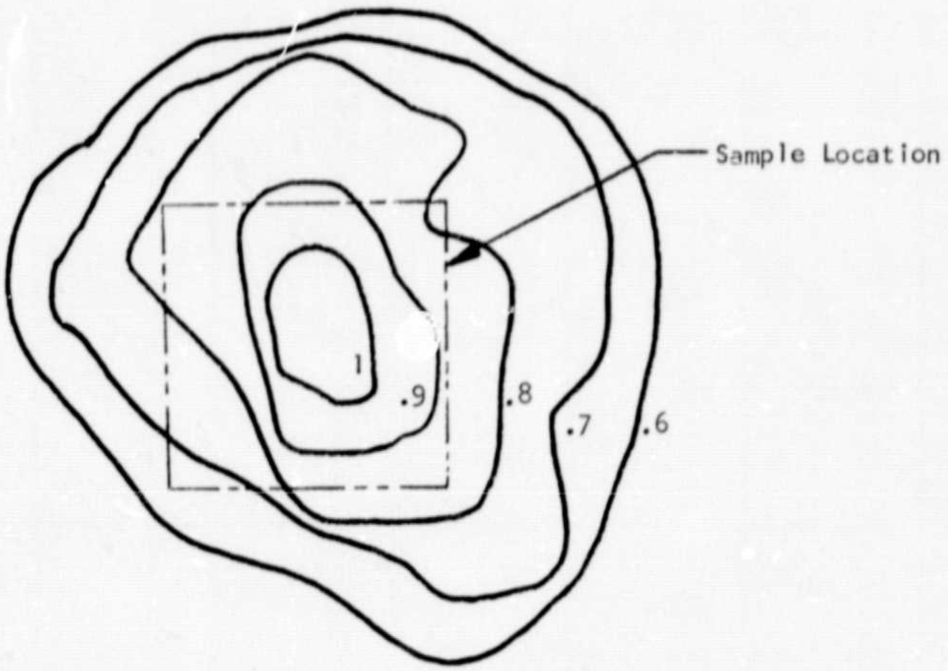
** MLI : Multilayer Insulation

Table 2. - Specimen Grounding System Resistance

Specimen	Resistance (ohms)**		Test
	Before Test	After Test	
Specimen 1 Kapton/Mylar MLI*	Not Measured	190	Survey
	190	3800	Extended Duration
Specimen 2, Teflon/Mylar MLI	5	Open	Survey
Specimen 3, Kapton/Mylar MLI	2	2	Survey
Specimen 4, Teflon/Mylar MLI	Not Measured	2	Survey
Specimen 5, Second Surface Mirror	1	1	Survey

* MLI:multilayer insulation

** Measured from aluminized side of outer sheet to ground connection terminal lug of ground wire.



Data is nanoamperes per square centimeter.

Figure 1. - Typical electron beam current density in the sample plane.

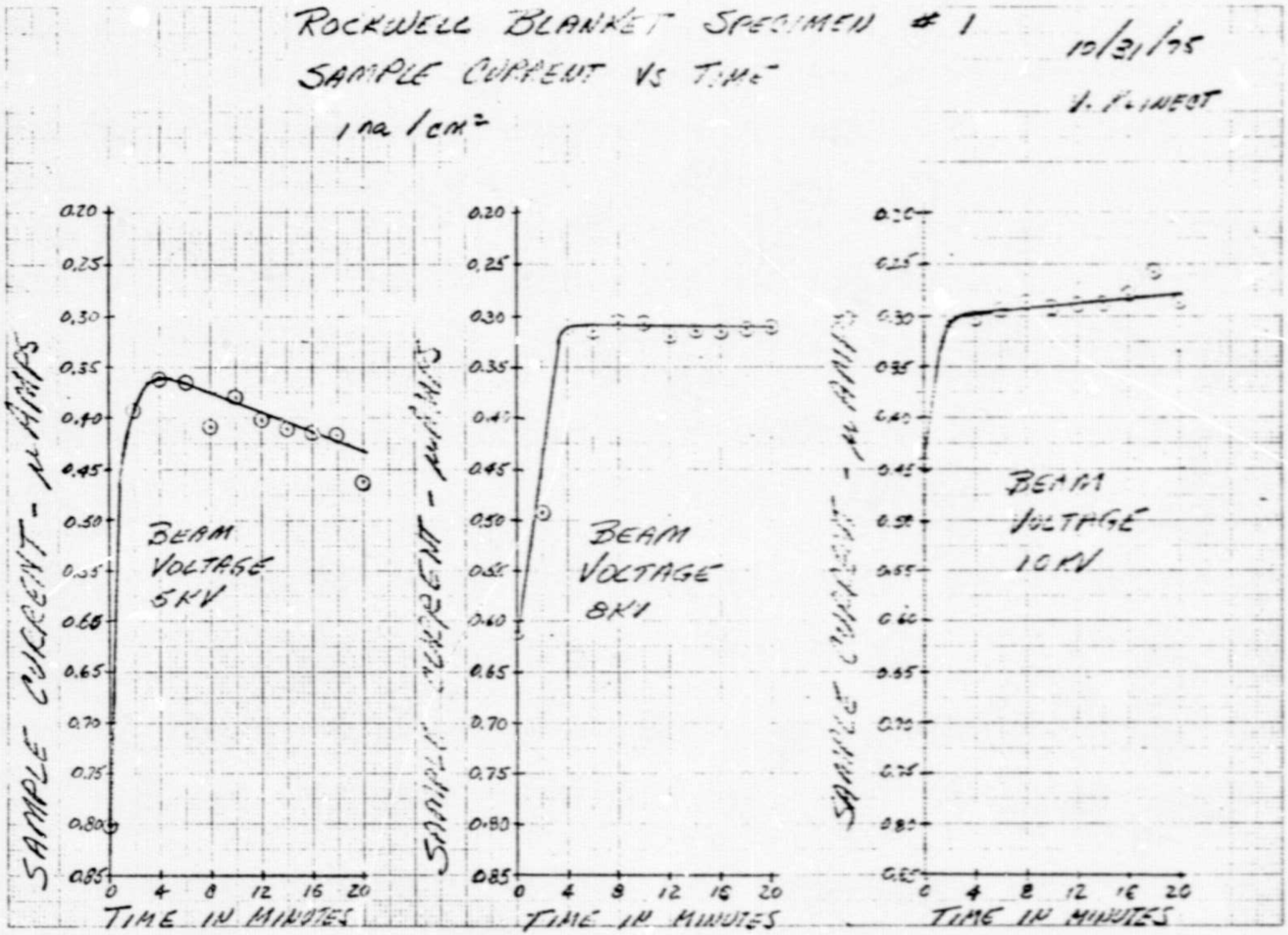


Figure 2. - Specimen current as a function of time for various beam voltages at 1 nanoampere per square centimeter current density; Specimen 1, aluminized Kapton outer sheet, grommeted, serrated washer grounding technique.

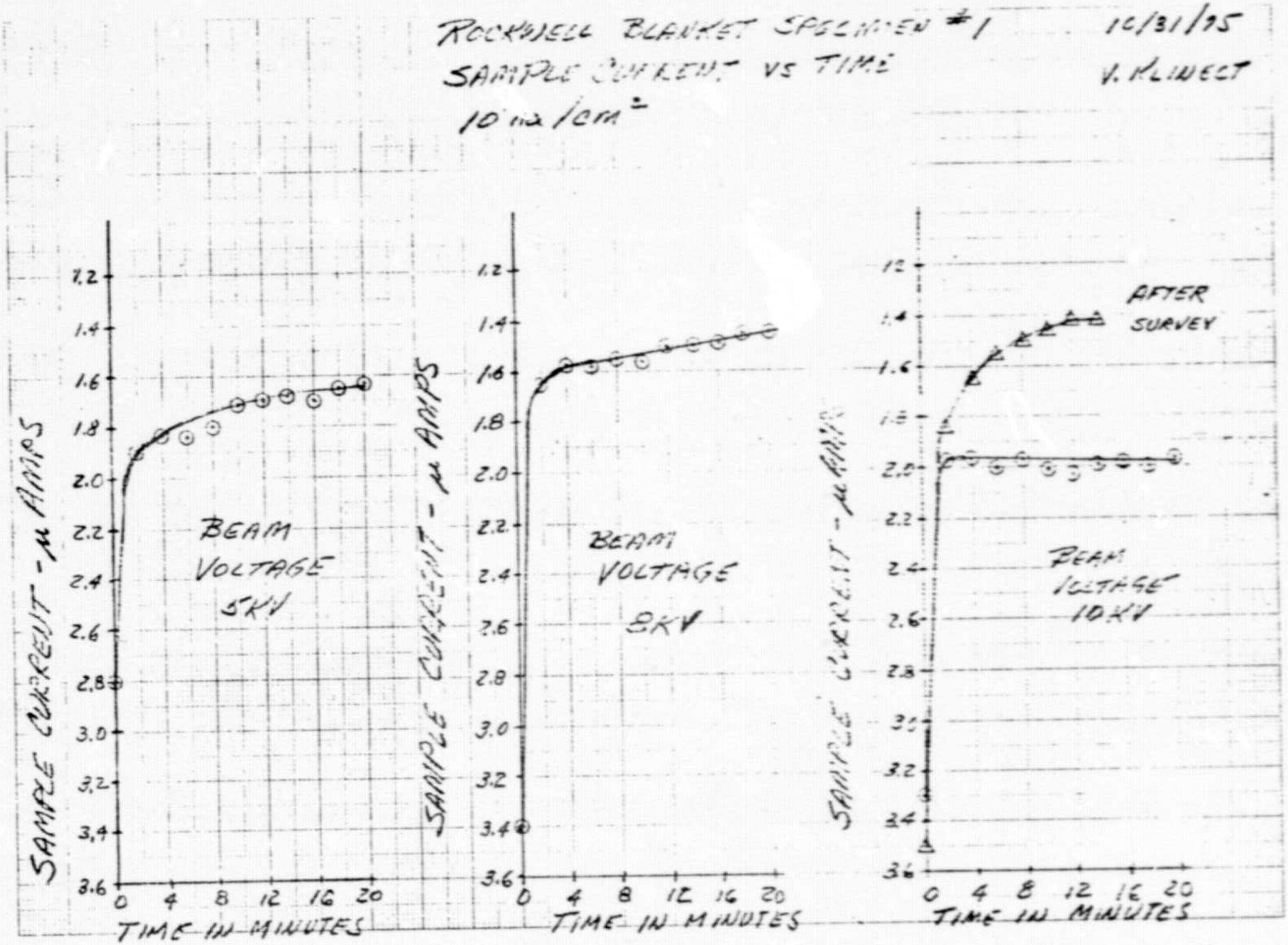


Figure 3. - Specimen current as a function of time for various beam voltages at 10 nanoamperes per square centimeter current density; Specimen 1, aluminized Kapton outer sheet, grommeted, serrated washer grounding technique.

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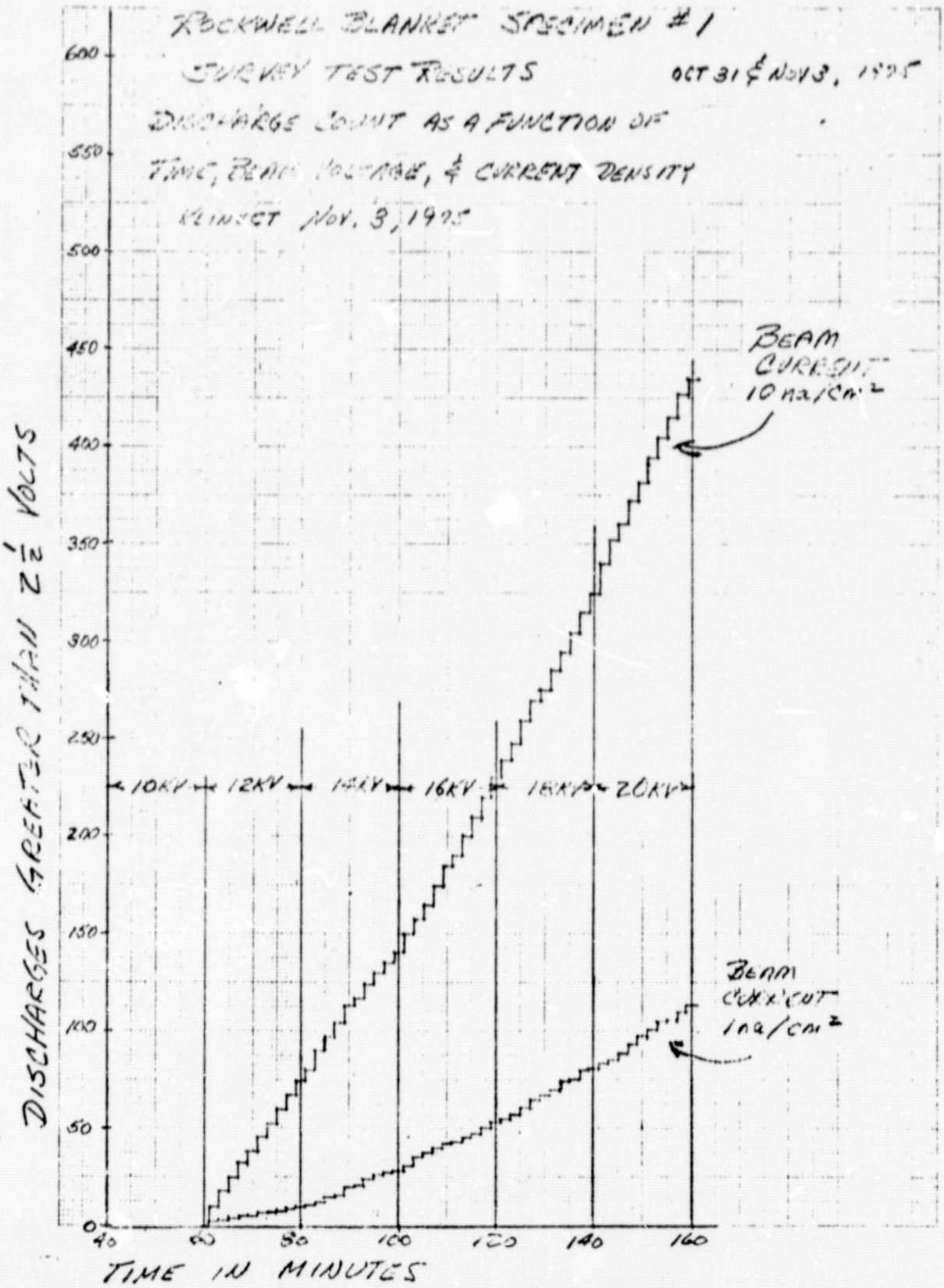

Figure 4. - Cumulative discharge count as a function of time for various beam voltages and current densities; Specimen 1, aluminized Kapton outer sheet, grommeted, serrated washer grounding technique.

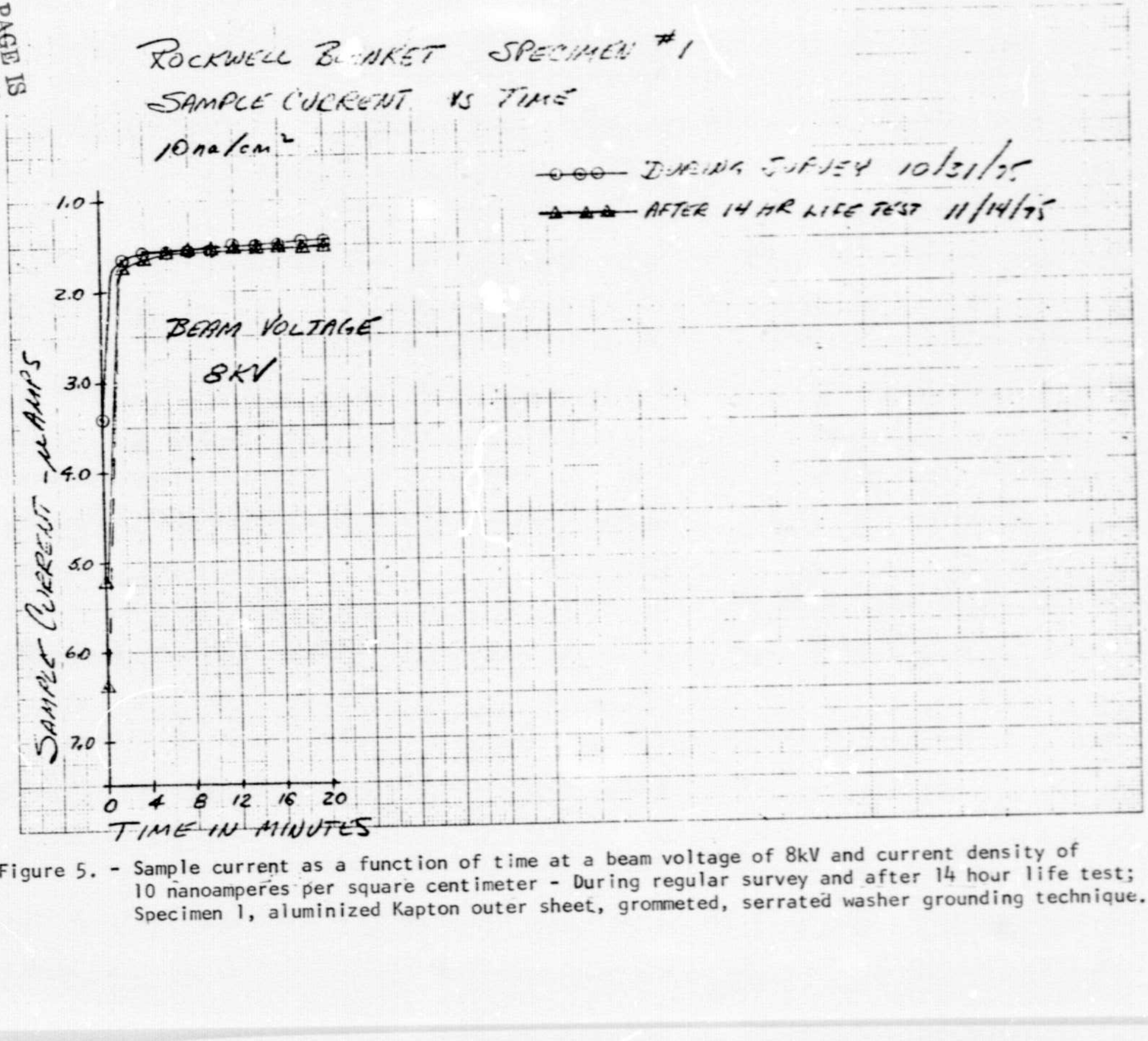

Figure 5. - Sample current as a function of time at a beam voltage of 8kV and current density of 10 nanoamperes per square centimeter - During regular survey and after 14 hour life test; Specimen 1, aluminized Kapton outer sheet, grommeted, serrated washer grounding technique.

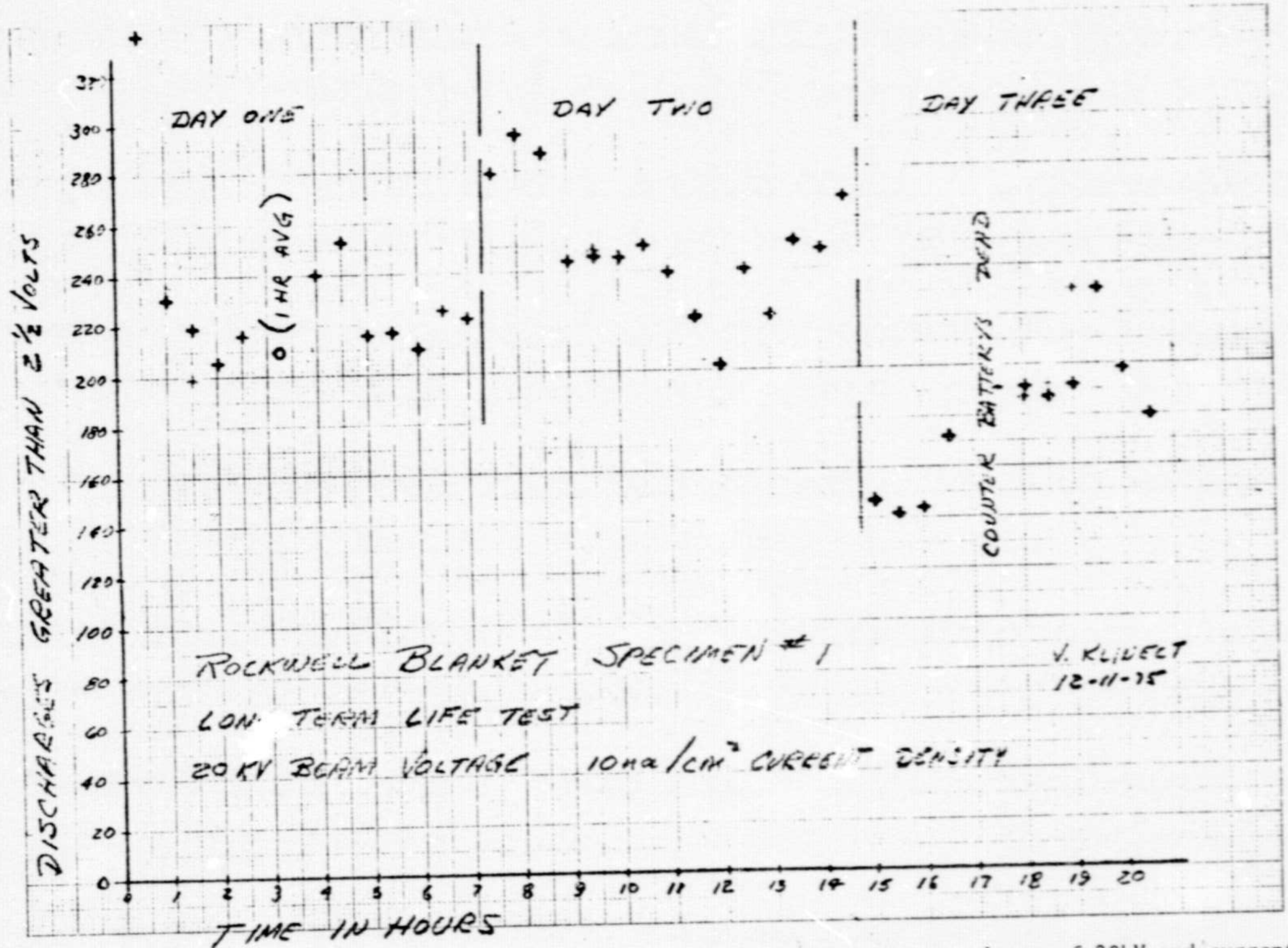

Figure 6. - Discharge count as a function of time for life testing at a beam voltage of 20kV and current density of 10 nanoamperes per square centimeter; Specimen 1, aluminized Kapton outer sheet, grommeted, serrated washer grounding technique.

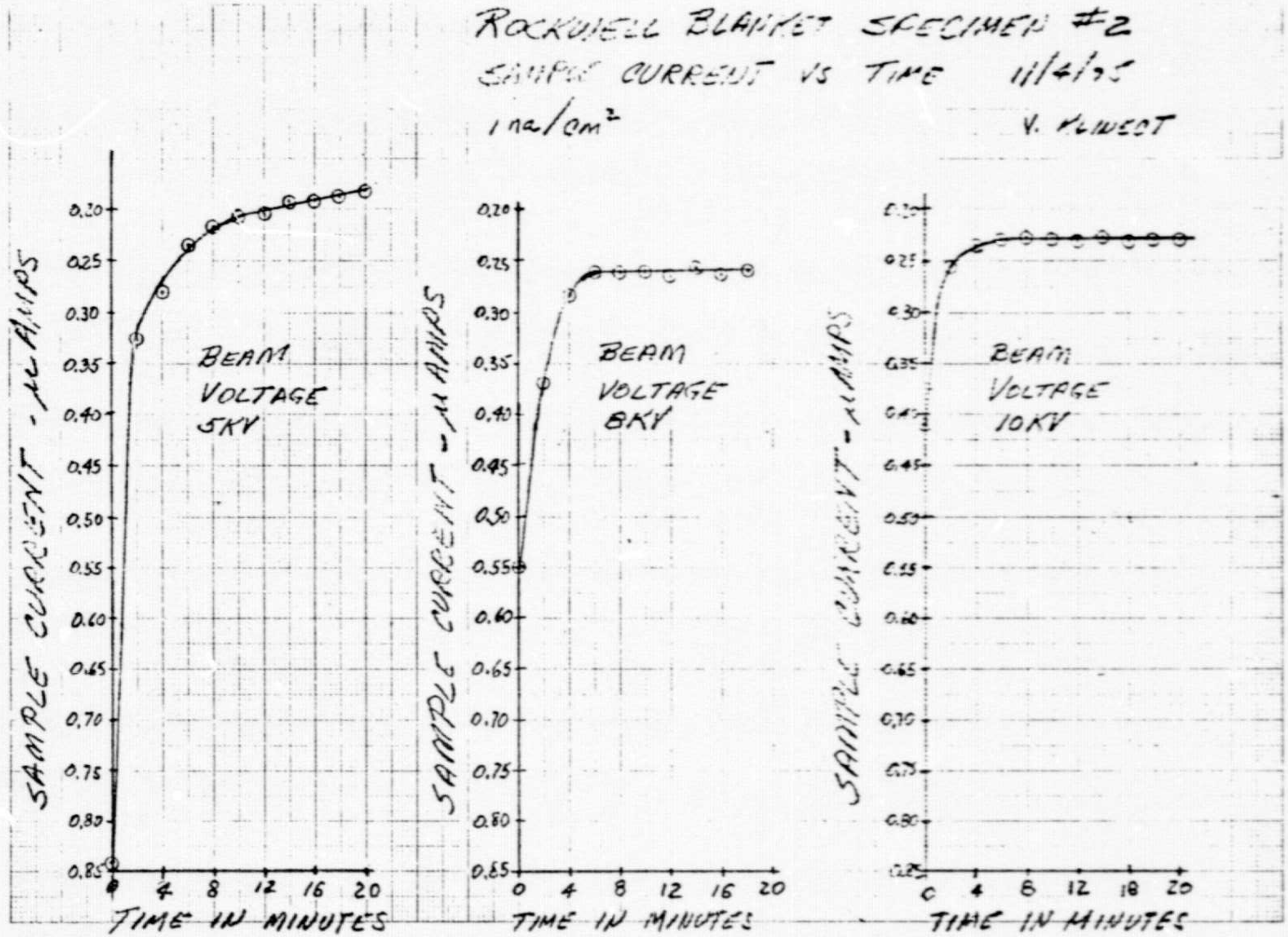

Figure 7. - Specimen current as a function of time for various beam voltages at a current density of 1 nanoampere per square centimeter; Specimen 2, aluminized Teflon outer sheet, grommeted.

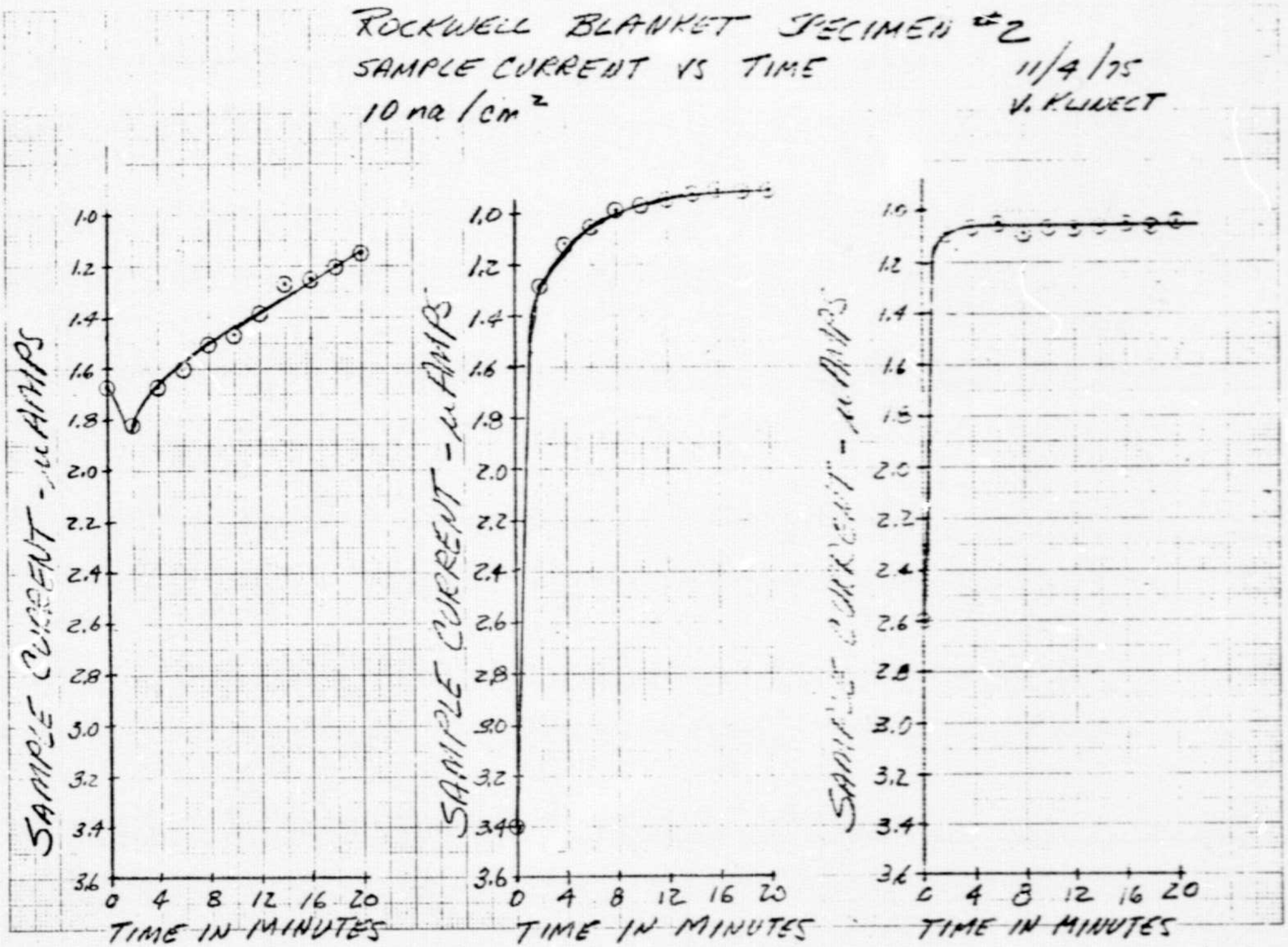

Figure 8. - Specimen current as a function of time for various beam voltages at a current density of 10 nanoamperes per square centimeter; Specimen 2, Aluminized Teflon outer sheet, grommeted, serrated washer grounding technique.

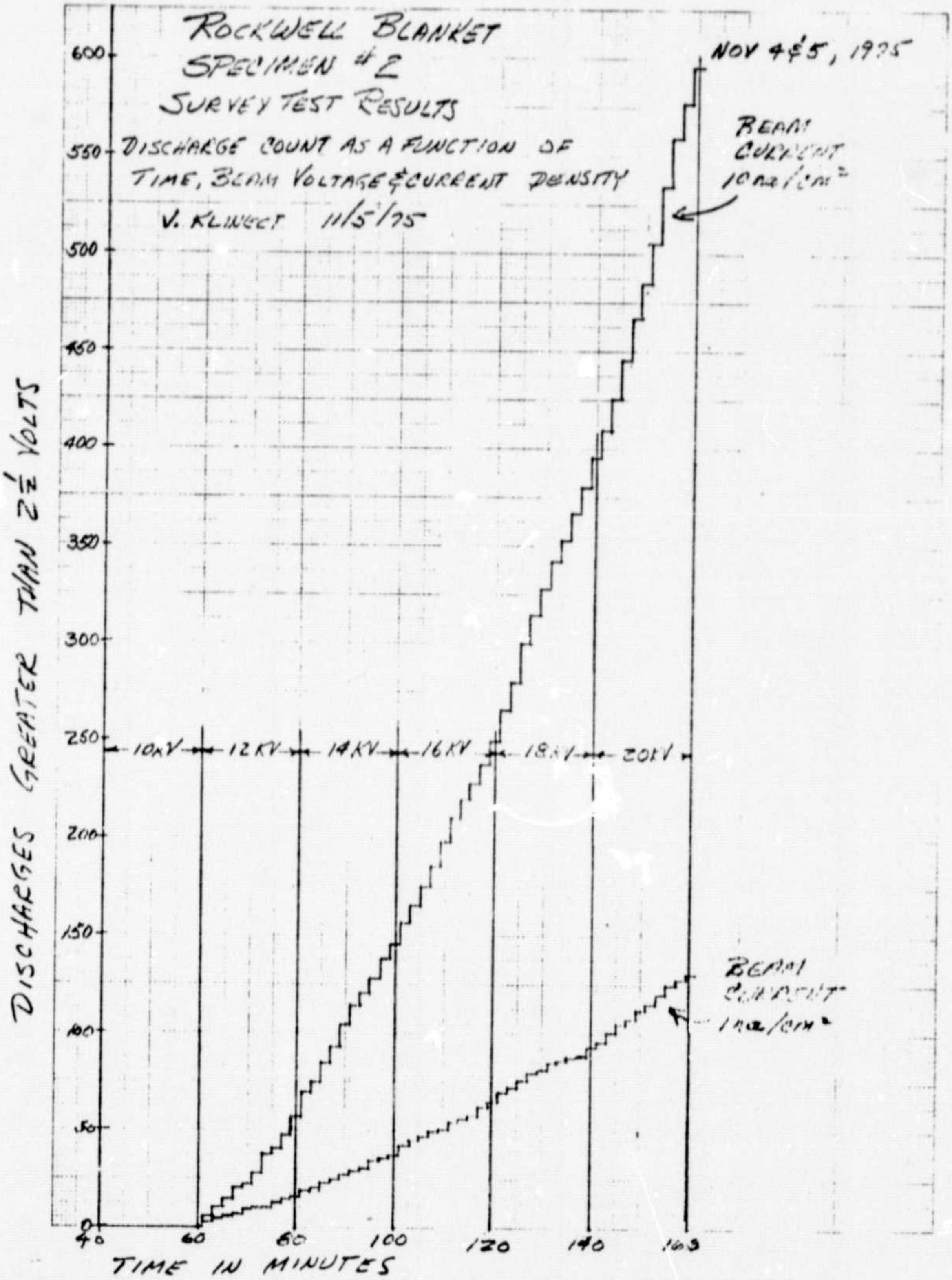

Figure 9. - Cumulative discharge count as a function of time for various beam voltages and current densities; Specimen 2, Aluminized Teflon outer sheet, grommeted, serrated washer grounding technique.

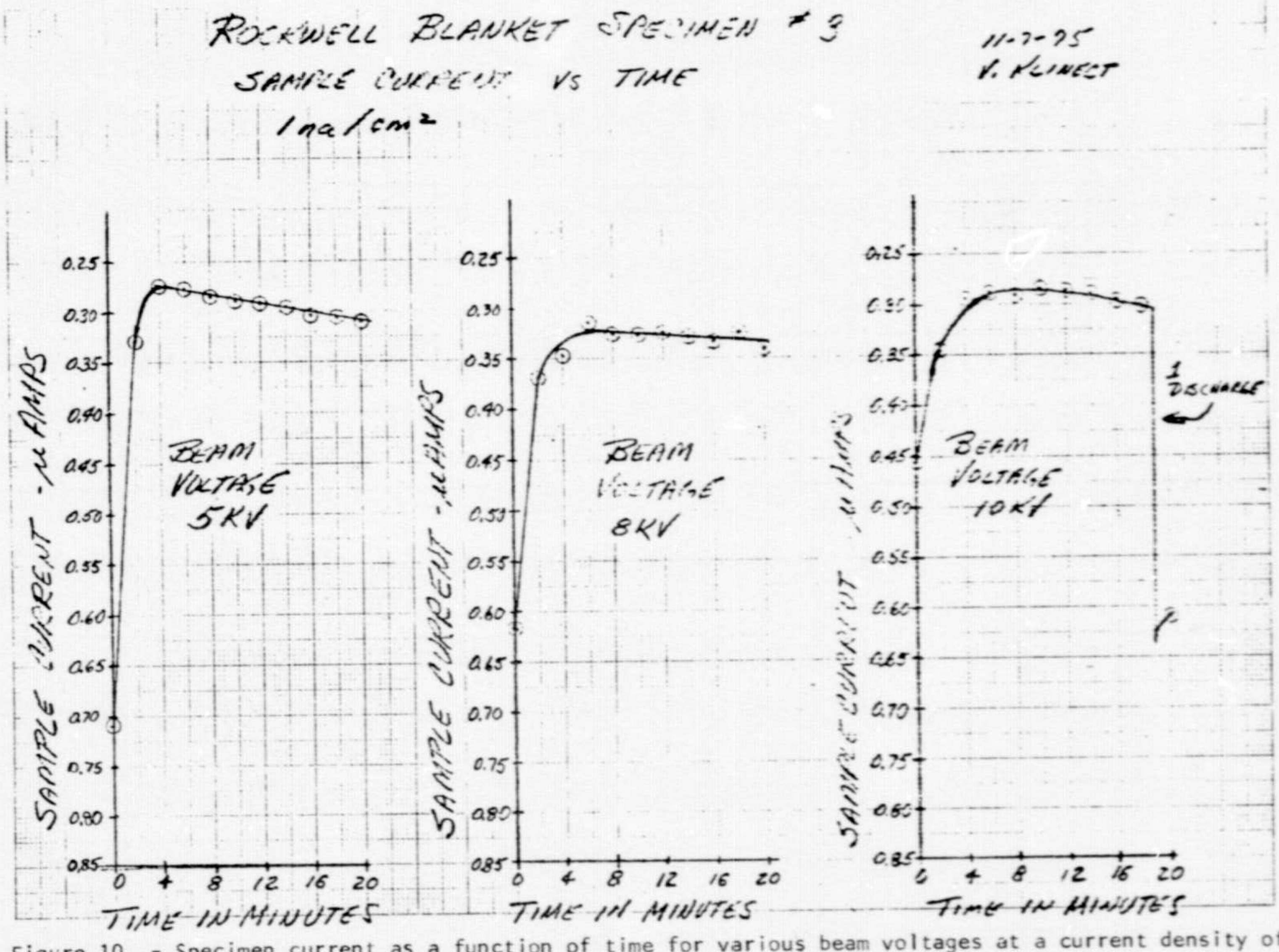

Figure 10. - Specimen current as a function of time for various beam voltages at a current density of 1 nanoampere per square centimeter; Specimen 3, Aluminized Kapton outer sheet, taped aluminum foil ground strap.

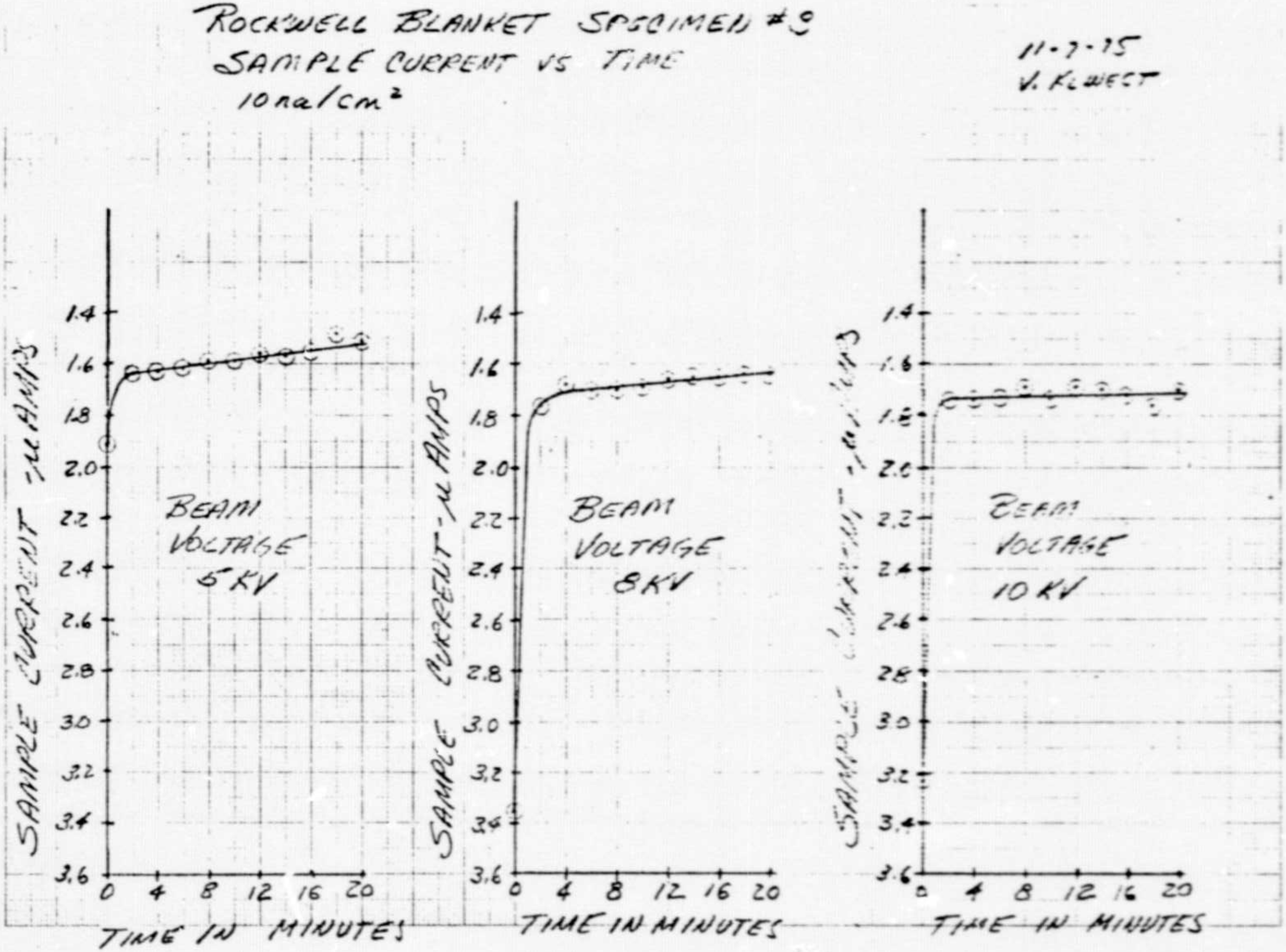

Figure 11. - Specimen current as a function of time for various beam voltages at a current density of 10 nanoampères per square centimeter; Specimen 3, Aluminized Kapton outer sheet, taped aluminum foil ground strap.

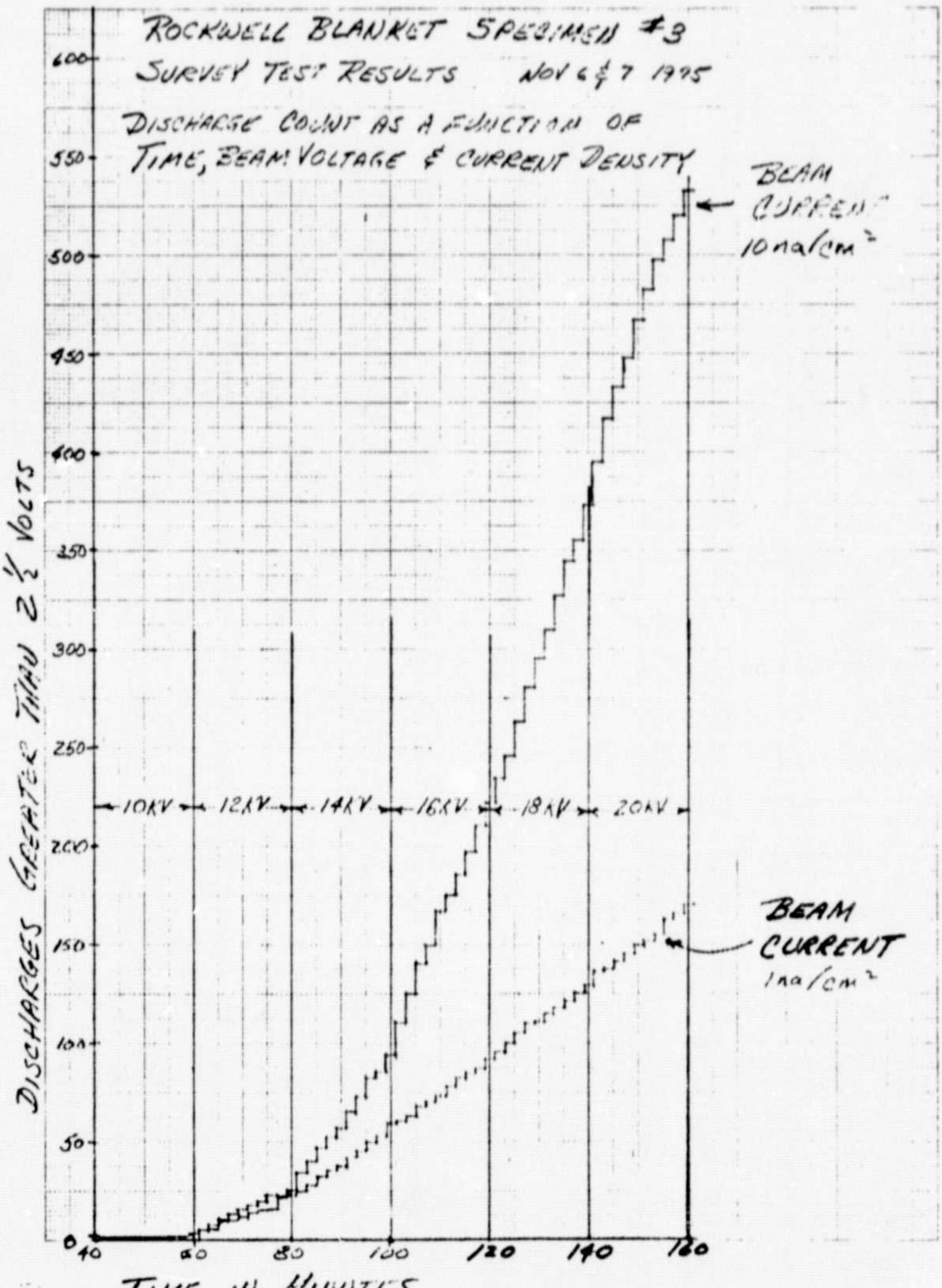

Figure 12. - Cumulative discharge count as a function of time for various beam voltages and current densities; Specimen 3, Aluminized Kapton outer sheet, taped aluminum foil grounding strap.

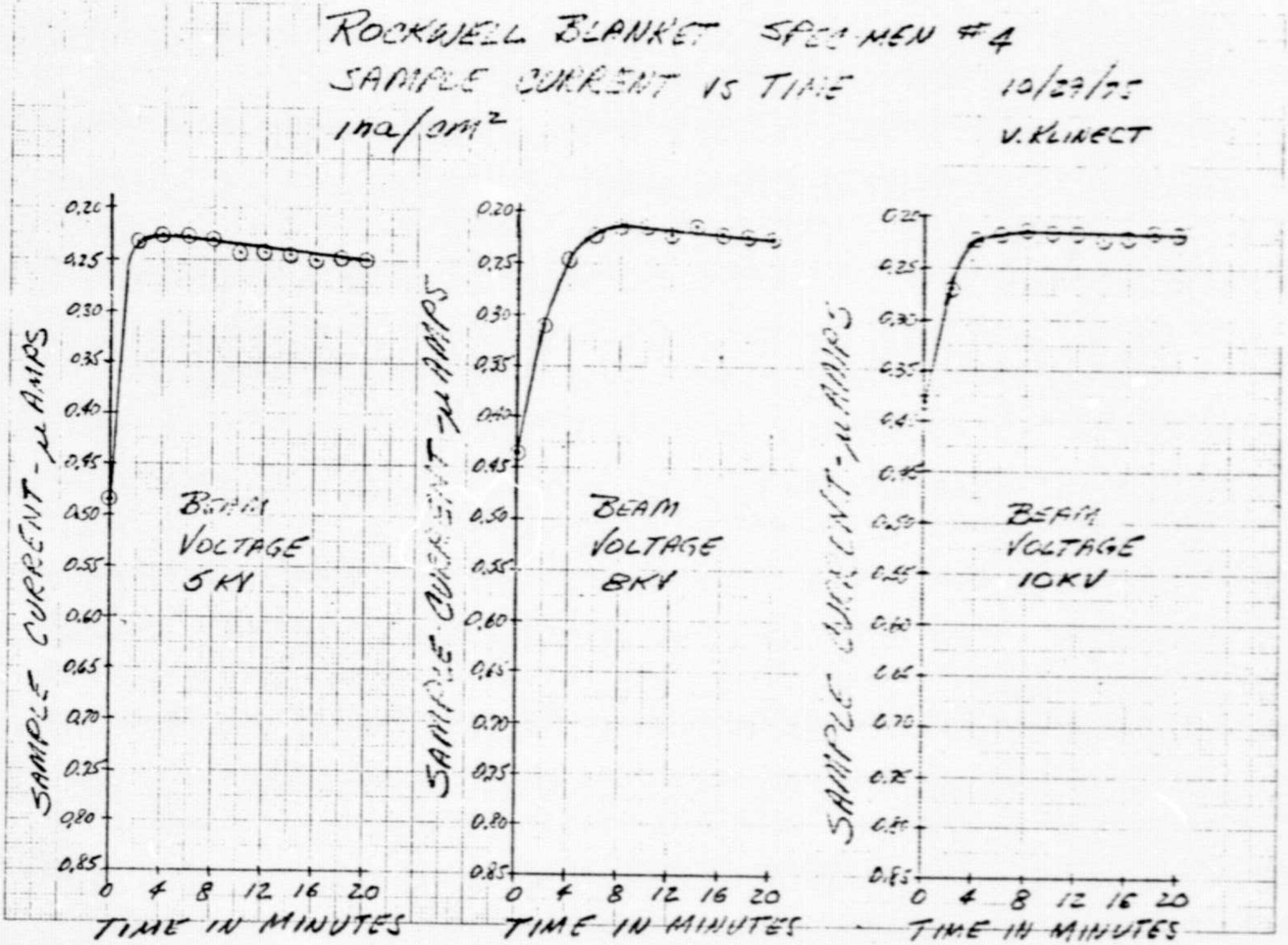

Figure 13. - Specimen current as a function of time for various beam voltages at a current density of 1 nanoampere per square centimeter; Specimen 4, Aluminized Teflon outer sheet, taped aluminum foil grounding strap.

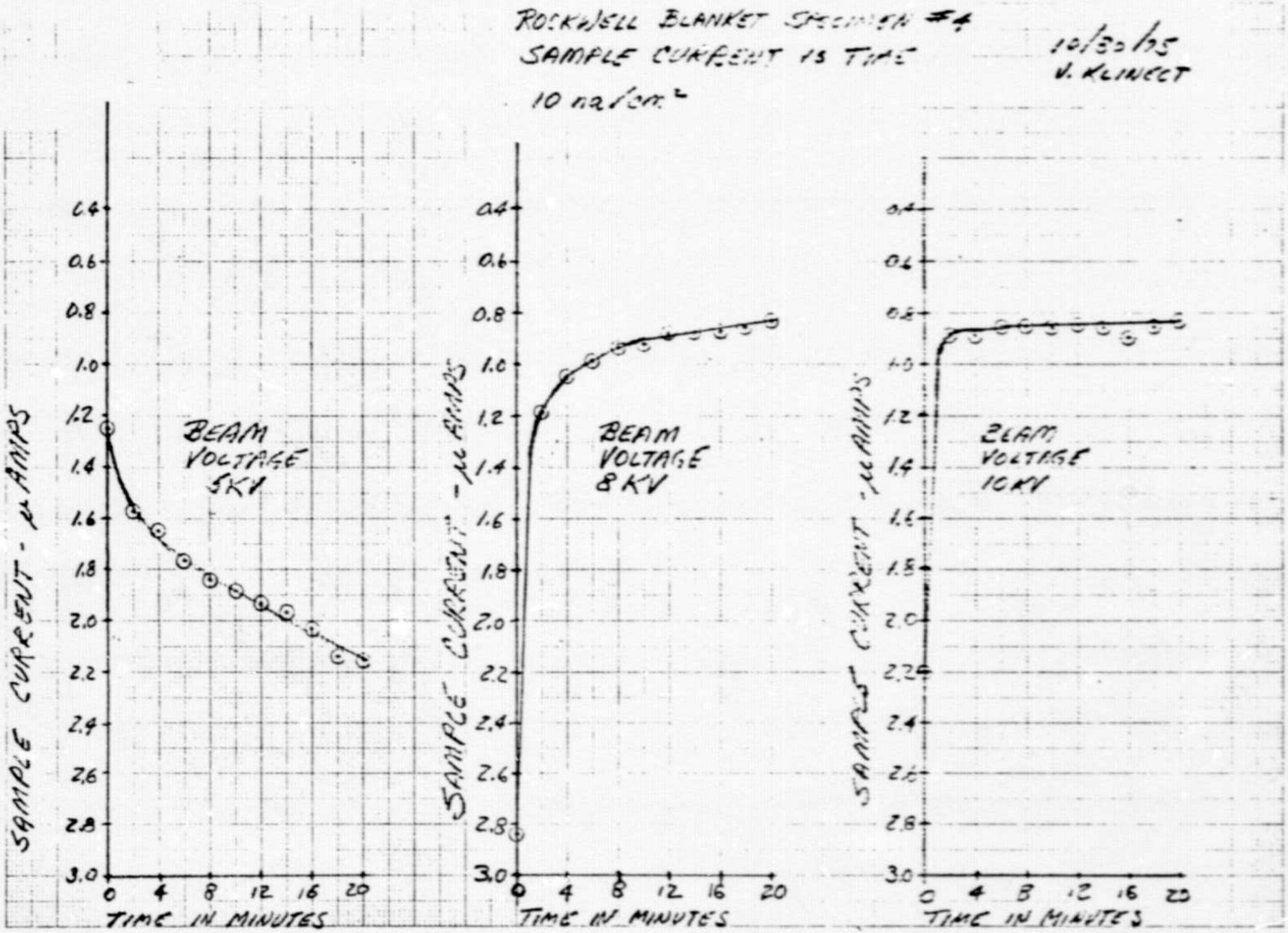

Figure 14. - Specimen current as a function of time for various beam voltages at a current density of 10 nanoamperes per square centimeter; Specimen 4, Aluminized Teflon outer sheet, taped aluminum foil grounding strap.

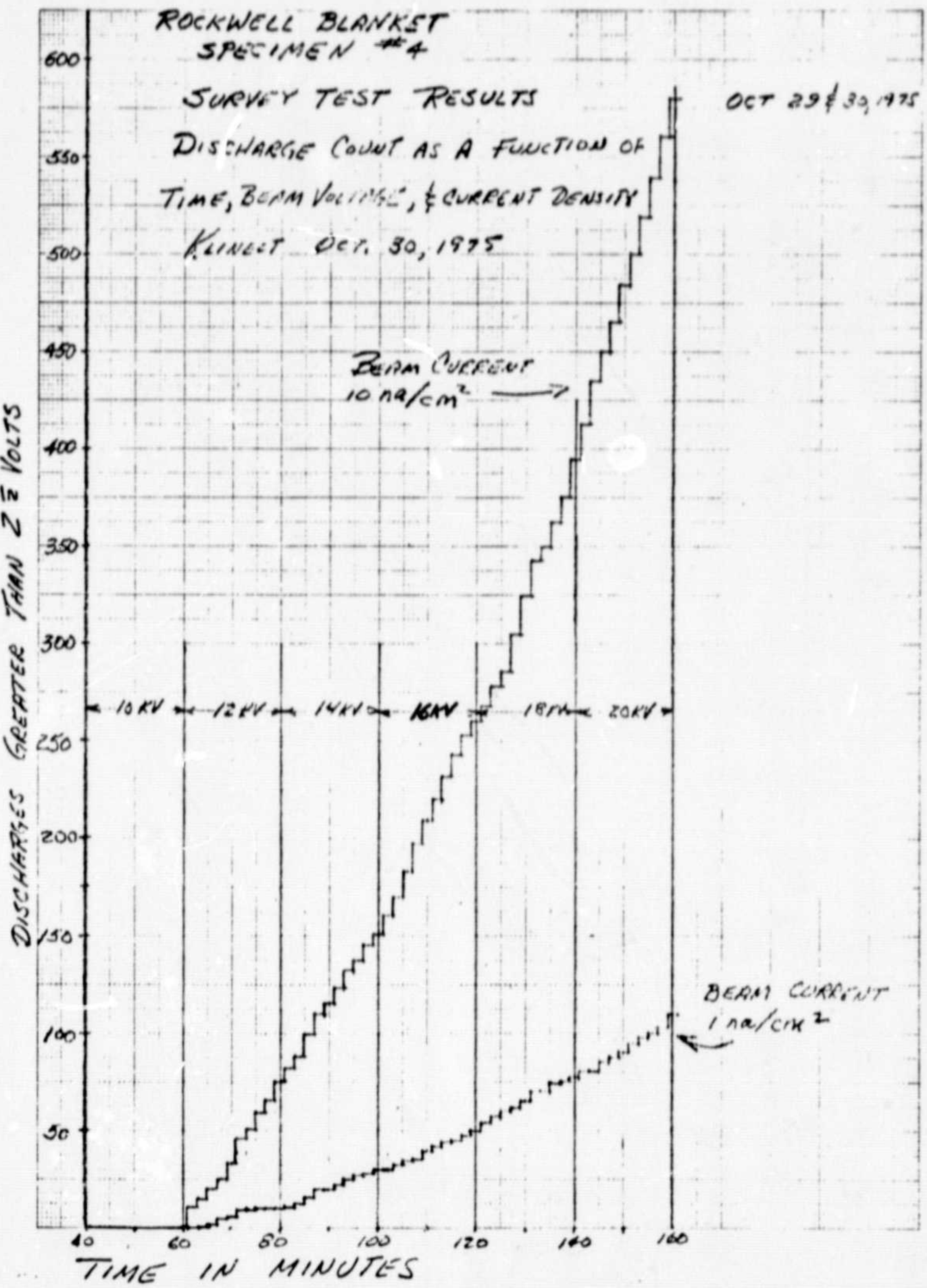

Figure 15. - Cumulative discharge count as a function of time for various beam voltages and current densities; Specimen 4, Aluminized Teflon outer sheet, taped Aluminum grounding strap.

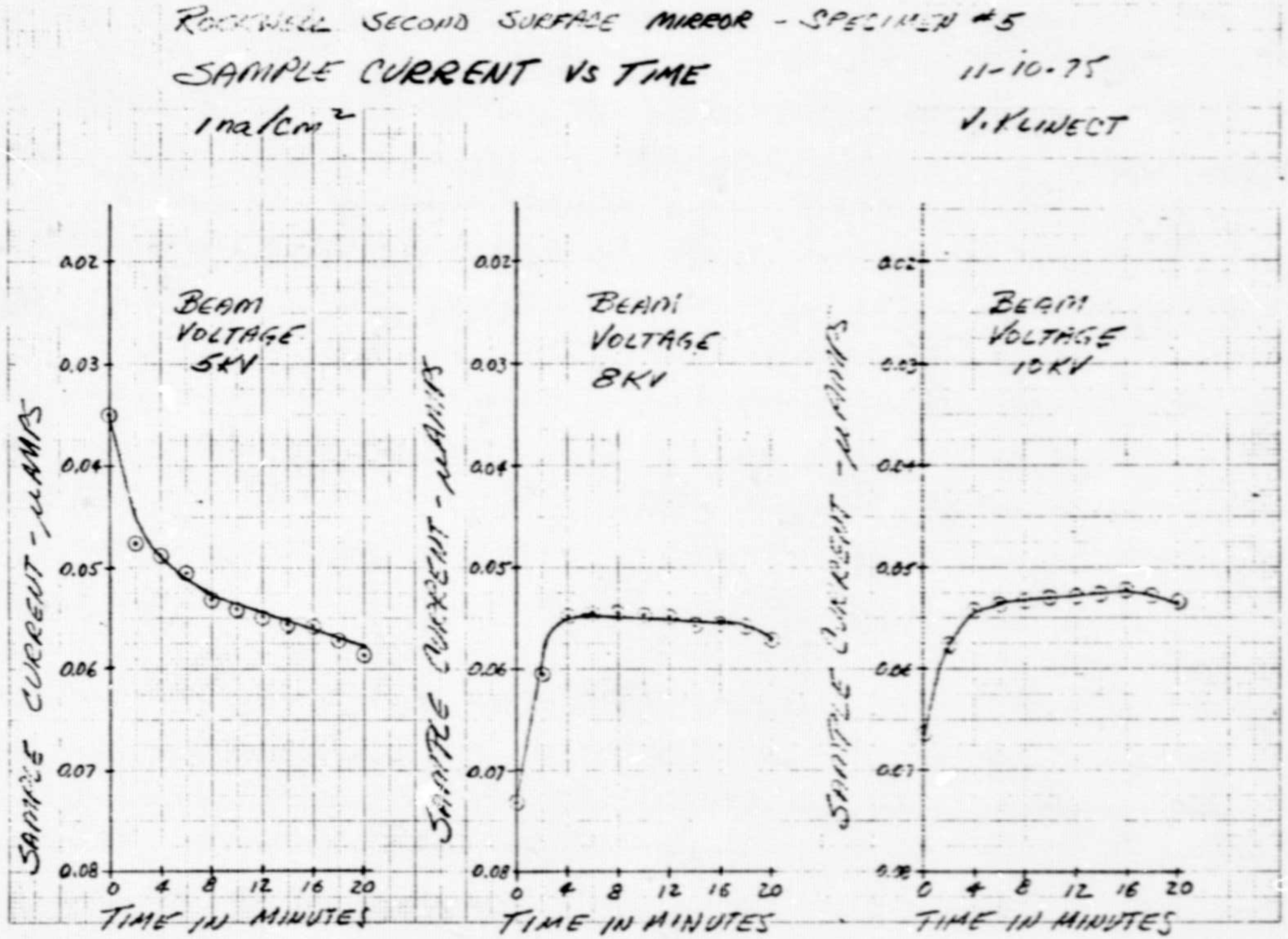

Figure 16. - Specimen current as a function of time for various beam voltages at a current density of 1 nanoampere per square centimeter; Specimen 5, fused silica second surface mirrors.

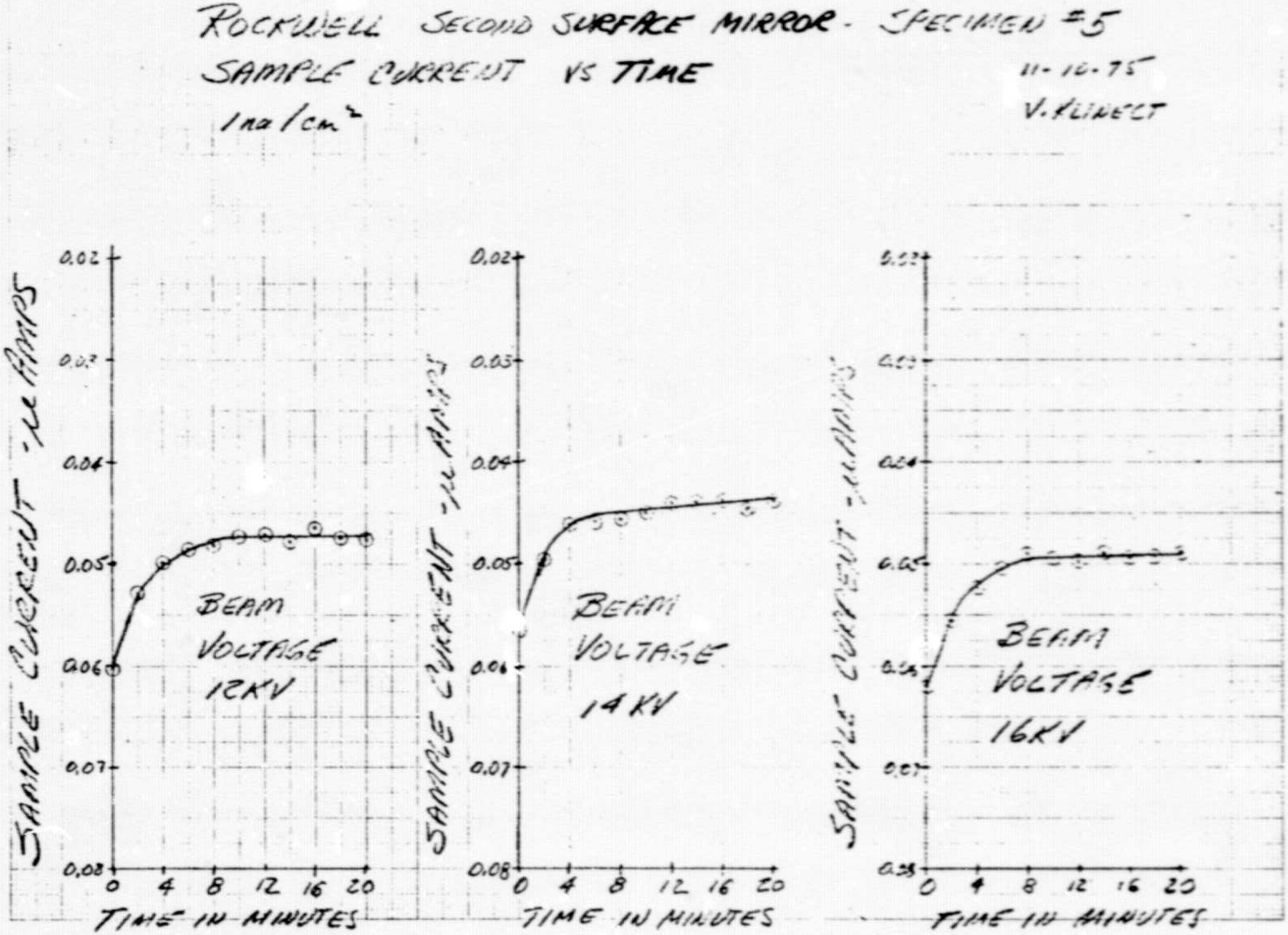

Figure 17. - Specimen current as a function of time for various beam voltages at a current density of 1 nanoampere per square centimeter; Specimen 5, fused silica second surface mirrors.

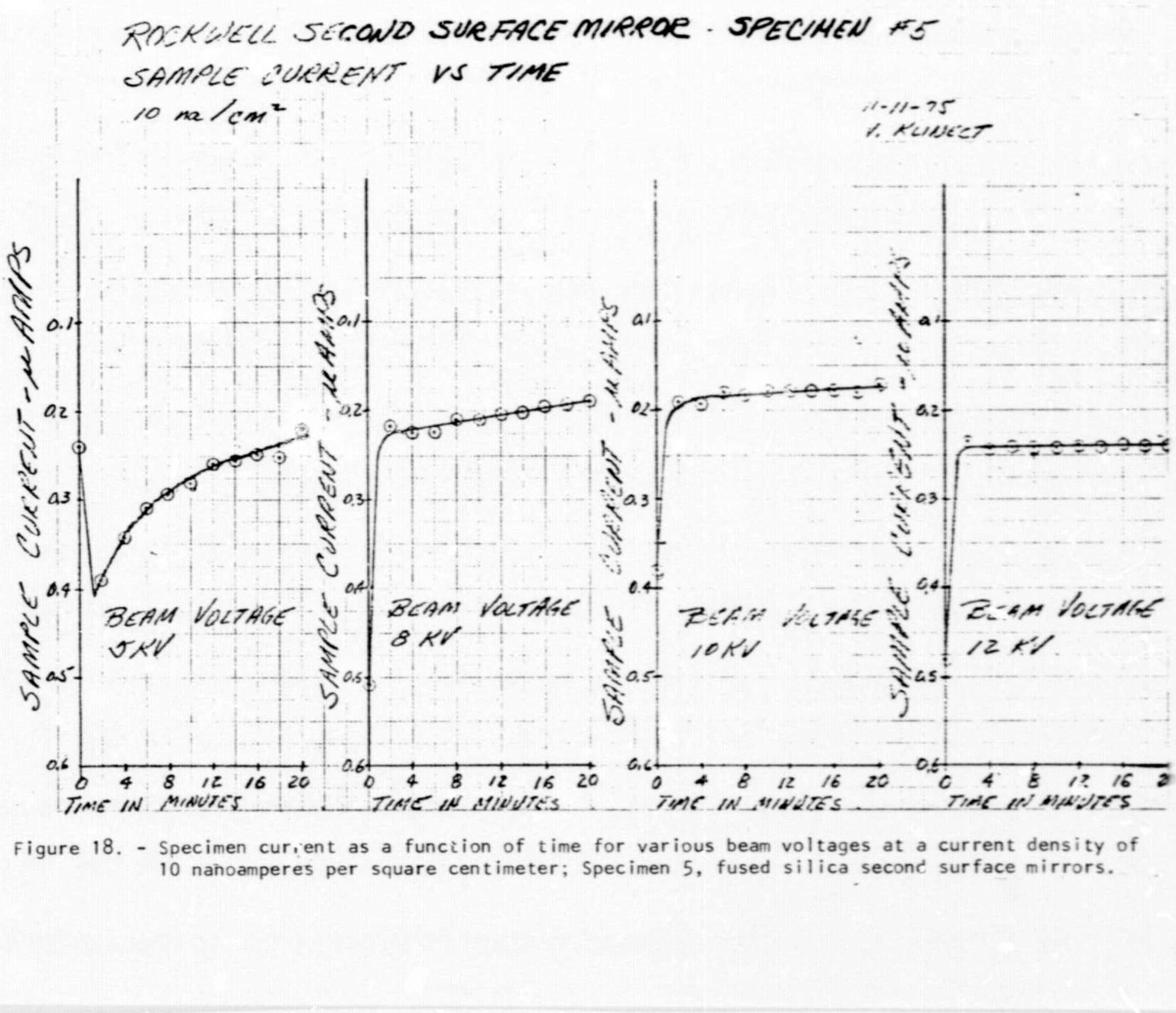

Figure 18. - Specimen current as a function of time for various beam voltages at a current density of 10 nanoamperes per square centimeter; Specimen 5, fused silica second surface mirrors.

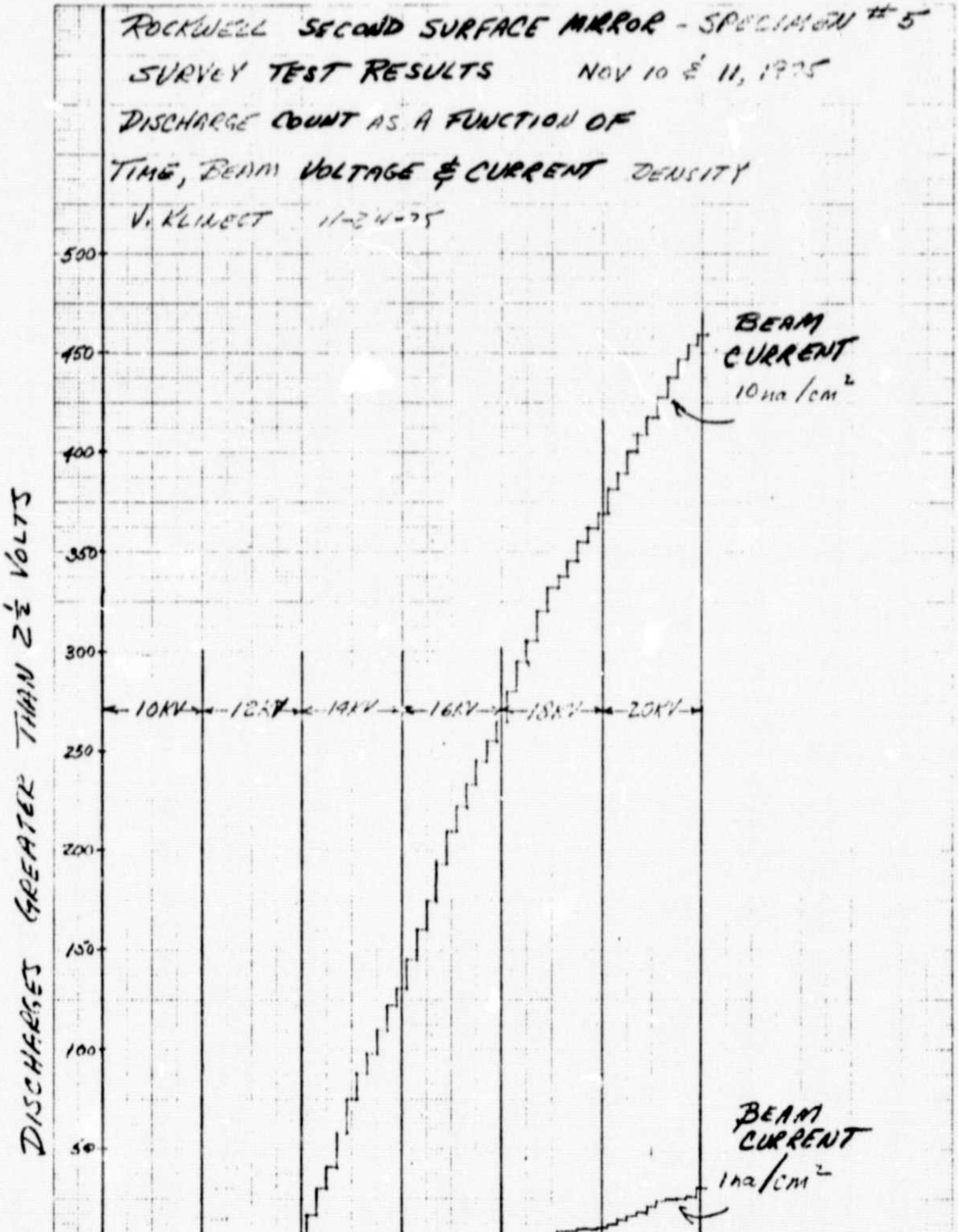

Figure 19. - Cumulative discharge count as a function of time for various beam voltages and current densities; Specimen 5, fused silica second surface mirrors.

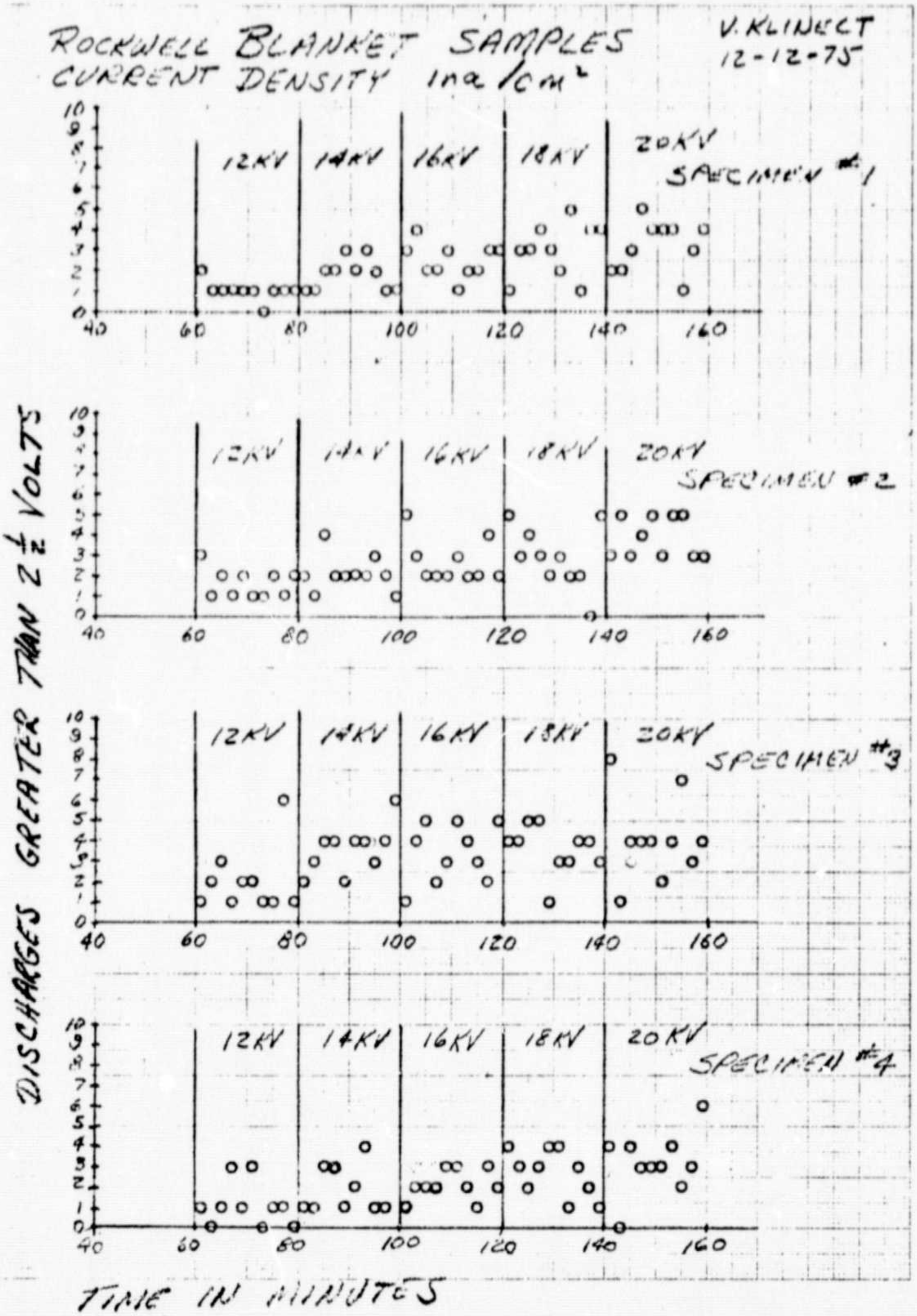

Figure 20. - Discharge count as a function of time for various beam voltages and a current density of 1 nanoampere per square centimeter; Specimens 1, 2, 3, and 4, thermal blankets.

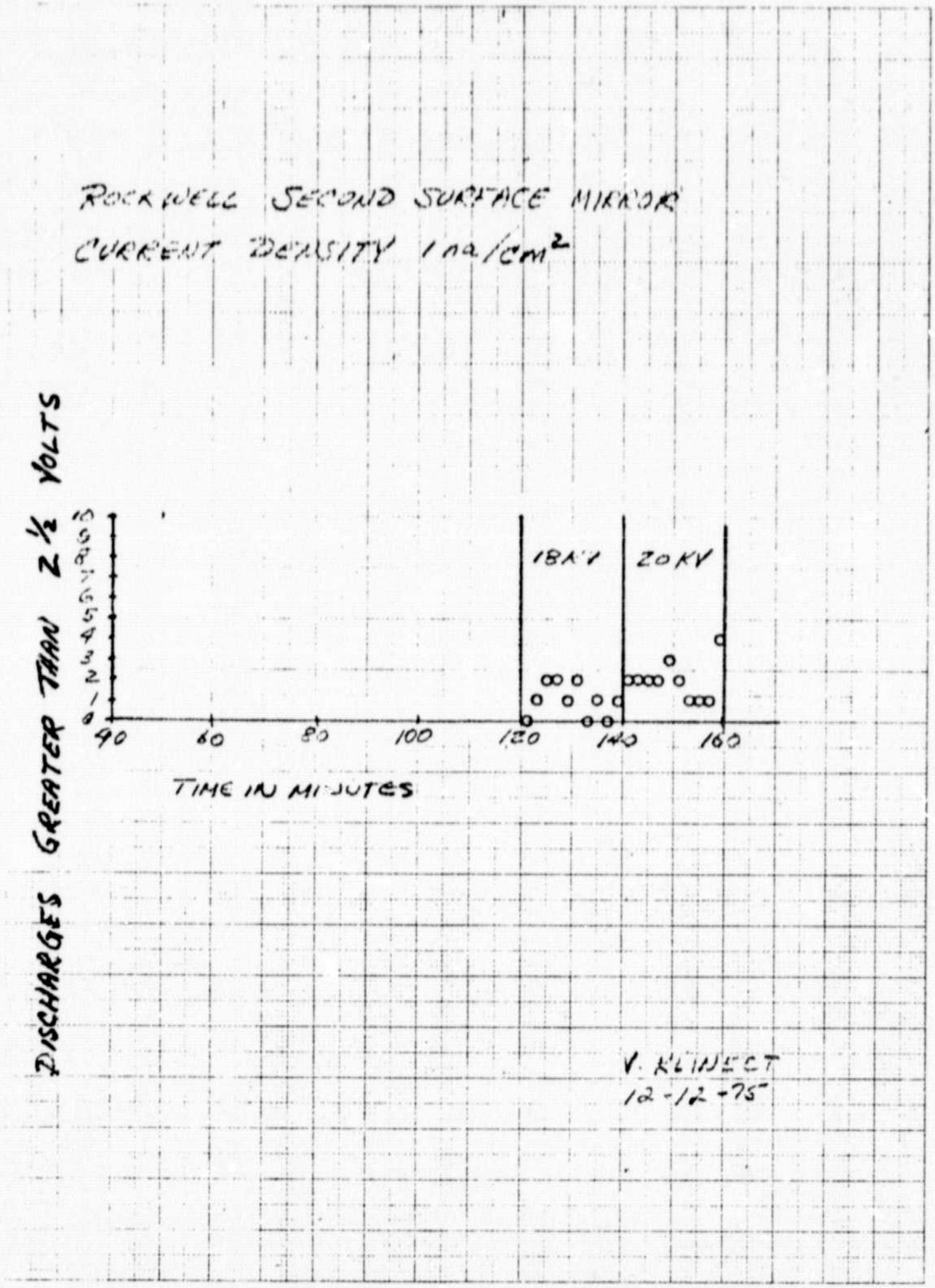

Figure 21. - Discharge count as a function of time for various beam voltages at a current density of 1 nanoampere per square centimeter; Specimen 5, fused silica second surface mirrors.

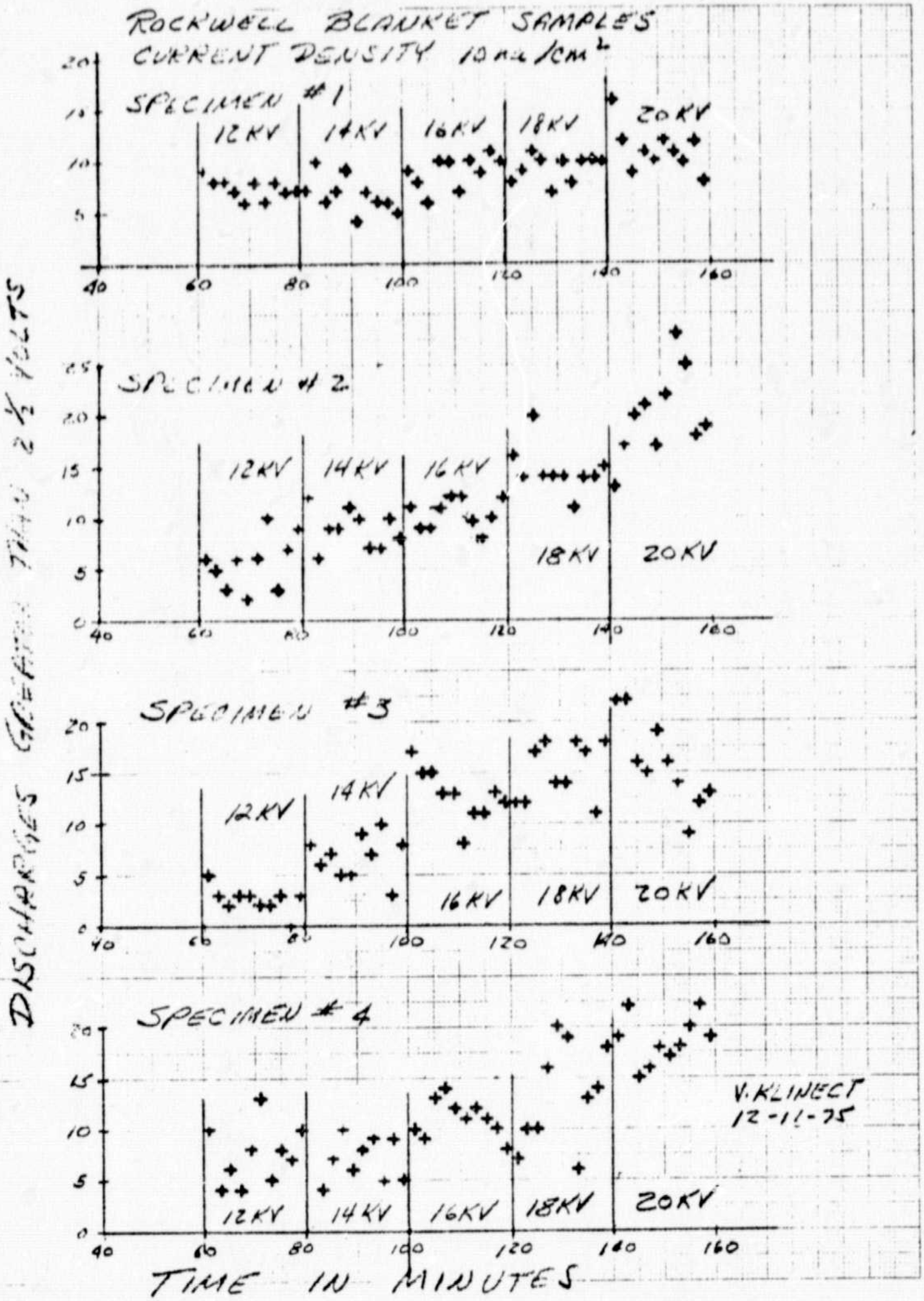

Figure 22. - Discharge count as a function of time for various beam voltages at a current density of 1 nanoampere per square centimeter; Specimens 1, 2, 3, and 4, thermal blankets.

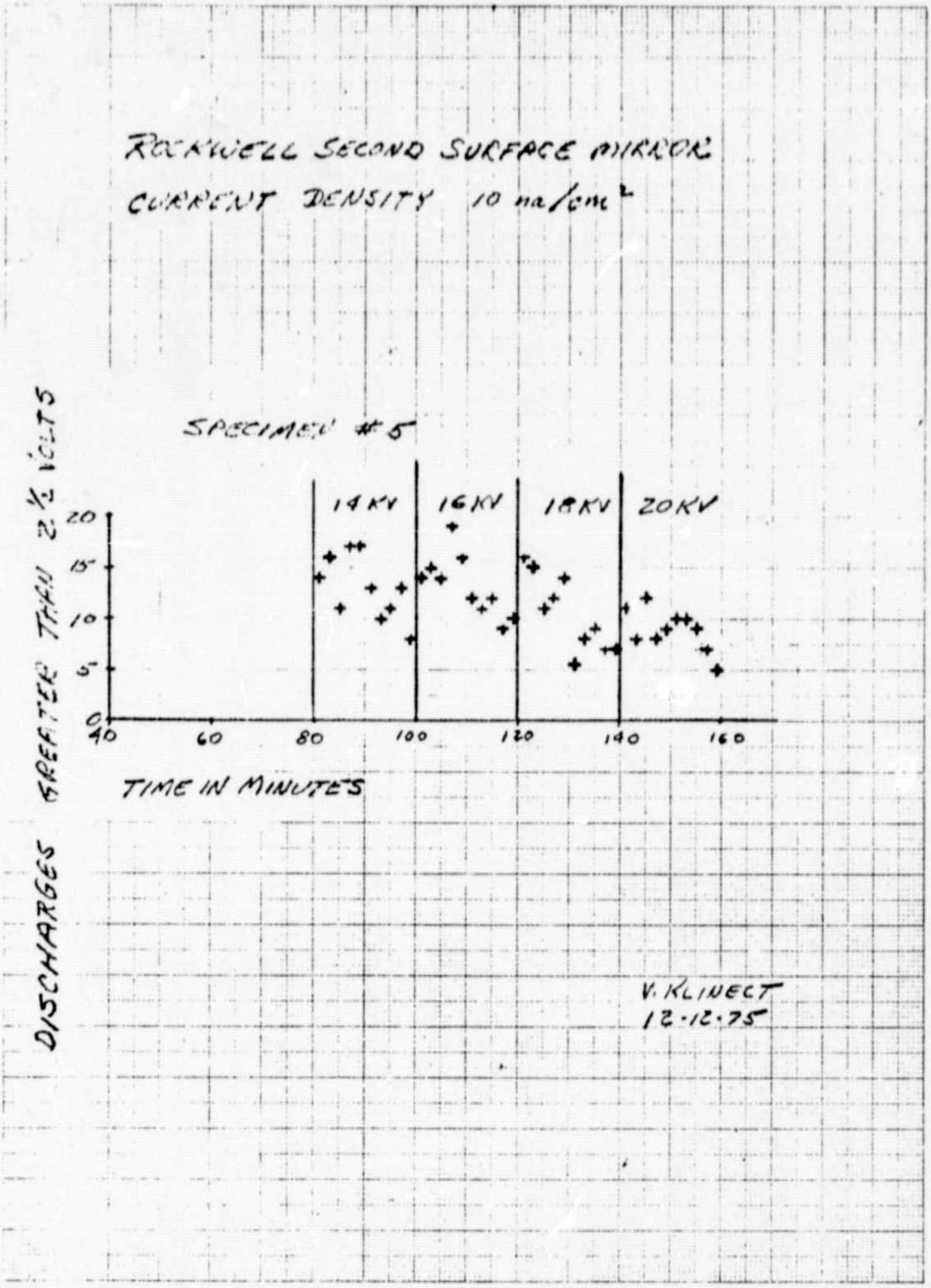

Figure 23. - Discharge count as a function of time for various beam voltages and a current density of 10 nanoamperes per square centimeter; Specimen 5, fused silica second surface mirror.

APPENDIX I

TEST PROCEDURE

1.0 SCOPE

This test defines the procedure used to survey the characteristics of materials (primarily insulators) exposed to fluxes of high voltage electrons. This procedure applies to short term testing at various electron beam voltages and current densities as well as any extended duration testing at a given beam voltage level.

2.0 TEST FACILITY

The test facility is shown schematically in Figure 1. The tests are performed in a 1.8 meter diameter by 1.8 meter long (6 ft. diameter x 6 ft. long) vacuum chamber capable of operating at a pressure of about 1×10^{-7} torr using conventional diffusion pumping. The grounded, conductive wall forms a boundary condition for all tests.

The primary elements of the test facility are the electron beam gun, the test sample, and the charge-discharge instrumentation.

A divergent electron beam is generated from a hot wire filament by means of a curved accelerating screen. The filament is biased to the desired voltage level while the accelerating screen is kept at ground potential. The electron beam gun is surrounded by a ground screen to minimize any stray electric fields from the high voltage system. Hence, the electron beam enters a grounded chamber and is influenced only by the surface being charged. The gun is designed to produce a uniform beam at the test plane about one meter from the gun exit plane. A typical current density profile at the test plane is shown in Figure 2.

The test sample is located on the gun centerline about one meter from the gun. The nominal size of the test sample is 17cm x 20cm and the sample is mounted normal to the electron beam. Sample sizes up to 30cm x 30cm can be readily accommodated in this facility. The substrate (or any other selected ground surface) is brought to ground by means of a coaxial cable through a digital electrometer. The output of this instrument is connected to an oscillograph. The purpose of this system is to monitor the leakage current during a test.

The test instrumentation consists of the current sensors, loop antennas, oscillograph, arc counter, oscilloscopes, and the photographic system. Four current sensors (plain metal discs) surround the test sample to permit continuous monitoring of the beam current during testing. A fifth sensor is mounted on a 30cm x 30cm grounded plate which is centered over the sample at the start of each test phase to determine the current density. The plate keeps the test sample from being charged until the sensor is raised, exposing the sample to the electron flux and signaling the start of a test. The beam current density can be checked periodically during the test by lowering this sensor.

There are two 15cm diameter loop antennas in the facility mounted about 33cm from the test sample. The plane of the loop points towards the center of the sample. One of the antennas is connected to a fast storage oscilloscope using coaxial cable with a 50 ohm termination. This oscilloscope monitors the discharge activity. The data is recorded photographically for permanent record. The second antenna is connected to an arc counter that is activated by any discharge that produces a pulse greater than $2\frac{1}{2}$ volts in the antenna. The counts are recorded manually by the operator during the test.

The lead from the test sample to ground can be switched to bypass the electrometer and its associated arc protection circuitry. This shorted lead is used to monitor the transients in the current to ground introduced by surface discharges. A current probe is connected to the lead and read on a fast storage oscilloscope. The data is photographed for permanent record.

The photographic system consists of two cameras mounted at ports on the test chamber. One camera is used to take Polaroid pictures of the front of the test sample. These can be multiple arc exposures or a single arc. The second camera looks at the side edge of the sample. All ports are sealed to prevent extraneous light from entering the chamber.

If light is desired in the chamber to determine the influence of photo-effects, it can be provided by a quartz arc lamp mounted inside the chamber.

A luminescent screen can be mounted behind the test sample to watch the activity as the sample is being charged and discharged. This visual data must be recorded by an observer.

The test system apparatus and instrumentation generally used is given in Table 1.

3.0 TEST PROCEDURE

3.1 TEST SAMPLE

A sample number shall be assigned to each sample tested. A log shall be kept by the test engineer giving the number, a description of the sample, and the date(s) of the test. This information shall also be recorded on the test data sheets (see Figure 3).

3.2 TEST START

The facility chamber shall be at a pressure of 5×10^{-7} torr or less before testing can start. The actual pressure shall be recorded and the pressure instrumentation shall be turned off.

The center current sensor shall be lowered such that the grounded plate attached to the sensor completely shields the test sample from direct electron impingement. The electron gun shall be brought to a generrl operating condition for the current density desired (heater and bias supply). The high voltage supply shall be brought to the desired beam voltage and the heater and bias supplies shall be adjusted to bring the current density to the proper level and uniformity, as determined by the sensors. All sensor readings shall be recorded on the data sheet.

The oscillograph shall be turned on. The center probe shall be raised above the sample exposing the sample to the electron flux. The initial leakage current jump when the sample is first exposed shall be recorded as the zero time data point. This is the maximum displacement current.

3.3 TEST CONDITIONS

A survey test shall consist of exposing a sample to electrons accelerated through potentials of 5KV, 8KV, 10KV, 12KV, 14KV, 16KV, 18KV, and 20KV. The current density shall be 1 nanoampere/ cm^2 and 10 nanoamperes/cm^2. Hence, 16 data sets are required to complete the survey.

The test shall be run in the following manner: the tests at the lowest current density shall be run first starting at the lowest beam voltage and progressing to the highest. Then, the test at the next highest current density shall begin starting at the lowest beam voltage and proceeding to the highest.

A sample shall be exposed to a given current density and a specified beam voltage for 20 minutes. The leakage current value and the arc count shall be recorded on the data sheet every two minutes. During the 20 minutes of the test the following photographic data must be taken at least once (more photographs may be taken at the discretion of the operator):

a. Photograph of the antenna pickup of the discharge (if any);
b. Photograph of the leakage current transient (if any).

The photographs shall be marked with the test conditions, the test and sample identification, and the duration of exposure.

At the conclusion of the 20 minute period, the center current sensor shall be lowered and the data from the five sensors recorded. The test can then proceed to the next beam voltage level. NOTE: It is necessary to discharge the test sample completely after the 20KV test and before beginning the 5KV test at the next electron current density. This can be accomplished by shutting the electron gun off for a period of time determined by the properties of the sample.

The tank pressure shall be monitored periodically during the test when the center probe covers the sample. If the pressure rises above 5×10^{-7} torr, the test shall be terminated. The pressure instrumentation shall be turned off before further testing.

The photographs of the discharges (front and side) shall be limited to those beam voltages known to give visible discharges. Hence, verification of visible discharges will be required before photographs will be taken. This usually limits photographs to testing at beam voltages of 16KV or greater. The backs of the photographs shall be marked with the test and sample identification, the test condition, the duration of exposure, and the number of arcs.

3.4 EXTENDED DURATION TESTING

At the discretion of the test engineer an extended duration test can be run. The test conditions shall be specified by the engineer and the purpose of the test recorded in the log and on the data sheet.

The conditions at the start of the test shall be the same as those given in paragraph 3.2. During this test the following data shall be taken every 30 minutes: sample leakage current and arc count. Periodically during this test photographs shall be taken of the oscilloscope trace from the loop antenna and the leakage current transient. The oscillograph shall be on.

Every two hours during this test, the center current sensor shall be lowered. All current sensor data shall be recorded. If the electron gun has drifted from the original setting, it shall be readjusted to the prescribed value and the old and this new data shall be recorded.

4.0 TEST REPORT

The test engineer shall prepare a test report at the conclusion of each test. This report shall include identification of the test sample, the test dates, the purpose of the test, the test conditions, any test procedure pecularities or anomalies, the test data sheet, the photographs of the antenna and leakage current transients and a summary of the results. The summary of results shall include plots of the leakage currents when no discharges occurred and the computed value of the surface voltage for these conditions. For the test conditions in which there were discharges, a plot of the accumulated number of discharges versus beam voltage shall be provided.

If extended duration testing was conducted in addition to the survey, this information shall be included in the test report. A plot of arc count as a function of time shall be included.

TABLE I. - TEST SYSTEM APPARATUS AND INSTRUMENTATION

Protection Circuitry:	LeRC design and manufacture
Electron Gun:	LeRC design and manufacture
Electron Gun Power Supplies and Controls:	LeRC design and manufacture
Current Sensors:	LeRC design and manufacture
Arc Level Discriminator:	LeRC design and manufacture
Luminescent Screen:	LeRC design and manufacture
Oscillograph:	Brush Instruments Mark 200 8-channel recorder
Counter:	Berkley Instruments, Inc. 6220 Dual Present Counter
Electrometer:	Keithley Instruments, Inc. Digital Electrometer Model 616
Oscilloscopes:	Tektronix, Inc. R7844 Dual Beam Oscilloscope Plug-in units: 7A16A Amplifier 7A14 Current Probe Amplifier 7M13 Readout Unit 7B92 Dual Time Base P6021 AC Current Probe C-50/C-70 Film Back (Roll Film)
	Tektronix, Inc. 7633 Oscilloscope Plug-in units: 7A16A Amplifier 7M13 Readout Unit 7B53A Dual Time Base C-50/C-70 Film Back (Pack Film)
High Voltage Power Supply:	Beta Electric

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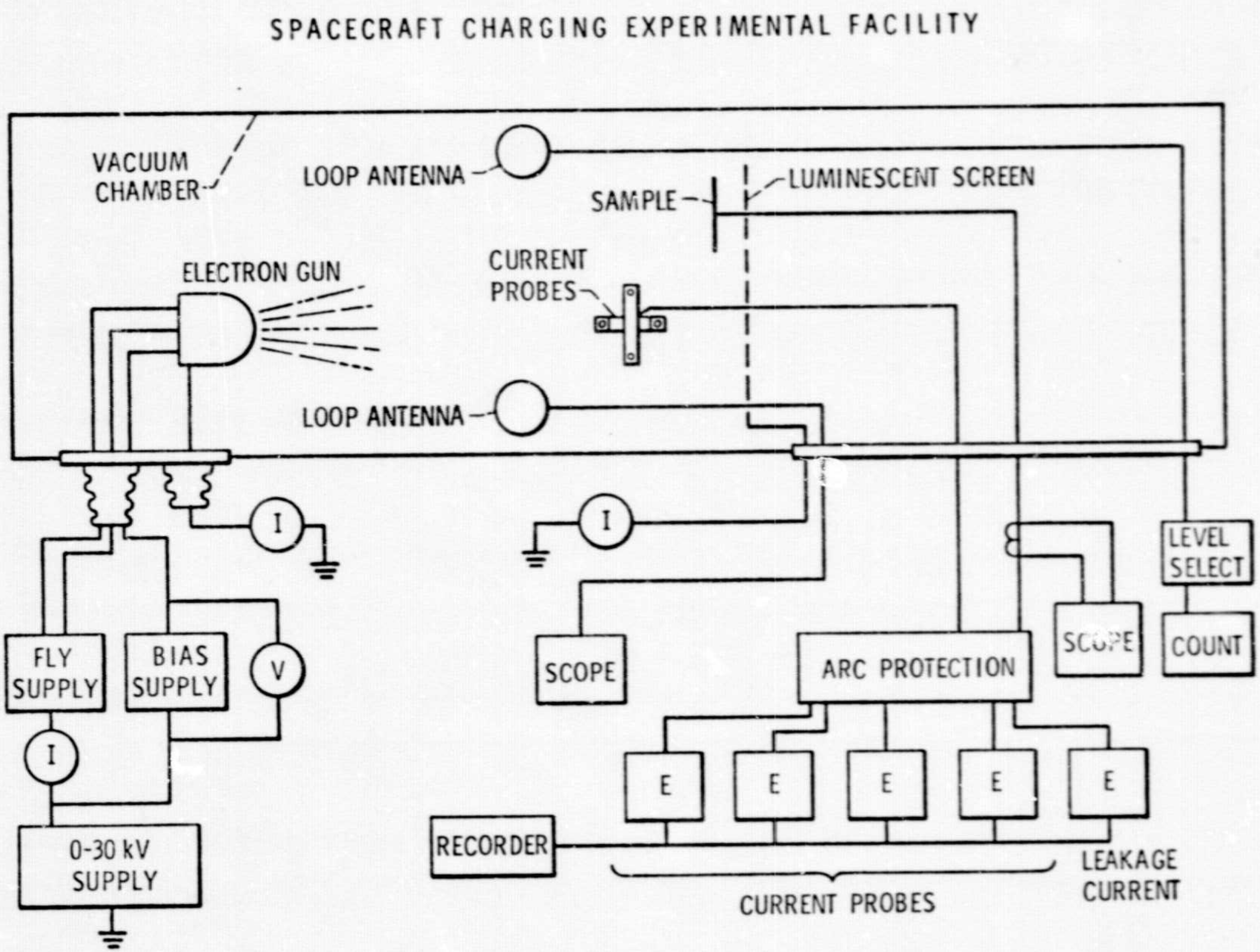
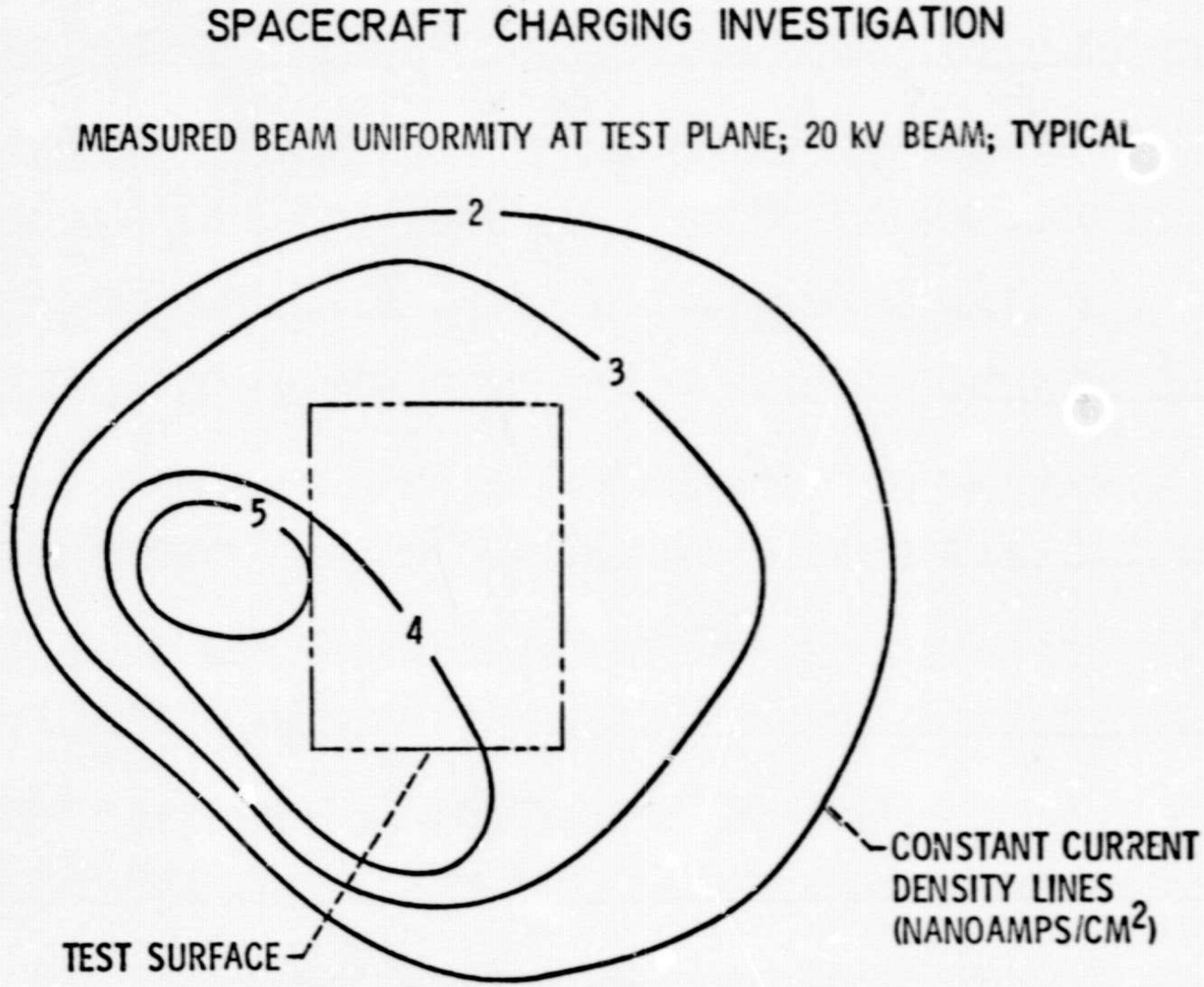


Appendix Figure 1. - Schematic of Test Facility



Appendix Figure 2. - Beam Uniformity at the Test Plane

TEST ENGINEER ____________________ SAMPLE: ____________________

TEST TECHNICIAN ____________________ DATE: ____________________

	BEAM VOLTAGE KV	BEAM CURRENT μ(A)	FILAMENT CURRENT (A)	GROUND CURRENT μ(A)	BIAS VOLTAGE (Volts)	BIAS CURRENT μ(A)	-TANK PRESSURE-
ELECTRON GUN PARAMETERS							

______ KV TEST

FARADAY CUP: ______ PROBE: ______

	#2	#3	#4	#5
PROBES INITIAL				
PROBES FINAL				

	TIME	I SAMP.	TOTAL > 2.5V
0			
2			
4			
6			
8			
10			
12			
14			
16			
18			
20			

______ KV TEST

FARADAY CUP: ______ PROBE: ______

	#2	#3	#4	#5
PROBES INITIAL				
PROBES FINAL				

	TIME	I SAMP.	TOTAL > 2.5V
0			
2			
4			
6			
8			
10			
12			
14			
16			
18			
20			

______ KV TEST

FARADAY CUP: ______ PROBE: ______

	#2	#3	#4	#5
PROBES INITIAL				
PROBES FINAL				

	TIME	I SAMP.	TOTAL > 2.5V
0			
2			
4			
6			
8			
10			
12			
16			
18			
20			

______ KV TEST

FARADAY CUP: ______ PROBE: ______

	#2	#3	#4	#5
PROBES INITIAL				
PROBES FINAL				

	TIME	I SAMP.	TOTAL > 2.5V
0			
2			
4			
6			
8			
10			
12			
14			
16			

Appendix Figure 3. - Test Data Sheet