AD-A050 112   TRW DEFENSE AND SPACE SYSTEMS GROUP REDONDO BEACH CALIF   F/G 20/3

STORED CHARGE RELEASE IN CABLES IN LOW FLUENCE X-RAY ENVIRONMEN--ETC(U)

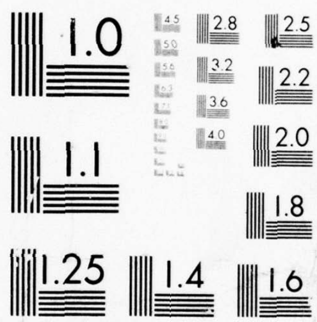
APR 77 D M CLEMENT, T J SHEPPARD, L C NIELSEN   DNA001-77-C-0084

UNCLASSIFIED   DNA-4406T   NL

| OF |

AD
A050 112

END
DATE
FILMED
3-78
DDC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

DNA 4406T

STORED CHARGE RELEASE IN CABLES IN LOW FLUENCE X-RAY ENVIRONMENTS

TRW Defense & Space Systems Group
One Space Park
Redondo Beach, California 90278

8 April 1977

Topical Report for Period January 1977—April 1977

CONTRACT No. DNA 001-77-C-0084

APPROVED FOR PUBLIC RELEASE;
DISTRIBUTION UNLIMITED.

THIS WORK SPONSORED BY THE DEFENSE NUCLEAR AGENCY
UNDER RDT&E RMSS CODE B323077464 R99QAXEE50307 H2590D.

Prepared for
Director
DEFENSE NUCLEAR AGENCY
Washington, D. C. 20305

(18) DNA SBIE (19) 4406T, AD-E300 086

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER DNA 4406T	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) STORED CHARGE RELEASE IN CABLES IN LOW FLUENCE X-RAY ENVIRONMENTS.		5. TYPE OF REPORT & PERIOD COVERED Topical Rep[redacted]t for Period Jan[redacted]—Apr[redacted]77
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) David M. Clement, T. J. Sheppard, L. Carlisle Nielsen, Charles E. Wuller		8. CONTRACT OR GRANT NUMBER(s) DNA 001-77-C-0084 new
9. PERFORMING ORGANIZATION NAME AND ADDRESS TRW Defense & Space Systems Group One Space Park Redondo Beach, California 90278		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Subtask R99QAXEE503-07
11. CONTROLLING OFFICE NAME AND ADDRESS Director Defense Nuclear Agency Washington, D.C. 20305		12. REPORT DATE 8 Apr[redacted]977
		13. NUMBER OF PAGES 42 (12) 40p.
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

This work sponsored by the Defense Nuclear Agency under RDT&E RMSS Code B323077464 R99QAXEE50307 H2590D.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Cables
X-Ray Response
Stored Charge Release

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Stored charge release in cables exposed to low fluence X-radiation has been investigated in the SPI-6000 X-ray simulator. No anomalous response in vacuum has been observed in all cable samples except semirigid cables. However, even for semirigid cables this anomalous behavior disappears if the cable is not bent.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

409 637

CONTENTS

FIGURES

TABLES

1.0 INTRODUCTION

It has been known for some time that dielectrics, particularly polymer dielectrics, have a propensity for acquiring charge which then resides near the dielectric surface. The amount of charge is estimated to be on the order of 5×10^{-11} C/cm^2 to 5×10^{-9} C/cm^2 by Taylor, et al.[1] It is not clear exactly how the charge is transported into the dielectric, though obviously manufacturing processes and handling affect the distribution of charge. However, what we are concerned with is how the charge, which might be stored in a cable dielectric, is released in a specified X-ray environment, and how the signal stimulated in the cable compares with the "normal" direct injection cable response[2].

Consider in more detail the nature of stored charge in cable insulation. The charge may be either free charge (homopolar charge) residing near the dielectric interface, or bound charge (heteropolar charge). The latter, which corresponds to a permanent polarization of the dielectric medium, is probably responsible for the observed signal when tantalum capacitors, which have been electrically stressed by a potential applied during burn-in, are subjected to irradiation, or are heated to the glass-phase transition point.[3] In the case of cables, which are not subjected to burn-in, the charge is probably electrostatic in nature, and may be developed during cable extrusion, cable flexing, or other handling procedures. Of course the possibility of charge being stored from previous irradiation is also to be considered.

Without prejudging the nature of the charge (i.e. free charge or bound charge) let us ask what are the consequences of irradiating a cable which has a negative amount of pre-existing free charge residing at the dielectric surface. We assume, further, that a gap or void, on the order of 10^{-5} m separates the insulation from the shield of the cable. (Gaps are commonplace for braided shielded cables, cf. Ref. 4). Now, if the cable is irradiated in vacuum, the surface charge will rearrange itself slightly, perhaps, but since no DC path has been provided for the surface charge across the gap, an external signal (i.e., replacement current) will not be affected by the stored charge. At most photon simulator fluence levels, radiation induced dielectric conductivity is negligible. On the other hand, if air is present in the gap, a shunt path exists through ionized air for the stored charge to be released. Competition is established between electrons crossing the gap on the one hand, having been emitted from the conductor, and a secondary current, which is set in motion by the pre-existing field across the gap. Whichever dominates will depend on the amount of stored charge, as compared to the charge emitted from the conductor.

A small set of applicable data exists in the published results of Fitzwilson, et al.[4], and Chivington, et al.[5] on the irradiation of cables in vacuum and air. The former employed the Aerospace Dense Plasma Focus Device, the latter the Simulation Physics SPI 5000 machine. Both of the facilities produce a fluence of X-rays between 10^{-4} to 10^{-3} cal/cm^2.

The experiments that Fitzwilson performed which are of interest to us were those where he first irradiated the cable in vacuum, and then performed successive shots in air. He found that the first shot response in air was somewhat larger than that in vacuum, but opposite in sign, and that repeated shots in air led eventually to a bipolar response. As discussed above, the direct injection charge transferred in the vacuum shot could be released in subsequent air shots by the transient conductivity of the air. What intrigued us was the following statement in his paper: "The three samples of RG-174 (a braided shielded coax) were irradiated first in air without prior vacuum exposure. The induced current signals on the samples made by Amphenol and Surco were completely positive on the first shot [i.e., opposite in sign to "normal" vacuum shots], and became bipolar on successive shots, while the response of the cable made by Belden was quite different, in that the induced signal was completely negative even on the first air exposure." Since these cables were not previously irradiated, we suggest that stored charge was responsible for their anomalous response in air.

Similar response waveforms were observed by Chivington for the common mode response of the 24TPSJ (a twisted-shielded pair) cable. The six shots which he observed at 1 atmosphere of air are shown in Fig. 1-1. Again, we emphasize that this cable had not previously been irradiated in the simulator.

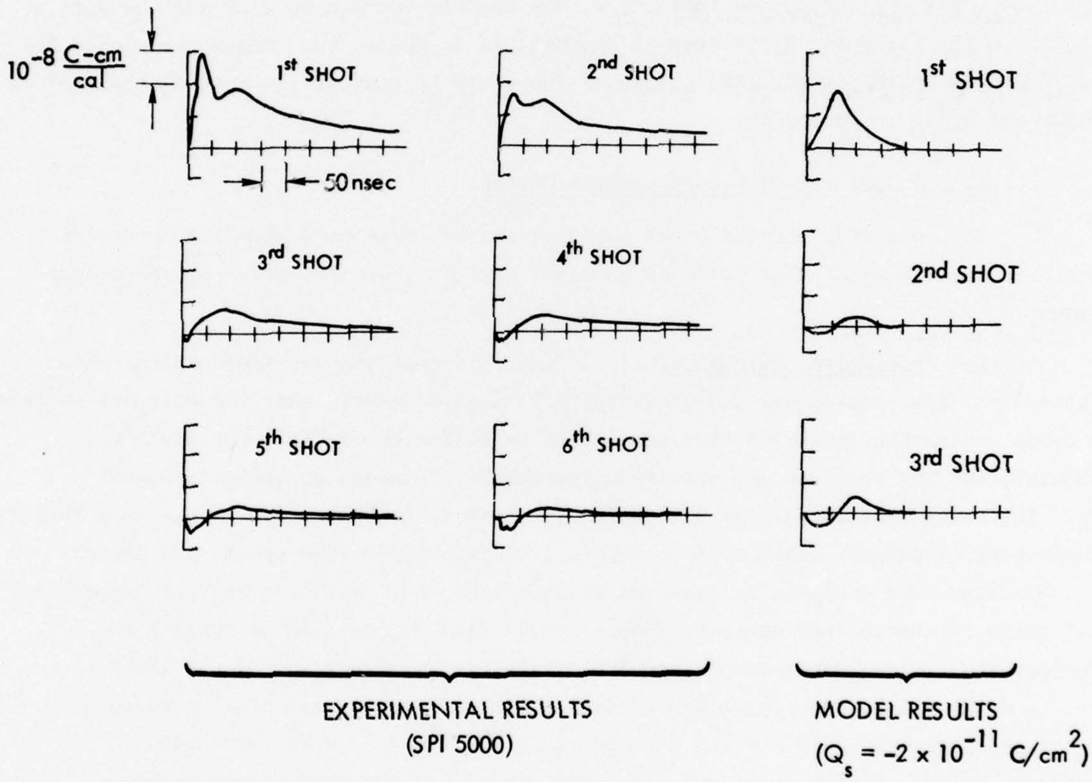


Figure 1-1. Normalized load response, current per unit length per unit peak flux, for 24TPSJ cable. The peak flux is 4.2×10^{3} cal/cm^{2}-sec. Experimental results are from Chivington, et.al., Ref. 5.

2.0 CABLE MANUFACTURING PRACTICES AND STORED CHARGE RELEASE

In this section we report our findings during tours of both LaBarge Wire and Cable Corporation, and Raychem Corporation which were conducted for the purpose of examining how stored charge might become trapped in cable insulation during manufacture.

Sources of Bound Charge (Heteropolar Charge)

We are referring here to the macroscopic uni-directional polarization which would be introduced by an applied bias between shield and conductor(s) across the cable insulation as the cable is cooled from its glass phase transition point during cable manufacturing.

The only place where this might occur, in our opinion, is just after the dielectric has been extruded onto the center wire. The wire is immediately passed through a water trough to cool and solidify it, and then it is passed through a field tester to check for insulation integrity. The applied voltage is 2 kV and the wire is subject to the field for a few seconds at most, as it passes by. Since presumably the insulation is cooled by the time it passes the field tester, it is doubtful that polarization can still be frozen in.

Sources of Free Charge (Homopolar Charge)

The following sources of free charge in the cable manufacturing processes have been identified, though it is by no means certain that they give rise to trapped charge.

(1) *Dielectric Extrusion:* It is possible that polymer dielectrics, when extruded at high temperature and pressure, will acquire charge near the extruded surface. In cable dielectric extrusion the temperature is sufficient to melt the dielectric material, but the pressure may vary from atmospheric to seven or eight thousand psi. The range depends on both the dielectric, and cable line speed. Note that the manufacturer's primary concern is to obtain a maximum cable line speed, and the mix of temperature and pressure is directed towards that end. While we are not suggesting that these parameters are uncontrolled, it would take a good deal of digging to find out how a given cable sample had its dielectric extruded. To put it another way, if dielectric extrusion is identified as a prime suspect for storing charge, then a cable manufacturer such as Raychem could be funded to draw the cables at different speeds, temperatures and pressures; and radiation experiments, such as those described below, could be conducted.

(2) Dielectric Wrap: The insulation Kapton, which is desirable for satellite cables because of its high radiation resistance and low density, comes in thin sheets which are then cut into strips and wrapped around the conductor. Electrostatic charging of the sheet surfaces is certainly possible, though essentially uncontrolled.

(3) Direct Irradiation: Certain polymer materials, when subjected to high energy radiation can cause permanent crosslinking, or intermolecular joining of adjacent molecules. This crosslinking creates chemical bonds in the molecular structure that prevents the material from melting or flowing at elevated temperatures. Raychem Corporation uses this process almost exclusively.

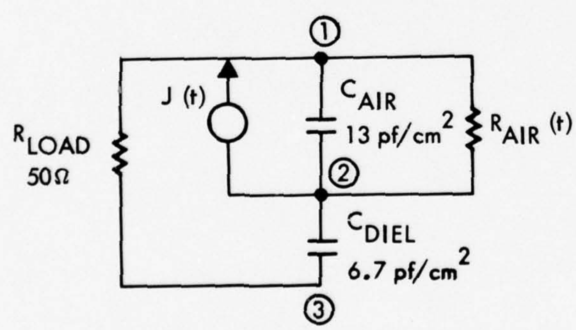
In our opinion, if dielectric charging is a problem, direct irradiation is the most likely source. In discussions with Raychem we found out the following: (a) their radiated cross-linked dielectrics are subjected to 10^6 rads(Si) using a 2 meV LINAC source of electrons. The insulated wire, before it is braided, is passed back and forth in front of the source. After the braiding is put on, the external dielectric jacket is irradiated, thus subjecting the interior insulation to an additional dose of radiation. (b) The energy of the beam has to be sufficient to allow the electrons to come out the other side of the cable. If not, charge accumulates in the dielectric leading to breakdown which manifests itself as pinholes in the insulation. The LINAC electron energy is a carefully controlled parameter, at least in principle. (c) Raychem claims that the dose rate which they put into the material is enough to produce a transient conductivity which drains away the dielectric charge. (Actually, this point seems inconsistent with item (b) above).

3.0 PRELIMINARY MODEL OF STORED CHARGE RELEASE IN CABLES

In order to explain Chivington's results, and at the same time to govern our intuition in setting up a test plan, we propose the simple equivalent circuit shown in Fig. 3-1. The SGEMP current driver representing electrons emitted off the conductor is adjusted to give the correct response of the cable when it is in vacuum and, of course, it follows the radiation pulse. The shunt air conductance (at 1 atmosphere pressure) across the gap which exists in this cable is calculated by solving the air-ion rate equations, the details of which are presented in Ref. 6. The total amount of stored charge Q_s (charge/area) is inserted in the model as an initial condition on the potential drop across the dielectric $\Delta V_{21} = V_2 - V_1$ (which is equal and opposite (at t=0) to the potential drop across the air capacitor). Since both the air and dielectric capacitor in the equivalent circuit share the stored charge, the total charge (again, at t=0) is

$$Q_s = (C_{AIR} + C_{DIEL})\ \Delta V_{21}$$

In our model we allowed the initial value of ΔV_{21} to vary several orders of magnitude (-100,-10,-1,-0.1,-0.01v). We found that ΔV_{21} = -1v, or a negative amount of stored charge, $Q_s = -2\times10^{-11}$ C/cm^2 was sufficient to approximate the peak of Chivington's first shot in air, as shown in Fig. 1-1. At the end of the first shot the voltage across either capacitor is $<|0.1\ v|$, an amount which is insufficient to influence cable response in subsequent shots. However, the bipolar behavior of shots 5 and 6 is well represented in our model. This bipolar response is explained as follows: first, the direct transferred charge drives the external signal in one direction, and then a secondary current, responding to the accumulated transferred charge which has penetrated the dielectric, drives the signal in the opposite direction, overwhelming the original signal.



- The peak magnitude of J(t) is 0.26 mA/cm^2.
- $R_{AIR}(t)$ is calculated using the method of Ref. 6.

Figure 3-1. Stored charge release model for 24TPSJ cable.

On the basis of this model, we assert that small, physically realizable, surface charge densities discharged through a transient air conductivity are sufficient to explain some anomalous cable response data. Additional parametric investigations have shown that transient dielectric conductivity, even in the dose enhanced region near the surface, is too small to release sufficient charge from a layer trapped in the volume of the dielectric.

4.0 EXPERIMENTS TO MEASURE STORED CHARGE RELEASE IN CABLES

4.1 PROPOSED EXPERIMENTS AND RATIONALE

4.1.1 Selection of Photon Simulator

The SPI (Simulation Physics Incorporated) facility was used to conduct the "Quick Look" stored charge release experiments. This facility was selected for the following reasons:

1) It is a source of reasonably low energy X-ray photons.

2) Based on Chivington's experiments, Ref. 5, the fluence of X-rays is low enough (10^{-4} to 10^{-3} cal/cm^2) that the stored charge which might be released will not be swamped by the normal SGEMP signal.

3) The shots are fairly reproducible.

4) One can adjust to a certain extent the fluence and spectrum associated with each shot.

4.1.2 Experimental Parameters and Cable Selection

A list of experimental parameters, and the priority which we assign them in connection with stored charge release, is shown in Table 4-1.

Based on our discussion of cable manufacturing practices, given in section 2.0, the cable dielectric is of prime importance in stored charge release. A list of cable samples is given in Table 4-2. Four of the cables selected have dielectrics of irradiated Kynar plus irradiated polyalkene; one is made of Kapton, a tape-wrapped type of insulation. Two semirigid cables with a teflon dielectric are included on the grounds that if the stored charge release is indeed a surface charge effect, then a gapless cable will not exhibit the stored charge release phenomena. On the other hand, the bending or coiling of semirigid cables is known to introduce gaps.

Again, based on our previous hypothesis associated with release of surface charge, the presence of air in the gaps will make a considerable difference in the response. Vacuum/air and air/vacuum sequences are critical in sorting out the true nature of the stored charge. Of equal importance, in this regard, are the order of the shots, and time between shots.

Fluence is an important parameter since it determines the extent to which stored charge release is to be swamped by the normal SGEMP signal. Mechanical working also has some effect on the storage, though this is difficult to control. By the same token, "identical" cables made by different manufacturers have different stored charge release responses, as Fitzwilson's experiments on the RG-174 cables indicated.

Table 4-1. Prioritization of Parameters in Stored Charge Release in Satellite Cables

PARAMETER	PRIORITY	COMMENT
CABLE TYPE	1	DIELECTRIC MATERIALS MAY GOVERN RESPONSE
VACUUM/AIR	1	WILL DETERMINE WHETHER THE CHARGE IS ON THE SURFACE OR IN THE VOLUME
ORDER OF SHOTS	1	
TIME BETWEEN SHOTS	1	IMPORTANT IF THE STORED CHARGE DECAYS
FLUENCE	2	DETERMINES WHETHER STORED CHARGE RELEASE DOMINATES "NORMAL" DIRECT INJECTION RESPONSE
MECHANICAL WORKING	2	INTRODUCES TRAPPED CHARGE AND GAPS IN THE DIELECTRIC
"IDENTICAL" SAMPLE REPRO-DUCIBILITY	2	DIFFERENT MANUFACTURING TECH-NIQUES IN "IDENTICAL" CABLES WILL AFFECT STORED CHARGE
VOLTAGE BIAS	2	PROVIDES INFORMATION ON NATURE OF STORED CHARGE
AIR PRESSURE	3	AFFECTS TRANSPORT OF STORED SURFACE CHARGE
SPECTRUM	3	PROBABLY UNIMPORTANT FOR STORED CHARGE
	DELIBERATE PRE-CONDITIONING	
PRE-STRESSING (BURN-IN)	1	TRAPS POLARIZATION CHARGE
PRE-IRRADIATION	1	TRAPS FREE CHARGE
THERMAL ANNEALING	1	RELEASES STORED CHARGE

Table 4-2. List Of Cables Tested For Stored Charge Release

	TRW SPEC NO.	MANUFACTURER	DESCRIPTION	DIELECTRIC
1.	PT3-59-93	Raychem	Coax braid shield	extruded irradiated foamed polyolefin
2.	PT3-33N-22	Raychem	Coax braid shield	extruded irradiated kynar + irradiated polyalkene
3.	PT3-33P-20	Raychem	2-conductor braid shield	extruded irradiated kynar + irradiated polyalkene
4.	PT3-53-RR-18	Raychem	3-conductor braid-shield	extruded irradiated kynar + irradiated polyalkene
5.	3A002-006	LaBarge	coax braid shield	tape wrapped kapton
6.*	3A024-001	Precision Tubes	Semi-rigid coax (086)	extruded teflon
7.*	3A024-002	Precision Tubes	Semi-rigid coax (141)	extruded teflon

* The SR141 cable was not tested in the phase 1 tests. Only the SR086 and SR141 were tested in phase 2 tests.

Voltage biasing, air pressure and spectrum are useful parameters to vary, but in our opinion are of lesser importance at this time for the quick-look experiments.

Cable preconditioning, we feel, represents a very important set of parameters to be controlled. It should be pointed out, however, that cable preconditioning refers to our preconditioning, not to the complete history of the sample, which is nearly impossible for us to know.

The types of preconditioning include the following: Virgin (i.e., no preconditioning), thermal annealing (at 125°C for 30 minutes), and burn-in at 100 V bias during 80°C annealing and subsequent cooling.

The quick-look experiments are divided into two phases, each of one week's duration. The first phase is devoted to experiments which vary parameters associated with priority 1 as shown in Table 4-1; the second phase examines semirigid cables in more detail.

4.2 STORED CHARGE RELEASE EXPERIMENTS, PHASE 1

4.2.1 Sample Preparation

All coiled cable samples have 25 cm of length exposed to radiation. For coax cables the same type of coax connector (SMA or OSM) is used for all cables. For multiconductor cables, the center conductors are joined (common-mode) before installation.

The free end of the cable is prepared as follows. Its shield is stripped back approximately 1/4 inch and covered with heat-shrinkable tubing, and shrunk. The interior conductors have already been cut back before the ends of their insulation to prevent shorting. A cap of copper foil is then soldered in place about the entire free end.

A picture of the cassette used in the experiments is shown in Figure 4-1.

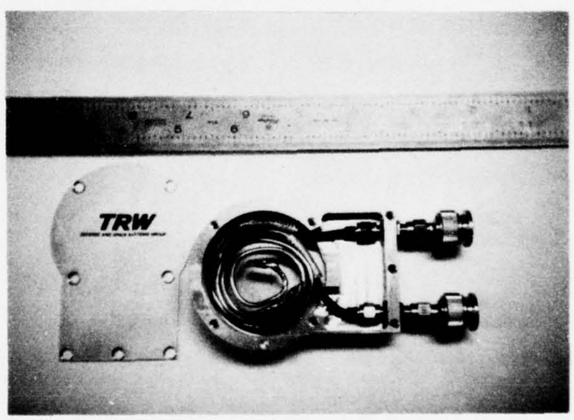


Figure 4-1. Cassette Employed to Hold the Cable Samples

4.2.2 Test Plan, Phase 1

The objectives of this set of tests are to determine the importance of cable type and/or dielectric type, as well as that of vacuum or air environments on the stored charge release in satellite cables.

For the first phase of tests we constructed 42 cable samples which are defined by the following variables:

6 cable types x 3 preconditions x 2 shot sequences = 36
(Table 4-2) (virgin, burn-in, anneal) (vac → air, air → vac)

plus an additional six for set-up and checkout. The cable types are the first six given in Table 4-2.

The types of cable preconditioning which were performed on the Phase 1 cables are

1) virgin cables (i.e., no preconditioning)
2) burn-in (+100 V bias maintained on center wire(s) 80°C anneal cycle for 30 minutes)
3) thermal anneal (125°C for 30 minutes)

Originally we had planned that the burn-in preconditioning would involve +2 KV voltage at 125°C for 30 minutes, but we could not achieve this without large leakage currents. These excessive leakage currents might have been due to dielectric breakdown, or leakage around the cable connectors which had already been installed. In order not to jeopardize the cable samples, we backed off to +100 V and 80°C peak temperature for the burn-in cycle.

By "vac → air" shot sequence we mean that a fresh sample is exposed to several shots in vacuum until no further change is observed in the peak amplitude. Then, without changing the sample the sample is shot in air until equilibrium. By "air → vac" a new sample is selected and now the sequence is air-to-vacuum, again without changing the sample. The objectives here are to (1) distinguish air from vacuum responses on the one hand, and (2) to distinguish the effects of naturally stored charge from charge transferred during the previous radiation pulses.

4.2.3 Test Set-Up for Phase 1 Tests

All tests were conducted on the SPI 6000 using the 2-1/2" diameter diode. All of the Phase 1 shots were conducted at the 0.2 mcal/cm^2 fluence level. This fluence level is obtained by charging the SPI 6000 diodes (the SPI is a bremstrahlung source of X-rays) to 200 kV, and allowing the discharged electrons to strike the 5 mil tantalum target. Such an experimental configuration allowed for an unlimited number of shots with nearly exact reproducibility from shot-to-shot. Source characteristics for this configuration are shown in Table 4-3.

Table 4-3. Source Characteristics of the SPI 6000 with 200 kV Diode Charging Voltage, 5 Mil Tantalum Target

Diode-Charging Voltage	200 kV
Tantalum Target Thickness	5 mil
Total Fluence Incident on Cassette	2×10^{-4} cal/cm^2 *
Total Dose Incident on Cassette	31 rad(Al) *
Total Fluence Transmitted to Cable Samples	1.8×10^{-4} cal/cm^2 **
Total Dose Transmitted to Cable Samples	18.6 rad(Al) **
Peak Flux Transmitted to Cable Samples	2.2×10^{3} cal/cm^2 · sec ***
Peak Dose Rate Transmitted to Cable Samples	2.3×10^{8} rad(Al)/sec ***

*Fluence and dose data incident on cassette provided by SPI

**Transmitted fluence and dose through 40 mil aluminum cassette cover based on calculations which used the X-ray spectrum of Figure 4-2a, provided by SPI, as input.

***Peak flux and dose rate transmitted to cables calculated from observed waveform shown in Figure 4-2b.

The total dose was monitored by TLD measurements. The average recorded dose per shot was 30 rad(CaF_2), in agreement with that quoted by SPI officials, but the TLD's which we were using were not accurate enough to monitor shot-to-shot fluence variations. Occasional photo-diode measurements were made to track the pulse reproducibility, but in fact the pulse waveform was essentially unchanged from shot-to-shot. This was observed in not only the photo-diode measurements but also in the diode voltage discharge measurements.

Fluence, Dose and Spectrum

The spectrum and waveform for our experimental configuration are shown in Figure 4-2.

The 0.2 mcal/cm^2 level of fluence and the spectrum of Figure 4-2 are incident on the face of the cassette, and transmitted through the 40 mil aluminum cassette face plate. The transmitted fluence and dose were calculated analytically using the spectrum in Figure 4-2a.

Vacuum

The residual air pressure in the tank containing the cassette was monitored and found to be $<10^{-2}$ torr. Pump-down time averaged about 15 minutes.

Air

The air shots were conducted at atmospheric pressure.

Instrumentation

The cassette employed to hold two cable samples is shown in Figure 4-1. The feedthrough for each line at the cassette is connected to a feedthrough at the vacuum tank which holds the cassette, which in turn is connected to the Tektronix 7844 dual beam oscilloscope being regarded as a nominal 50 Ω termination. The measurements reported are the potential drop to ground across this 50 Ω impedance.

For the Phase 1 tests no amplification of the signal was performed, and the scope traces could be read down to about ±2 mV.

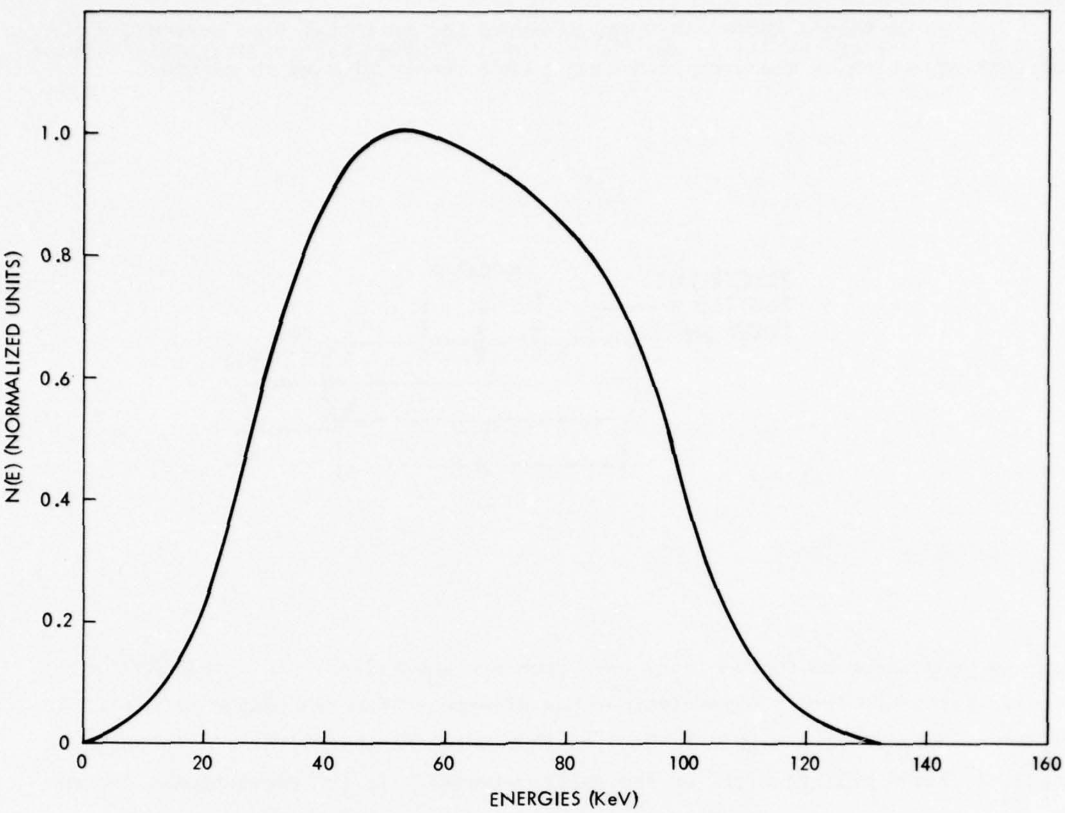


Figure 4-2a. SPI 6000 normalized spectrum, 200 keV diode-charging voltage, 5 mil tantalum target.

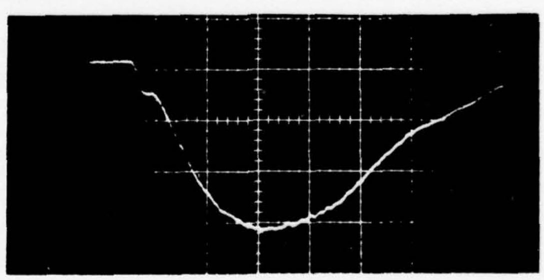
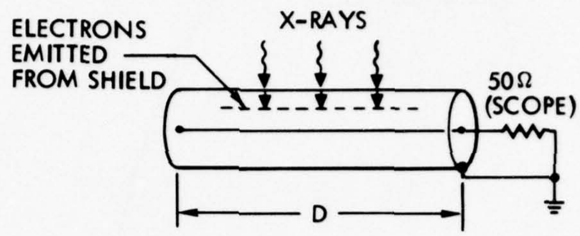


Figure 4-2b. SPI 6000 Photo-diode Waveform, 200 keV Diode-Charging Voltage, 5 mil Tantalum Target. Each Division on the Horizontal Axis Corresponds to 20 ns.

Discussion of Sign Conventions

As mentioned above the scope measured the potential drop across the 50Ω termination, which is measured from common mode center wire(s) to ground.



Now, in vacuum let us suppose more electrons are knocked off the shield and/or penetrate further into the insulation than electrons from the center wire(s). A negative replacement charge will have to flow onto the shield, or equivalently, a negative charge will flow off of the center wire(s). In the conventional current sense a negative current flows from center wire(s) to ground, and the scope trace, which measures the potential drop to ground, will be negative.

With this in mind, then, a positive response in vacuum corresponds to one of two things: (1) either more electrons are emitted from the center wire(s) (perhaps because the center wires are made of heavier Z materials and emit more electrons than the shield), or (2) they travel further (perhaps because a gap exists at the center wire, but not at the shield).

In air it is difficult to predict the sign a priori, but if our model of stored charge release, discussed in section 3.0, is at all plausible, a negative amount of a stored charge residing on the surface of a dielectric opposite the shield conductor will oppose the image current arising from the emitted electrons, by discharging themselves through an air shunt conductivity. Therefore the response will be positive at the scope, at least initially. When the surface charge is discharged sufficiently, the response will be negative early in the pulse, but eventually become bipolar, indicating the competition between emission and shunt currents.

The FWHM for the pulse, shown in Figure 4-3, is about 80 ns. Assuming a propagation speed of 2/3 c, this would correspond to wavelengths on the order of 2×10^8 m/sec x 80 ns = 16 m. Since the total length of cable was less than 2 m, including the tank-to-scope cables, no propagation effects or distortion of the pulse would be expected, and in fact none were observed.

Normalized Response: (C-cm/cal) and (C/rad(Al)-cm)

The peak injected current/length per unit flux may be obtained from the scope response in mV using

$$\text{normalized response (C-cm/cal)} = \frac{\text{response in mV}}{\text{peak flux x exposed cable length x } 50\Omega}$$

and, the peak current/length per unit dose rate,

$$\text{normalized response (C/rad(Al)-cm)} = \frac{\text{response in mV}}{\text{peak dose rate x exposed cable length x } 50\Omega}$$

Using a peak transmitted flux of 2.2×10^3 Cal/cm^2-sec, a peak transmitted dose rate of 2.3×10^8 rad(Al)/sec (from Table 4-3), and a cable length of 25 cm, we obtain the following conversion factors

$$1 \text{ mV} \longrightarrow 3.6 \times 10^{-10} \frac{\text{C-cm}}{\text{cal}}$$

$$1 \text{ mV} \longrightarrow 3.5 \times 10^{-15} \frac{\text{C}}{\text{rad(Al)-cm}}$$

4.2.4 Experimental Results Of The Phase 1 Tests

Presentation of the Data

A large amount of data was collected in the Phase 1 tests consisting of the load response waveforms (i.e., potential drop across the 50Ω scope load). In order to comprehend the data we have decided to present the data in six figures (Figures 4-3a to 4-3f). one for each of the cable types (nos. 1 through 6, Table 4-2). What is plotted is the peak response as a function of shot number. A (+) indicates a positive response, a (-) is a negative response, and a zero (0) is a missed data point. If the response is bipolar on a given shot, both peaks are indicated. Each cable was represented by six samples, namely

$$\left\{\begin{matrix}\text{3 types of}\\ \text{preconditioned}\\ \text{samples}\end{matrix}\right\} \times \left\{\begin{matrix}\text{vac} \rightarrow \text{air}\\ \text{air} \rightarrow \text{vac}\end{matrix}\right\} \text{ sequences.}$$

Overview of the Results of Phase 1 (Figures 4-3a to 4-3f)

All of the cables except the semirigid (SR086) had qualitatively similar behavior, namely:

- No anomalous behavior is observed in vacuum, i.e., the difference between the first shot and the N'th shot (equilibrium shot) in vacuum is no more than 15% of the first shot.
- The equilibrium shot in vacuum for all the samples of a given cable type was quite reproducible, and was negative in sign (exception: the PT3-59-93 coax, irradiated foamed polyolefin dielectric).
- Anomalies in air are observed in all cases, i.e., first shot amplitudes differ considerably from the equilibrium shot. The amplitudes, which are always positive on the first shot, eventually become bipolar with the first peak being negative, the second positive.
- In almost all cases the air response is positive on the first shot (exception: 3A002-006, coax, kapton dielectric).
- The behavior in air is not reproducible from sample to sample.
- Sample treatment (untreated, burn-in or annealing) does not affect air response in a predictable way, and the variation from sample-to-sample is large. Vacuum response is not affected very much by sample treatment (exception: PT3-59-93, foamed dielectric coax).
- Upon comparing responses of different cable types, the largest responses are for the multiconductor cables.

For the semirigid cable (SR086) the situation is qualitatively quite different:

- Anamolous behavior is observed in vacuum for the untreated cable sample, where the first shot in vacuum is 16X the equilibrium shot.
- Annealing the sample apparently removes the vacuum anomalous response.
- The air response, while not showing much variation from shot to shot, shows considerable variation from sample to sample.

Discussion of the PT3-33P-24 and PT3-53RR-18 Waveforms (Figure 4-4)

The selected waveforms which we present in Figure 4-4 are for two cables which shared the same cassette during the irradiation. These samples had no preconditioning, and the shot sequence started in vacuum, and finished in air. Both

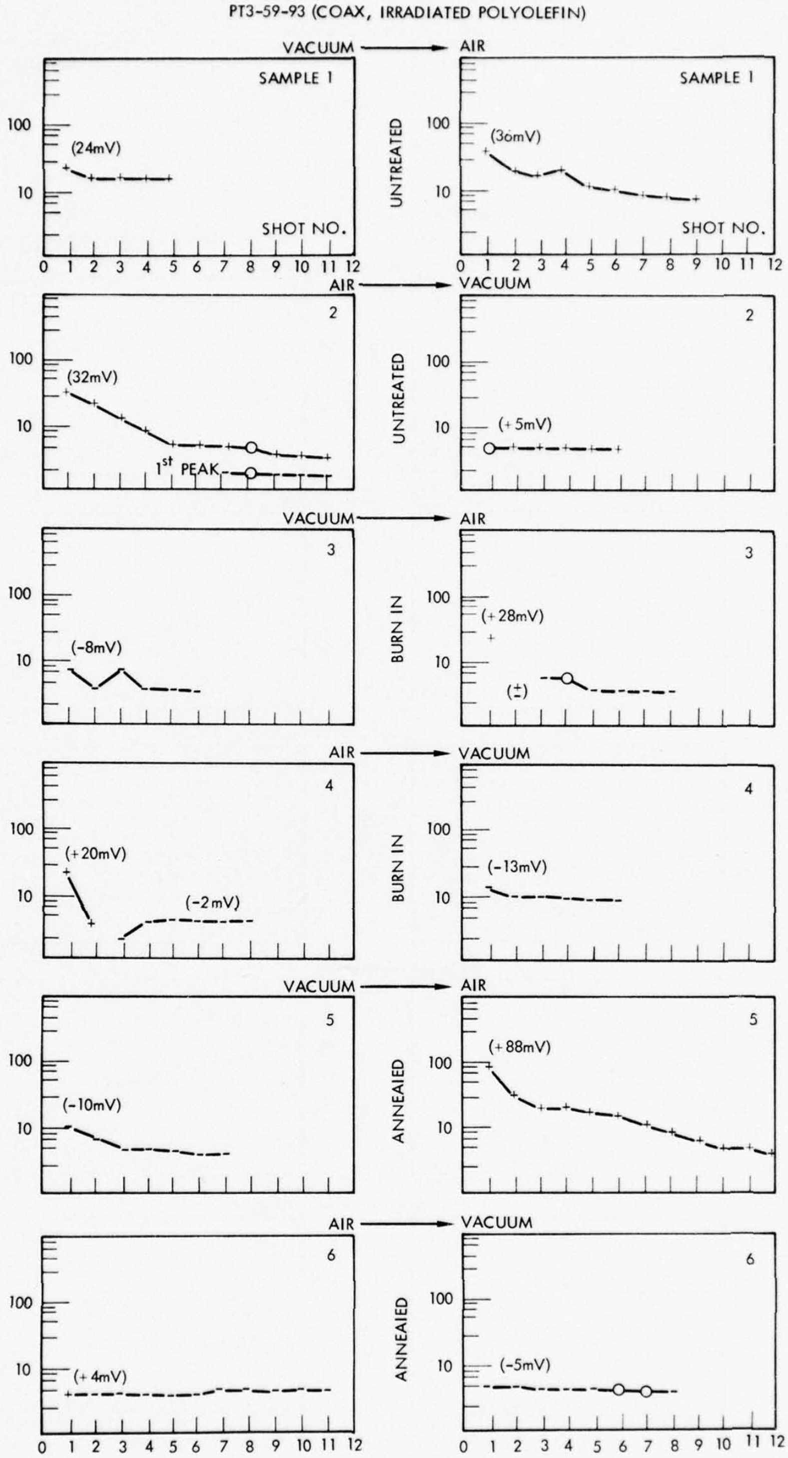


Figure 4-3a. Peak responses of the PT3-59-93 coax

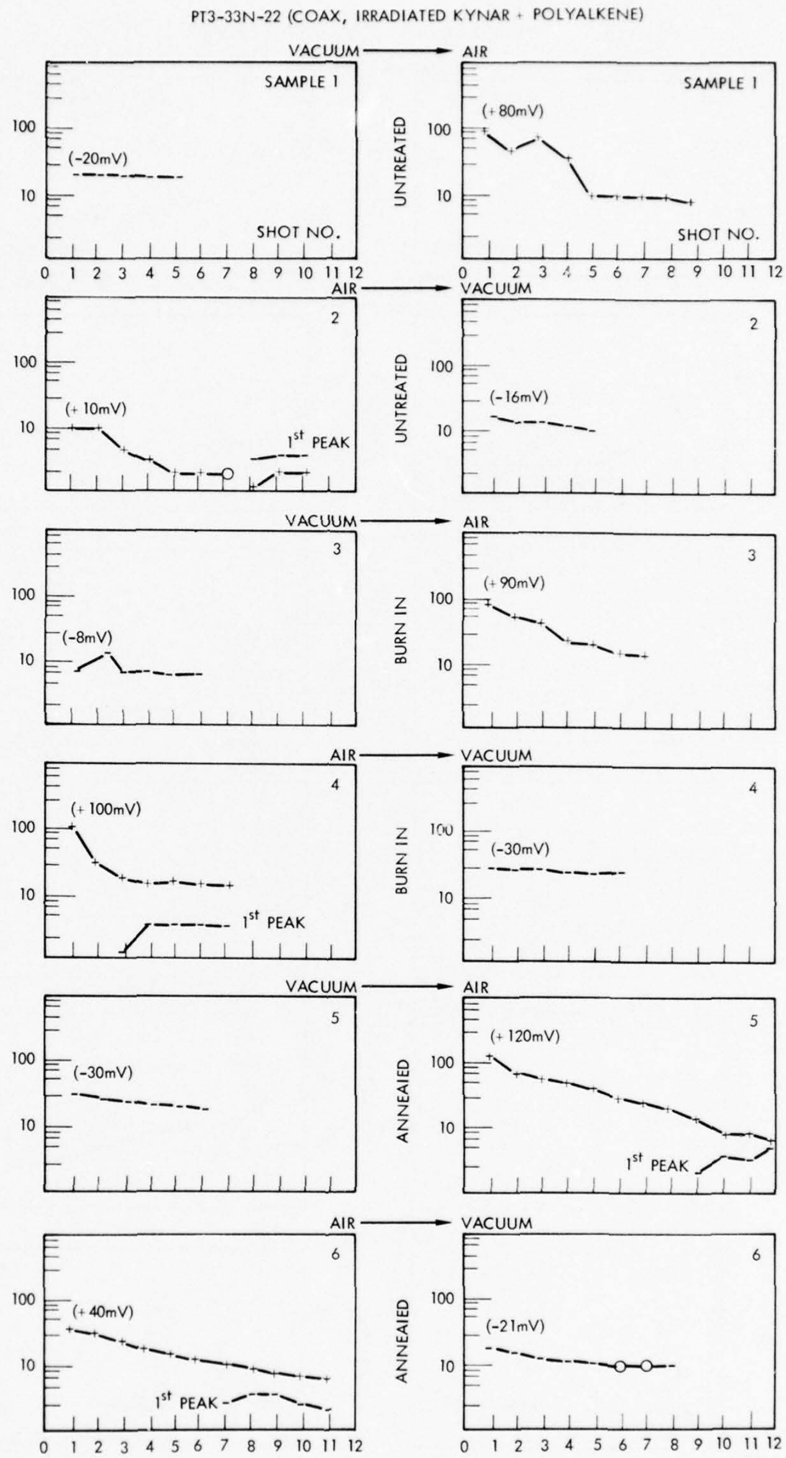


Figure 4-3b. Peak Responses of the PT3-33N-22, coax

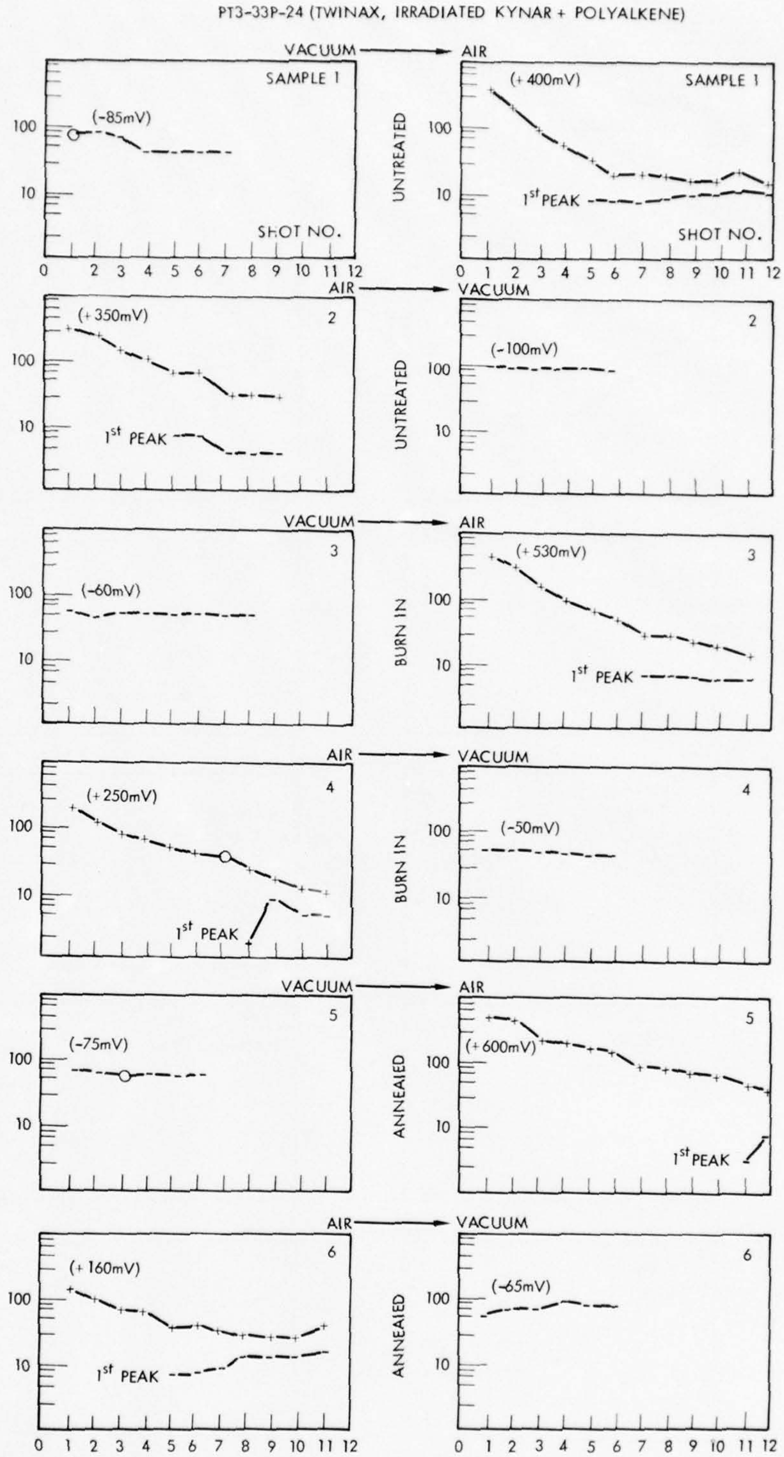


Figure 4-3c. Peak Responses of the PT3-33P-24, twinax

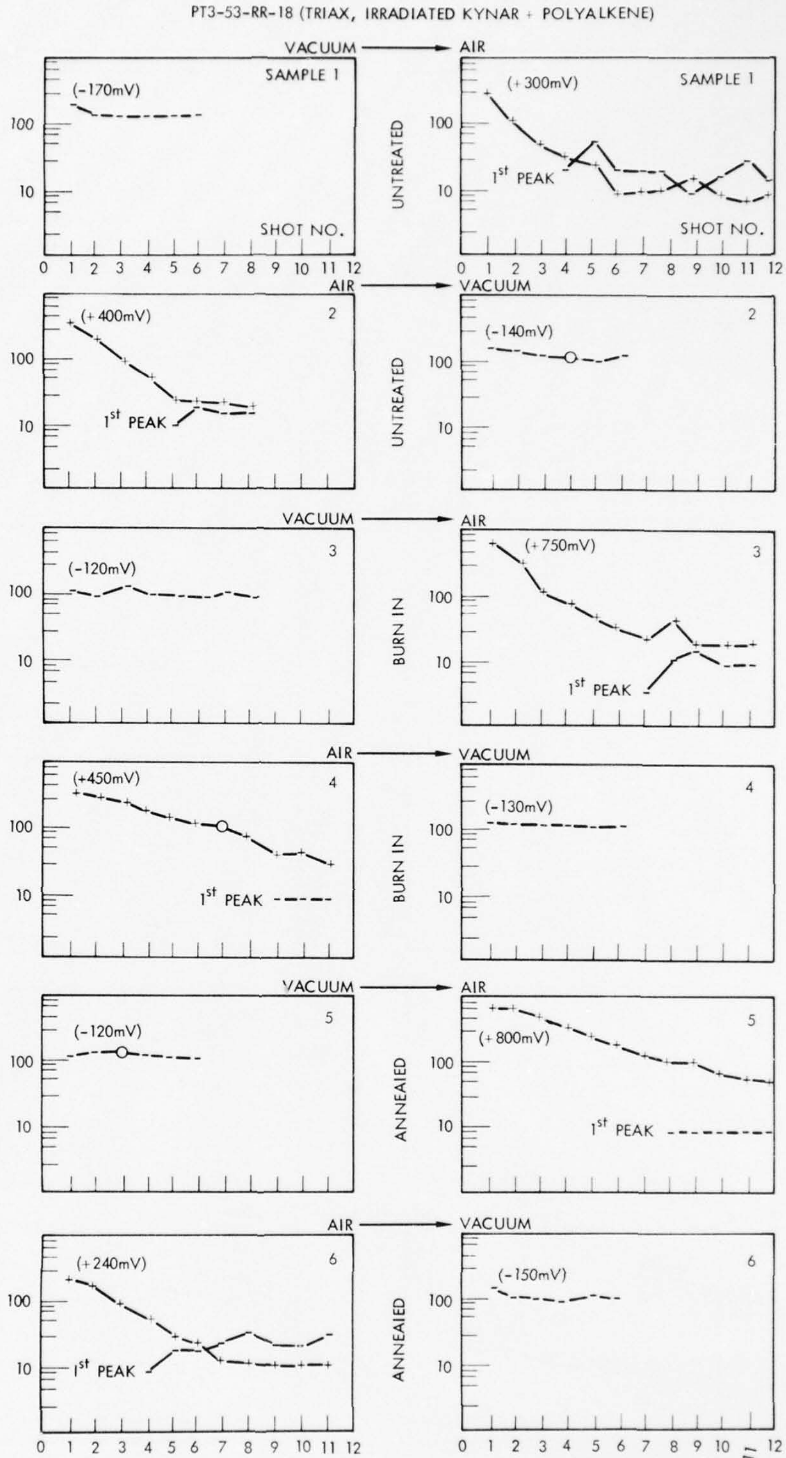


Figure 4-3d. Peak responses of the PT3-53-RR-18 triax

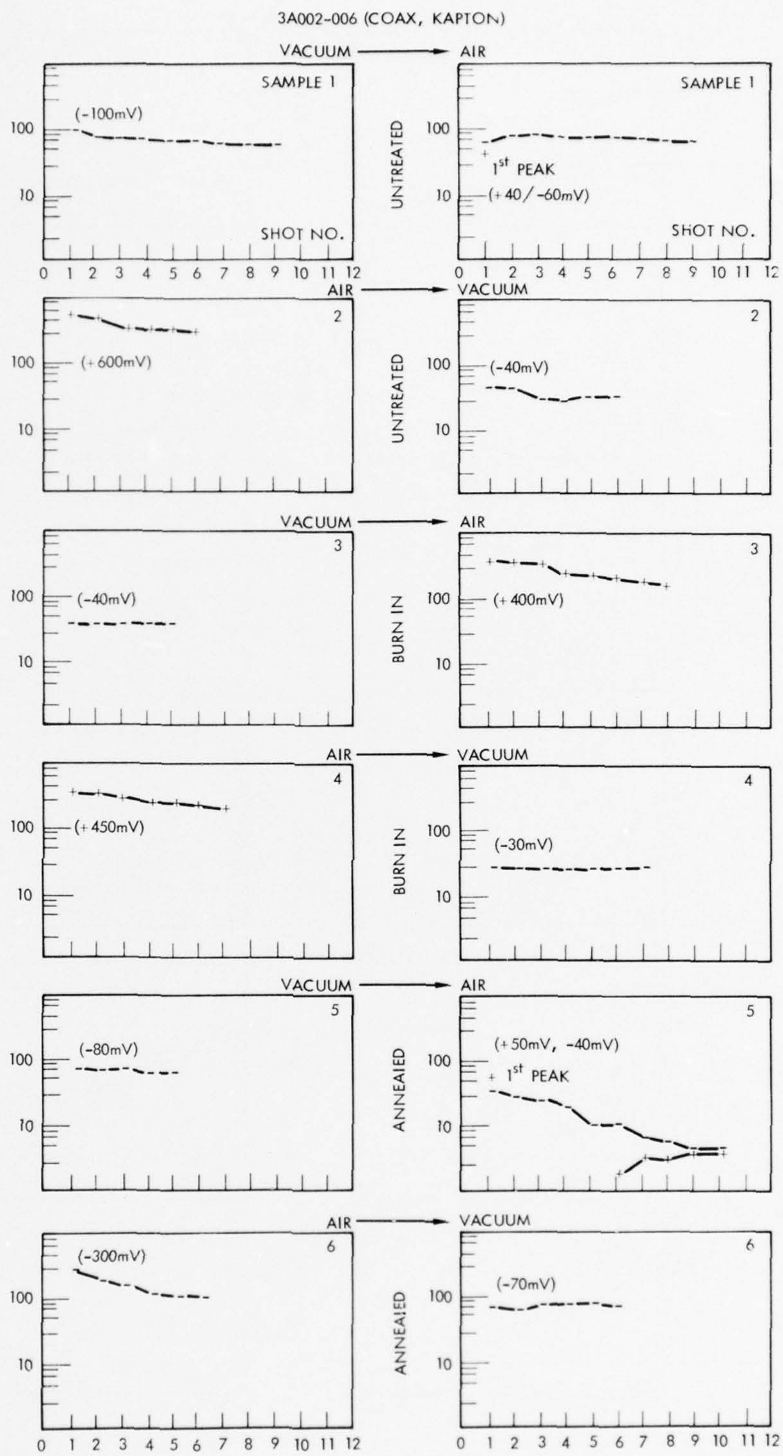


Figure 4-3e. Peak responses of the 3A002-006 coax

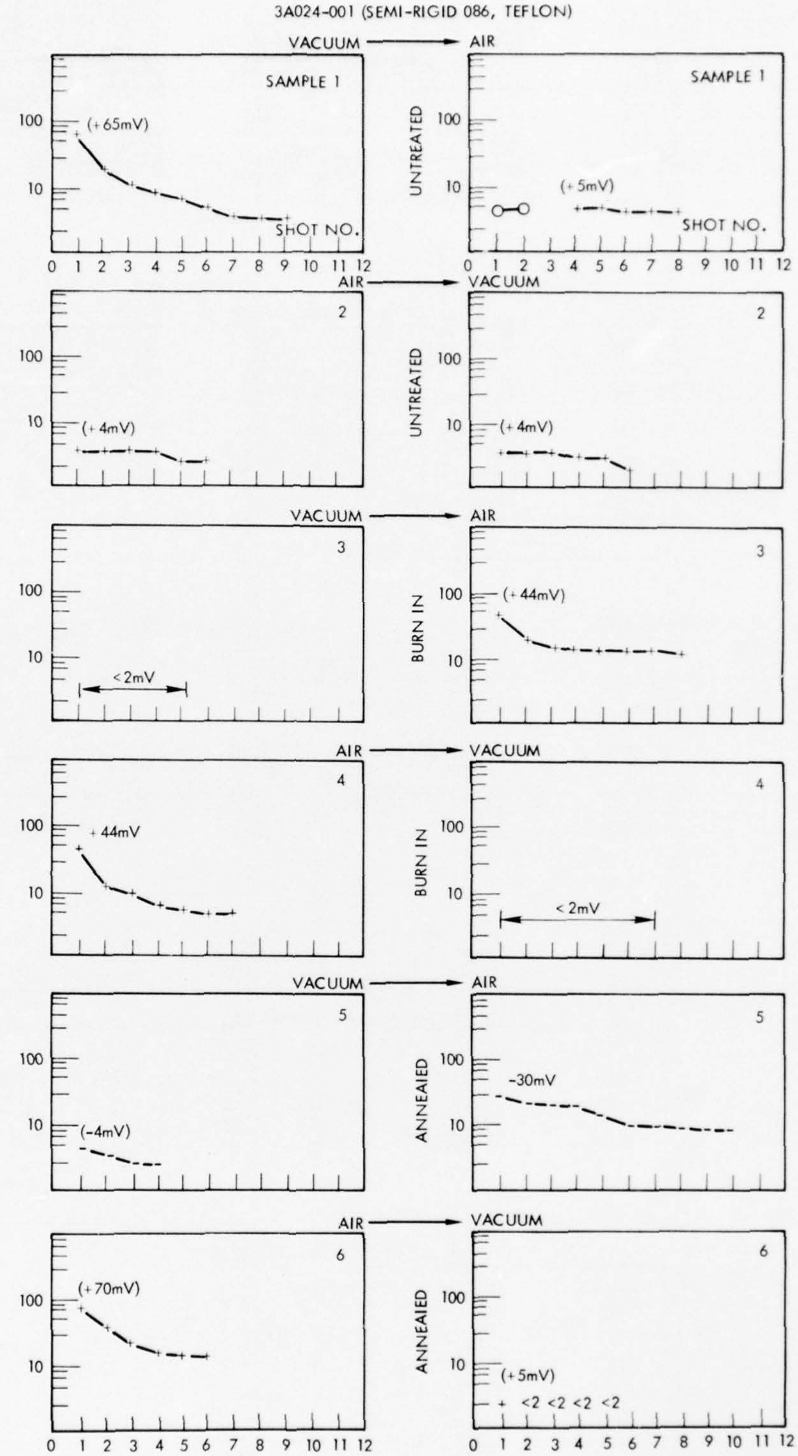
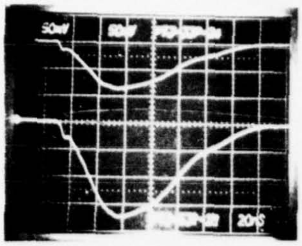
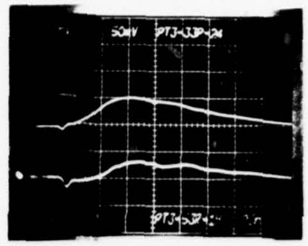


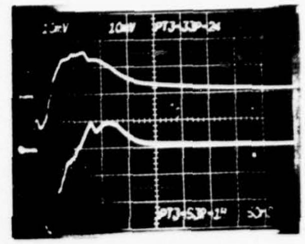
Figure 4-3f. Peak responses of the 3A024-001 semi-rigid 086 coax



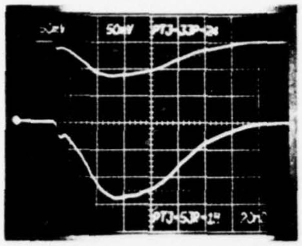
Vacuum Shot 2



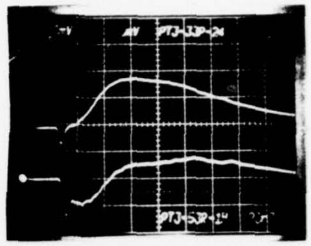
Air Shot 4



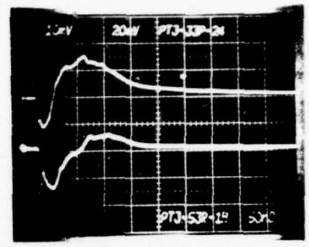
Air Shot 9



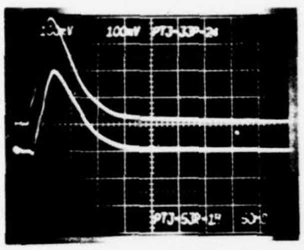
Vacuum Shot 8



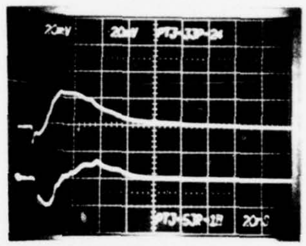
Air Shot 5



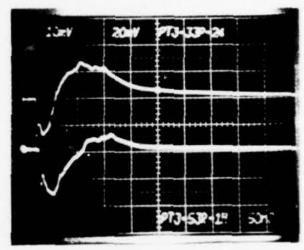
Air Shot 10



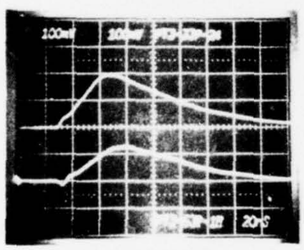
Air Shot 1



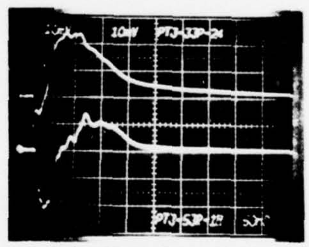
Air Shot 6



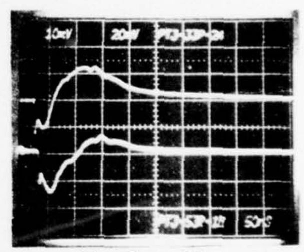
Air Shot 11



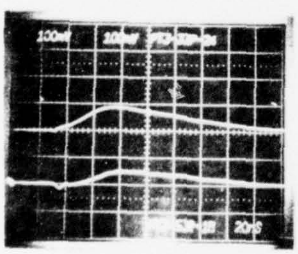
Air Shot 2



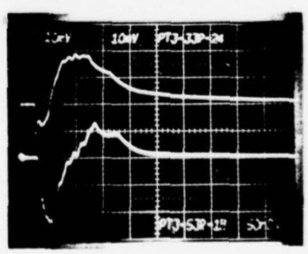
Air Shot 7



Air Shot 12



Air Shot 3



Air Shot 8

Figure 4-4. Response waveforms for the PT3-33P-24 Twinax and PT3-53RR-18 Triax. The time scale in ns/div is in the lower right hand corner. The response scale in mV/div is in the upper left corner for the upper trace *(PT3-33P-24), and in the upper center for the lower trace* (PT3-33RR-18) are multi-wire cables with braid shields.

For the vacuum there is about a 15% decrease in amplitude between shot 2 and shot 8. Note that the waveform follows the pulse (compare Figure 4-4 with Figure 4-2b).

The air response is mono-polar on the first shot, but of opposite sign compared to the vacuum response, and a factor of 2-4 higher. From the second shot onward the amplitude of the positive part continues to decrease, while a negative peak begins to appear. By the end of the sequence the negative peak is almost equal to the positive peak in magnitude.

Reproducibility of Equilibrium Vacuum Responses For Different Samples

In Table 4-4 we summarize the equilibrium vacuum response for all cable samples along with the MCCABE code prediction. As much as a factor of 2 variation among the different samples of the same cable type is observed, even though the shot-to-shot variation for a given sample was no where near as large. For the moment we suggest that the difference in response from sample-to-sample may be due to the vagaries of coiling the cable (and introducing gaps) in the cassette, or shadowing due to possible overlap of cables in the cassette.

One thing which surprised us was that the PT3-59-93 coax, which has an irradiated foamed polyolefin dielectric, experienced a sign change when the cable was deliberately preconditioned (burn-in or annealed), and which agreed in sign with the MCCABE code prediction.

Discussion and Interpretation of Results

For all cables excluding the semi-rigid, we believe that the stored charge release model presented in section 3.0 has been validated in its broad outlines. The basis of the model was that stored charge in cables resides on the dielectric surface facing a cable gap. In vacuum this charge is not released since no DC path is created for the electrons to cross the gap. In air a DC path is created by the ionization of the air. Successive shots are required to release this charge, and at that time the response is bipolar, indicating the competition between emission current and conduction current in the air.

This model would explain, at least qualitatively, the results mentioned above (excluding the semi-rigid cable):

- Vacuum response is fairly reproducible from shot-to-shot and sample-to-sample since stored charge is not released, and therefore does not compete with the (predictable) charge which is emitted from the

Table 4-4. Comparison of Analysis and Experiment for Equilibrium Response in Vacuum (mV)

CABLE	V→A UNCOND	A→V UNCOND	V→A ANNEAL	A→V ANNEAL	V→A BURNIN	A→V BURNIN	MCCABE PREDICTION
PT3-59-93 (irr. polyolefin coax)	21	5	-4	-4	-4	-10	-3
PT3-33N-22 (irr. Kynar, coax)	-17	-10	-20	-13	-7	-28	-7
3A002-006 (Kapton, coax)	-64	-36	-64	-80	-45	-32	-15
3A024-001 Teflon (semirigid 086)	4	2	2	2	-	-	+0.2
PT3-33P-24 (irr. Kynar, twinax)	-65	-78	-68	-80	-60	-44	-104
PT3-53RR-18 (irr. Kynar, triax)	-140	-110	-110	-120	-110	-120	-83

conductors. The small variation from shot-to-shot might be due to either the release of a residual amount of volume charge/polarization, or to the turning back of low energy secondaries by the accumulated transferred charge at the dielectric surface.

- The qualitative nature of the air response variation from shot-to-shot is accounted for in the model by the fact that several shots are needed to discharge the surface charge. The fact that there is variation from sample-to-sample in the peak response for the first shot indicates that the amount of stored surface charge is essentially an uncontrolled parameter. More than likely the charge resides at the dielectric surface nearest the shield indicating that its sign must be negative in order to oppose the primary emission current.
- Multi-conductor responses in air or vacuum are larger than coax responses because they have larger gaps.

For the semirigid cable we have no convenient explanation for the anomalous behavior in vacuum. Clearly it is not a dielectric surface charge effect, in the sense of our model discussed in Section 3.0, nor is it a volume charge/polarization effect, since we would expect that a gapless cable would respond the same in air and vacuum. Perhaps the key is in the last statement: the unsuspected presence of gaps introduced during coiling of the cable.

Conclusions from Phase 1 Tests

1) Anomalous response is observed in air shots for most cables, i.e., the first shot is substantially larger than the equilibrium shot amplitude.

2) The preliminary model (Section 3.0) of stored dielectric surface charge release in air is vindicated, at least in its broad outline. However, the amount of stored charge is essentially an uncontrolled parameter.

3) Based on the limited number of data points obtained in Phase 1 tests, only the semirigid cable (SR086) shows anomalous behavior in vacuum. At the moment we suspect that the introduction of gaps inside the cable during coiling and outgassing problems may be responsible for this behavior.

4.3 STORED CHARGE RELEASE EXPERIMENTS, PHASE 2

4.3.1 Sample Preparation

In the Phase 1 tests the only cable to show a significant first-shot anomaly was the semirigid SR086. We speculated that this might be due to the presence of air gaps, introduced during the coiling of the sample, and the difficulty in outgassing the air which was present. In order to investigate this we prepared several samples of semirigid cable which had been preconditioned in the following way:

- semirigid 086 and 141 coaxes, nonconditioned, coiled
- semirigid 086 and 141 coaxes, annealed, then coiled
- semirigid 086 and 141 coaxes, coiled, then annealed
- semirigid 086 and 141 coaxes, nonconditioned, straight segment
- semirigid 086 and 141 coaxes, annealed, straight segment

The straight samples were 5 cm in length, compared to the coiled sample length of 25 cm.

4.3.2 Test Set-Up for Phase 2 Tests

Instrumentation

The instrumentation was the same as in Phase 1 with the exception that an amplifier with 22 dB gain was used to amplify the signal.

Vacuum

For most samples the pump down time was $\approx$ 15 minutes. An overnight pump-down was also performed on one sample, but this had no recognizable effect on the results.

Air

Air response measurements were made at one atmosphere of pressure.

Fluence, Spectrum and Waveform

These were unchanged from the Phase 1 tests.

4.3.3 Experimental Results of the Phase 2 Tests

Overview of the Results of Phase 2

Our primary concern is whether or not the vacuum first-shot response is significantly greater than the equilibrium response. We report in Table 4-5 the ratio,

$$R = \frac{\text{first-shot response}}{\text{equilibrium response}}$$

for cables whose first radiation exposure was in vacuum. The samples were either non-conditioned, or annealed at 125°C for 30 minutes. A distinction was made between coiling the sample before annealing and coiling after annealing. Both Phase 1 and Phase 2 data are summarized.

Based on the data in Table 4-5 we make the following observations:

- The nonconditioned, coiled SR086 and SR141 show the largest anomalies (R = 16.3 and 4.0, respectively); of the braided shield samples only the PT3-59-93 coax, foamed polyolefin dielectric, has an R > 2.0.
- Annealing the cables reduces the first-shot anomaly in most cases.
- Annealing the cable after it is coiled seems to give a smaller anomalous response.
- The nonconditioned straight sample yields the smallest first-shot anomalies.

Presentation of Peak Response Data

The detailed vacuum response data on the SR086 and SR141 is shown in Figures 4-5 and 4-6 for the Phase 2 tests. What is plotted is the peak response (potential drop over the 50 Ω scope load) vs shot number. Note that the response is the absolute response (in mV) and that the 25 cm coiled samples might be expected to have 5 times the response of the 5 cm samples, with all other factors being equal.* The vacuum response has been arrived at in two sequences: (1) vacuum response of a fresh sample (labeled "initial vacuum response" in Figures 4-5(a) and 4-6(a)), and (2) a vacuum sequence following an air shot sequence (labeled "vacuum after air response" in Figures 4-5(b) and 4-6(b)).

First we discuss the SR086 data, presented in Figure 4-5. The data labeled "Phase 1 Setup" refers to a sample which was shot once during phase 1 checkout shots, and then shot during phase 2. Similarly the other "Phase 1" labels refer to testing of cables on phase 2 which had been shot during phase 1, and whose response has already been reported in Figure 4-3(f).

We notice some interesting things in comparing the samples which were irradiated during both phase 1 and phase 2 tests (cf Figure 4-3(f) and Figure 4-5(a)). The unconditioned sample, which had reached equilibrium during phase 1 (∿4 mV), seems to pick up where it left off in phase 2 (∿3 mV), and decreases to a value of 1 mV. In other words the anomalous behavior returns (after 2 weeks) but is not as pronounced. On the other hand, the annealed sample, which left off at -2 mV in phase 1, starts off now at -0.2 mV in phase 2. Note that the bending which occurs in phase 2 is not necessarily the same as in phase 1. Finally, the "vacuum after air" responses shown in Figure 4-5(b) do not exhibit first shot anomalies.

Turning to the SR141 data (Figure 4-6) we observe the anomalous response is smaller than the corresponding SR086 samples, but the sign of the response, even in equilibrium, is not reproducible. This is a strong indication to us that uncontrolled gaps exist in the cable.

* The amplification factor of 22 db for the amplifier has already been taken account in this data.

Table 4-5. Comparison of the Ratio, (First-Shot Response/ Equilibrium Response) in Vacuum for Phase 1 and Phase 2 Test Samples. The Shot Sequence Starts in Vacuum.

Cable Type	Conditioning	First-Shot Response / Equilibrium Response
PT3-59-93, coax	non-conditioned → coiled[a)]	1.1
	annealed → coiled[a)]	2.5
PT3-33N-22, coax	non-conditioned → coiled[a)]	1.2
	annealed → coiled[a)]	1.5
PT3-33P-24, twinax	non-conditioned → coiled[a)]	1.3
	annealed → coiled[a)]	1.1
PT3-53-RR-18, triax	non-conditioned → coiled[a)]	1.2
	annealed → coiled[a)]	1.1
3A002-006, coax	non-conditioned → coiled[a)]	1.6
	annealed → coiled[a)]	1.3
3A024-001, SR086	non-conditioned → coiled[a)]	16.3
	non-conditioned → coiled[b)]	5.4
	annealed → coiled[a)]	2.0
	annealed → coiled[b)]	3.4
	coiled → annealed[b)]	2.1
	non-conditioned → straight[b)]	1.1
3A024-002, SR141	non-conditioned → coiled[b)]	4.0
	annealed → coiled[b)]	1.3
	coiled → annealed[b)]	1.0
	non-conditioned → straight[b)]	1.2
	annealed → straight[b)]	1.9

a) Phase 1 test sample

b) Phase 2 test sample

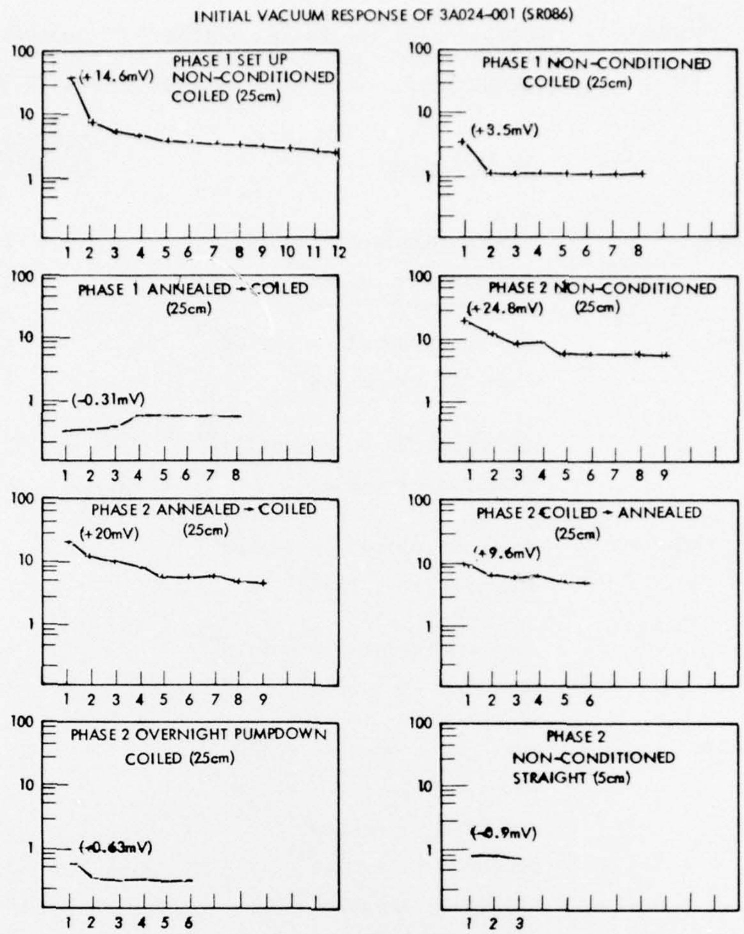


Figure 4-5(a). Peak Responses in Vacuum of the 3A024-001 (SR086), Initial Vacuum Sequence

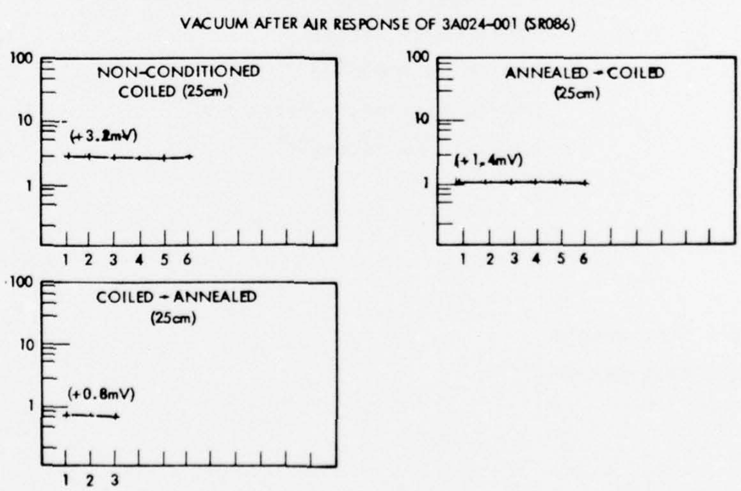


Figure 4-5(b). Peak Responses in Vacuum of the 3A024-001 (SR086), after Initial Air Sequence

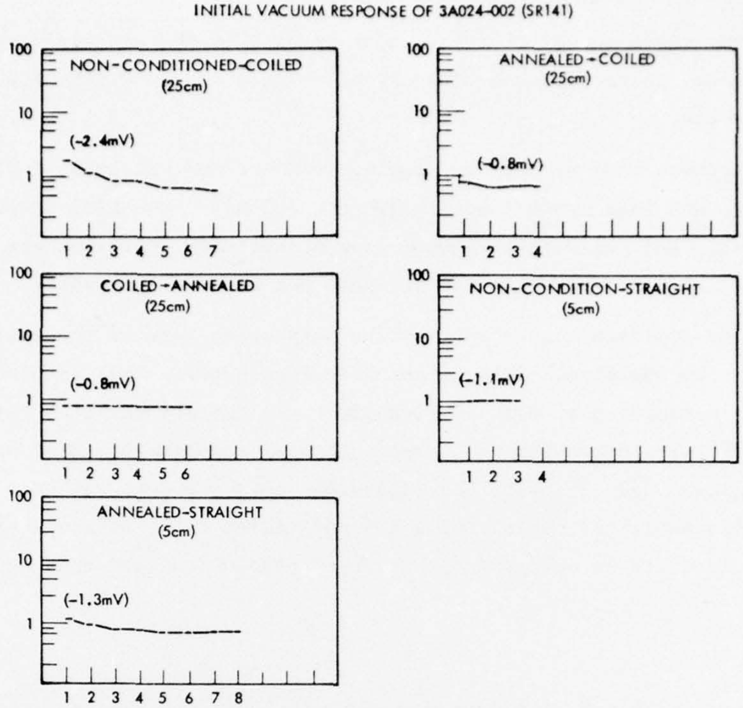


Figure 4-6(a). Peak Responses in Vacuum of the 3A024-002 (SR141), Initial Vacuum Sequence

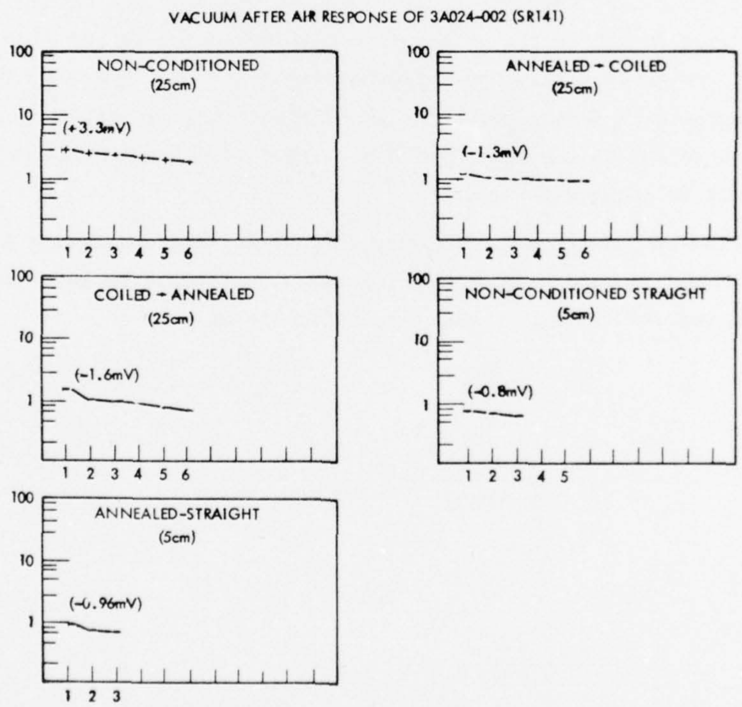


Figure 4-6(b). Peak Responses in Vacuum of the 3A024-002 (SR141), after Initial Air Sequence

Outgassing Experiments Performed During Phase 2 Tests

It seems clear to us, at least, that bending of the semirigid cable is correlated with anomalies in vacuum, and this may be related to the difficulty in outgassing the semirigid cables.

One approach that we used to examine this problem was to pump-down a fresh sample overnight, and then start shooting (Figure 4-5(a)). We still observed a first shot anomaly ($R \sim 2$), and the results didn't look appreciably different than when we pumped down for $\approx$ 15 minutes, which was standard for most of our tests.

A second approach was to look at the outgassing rate of the vacuum chamber with and without the cassette. This is shown in Figure 4-7. What is plotted is the tank pressure as a function of elapsed time after the outtake valve of the vacuum pump had been shut off. The curve labeled "empty chamber" represents a kind of asymtotic limit of outgassing rate. The fact that different curves result with and without the cassette (with its semirigid cable inside it) may indicate the presence of gaps in the cable and the difficulty in outgassing, but these conclusions are only speculative at this point.

Discussion

It seems clear from the data presented in Table 4-5 that the semirigid cables exhibit a first-shot anomalous behavior when they are coiled, but not when there is no bending, as in the straight samples. This anomalous behavior, we believe, is due to the introduction of gaps in the course of bending. Teflon, which is the dielectric for our semirigid cables, is known to have poor flow characteristics. Now, it may be true that the straight samples have gaps also, but the difference may be that the straight samples may have some continuity in the voids which are introduced, and therefore allow the outgassing of the air to occur with ease.

It should be pointed out, however, that performing outgassing experiments coincident with shooting cables is misleading since one cannot be sure if the shooting of the cable removed the charge, or the outgassing itself.

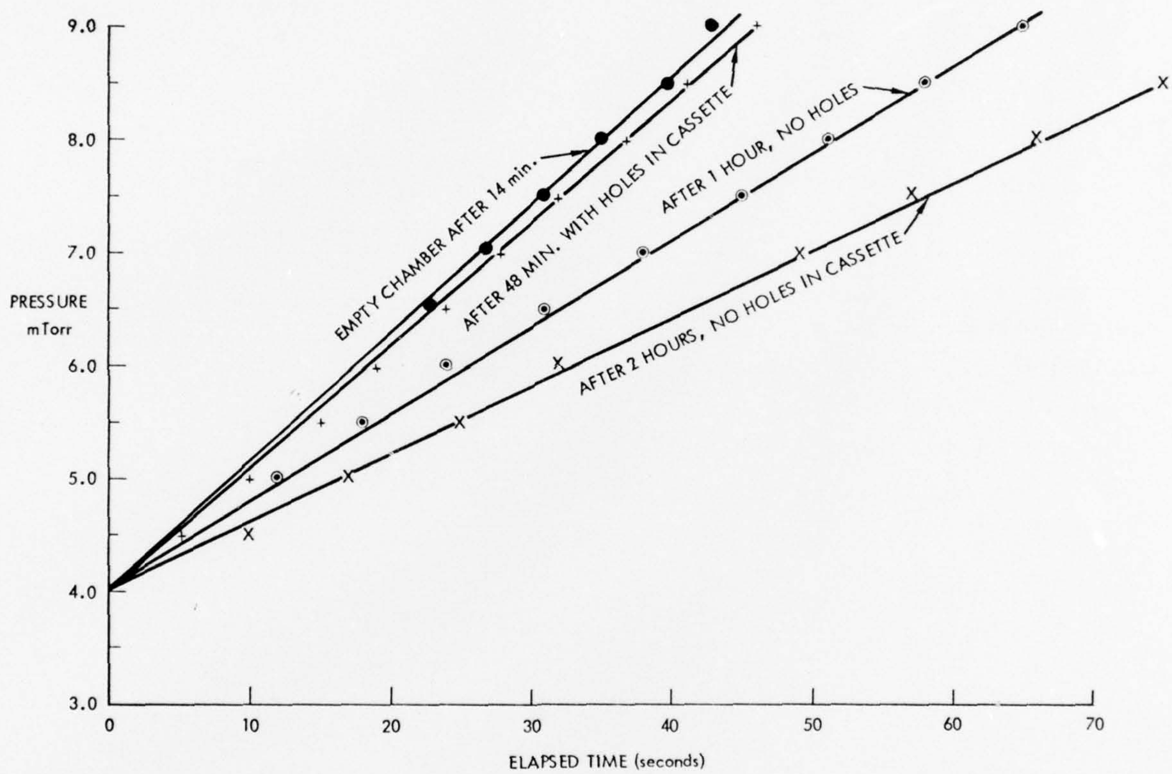


Figure 4-7. Outgassing Measurements during Phase 2 Tests

REFERENCES

1. D. M. Taylor, T. J. Lewis, and T. P. T. Williams, J. Phys. D: Appl. Phys. 7, 1756 (1974).

2. D. M. Clement, C. E. Wuller, and E. P. Chivington, IEEE Trans. Nucl. Sci. NS-23, 1946 (1976).

3. J. Wilkenfeld and V. Junkkarinen, "Thermal and Radiation Depolarization of Persistent Charge Stored in Polymer Dielectrics," IRT Corp., INTEL-RT 8124-005, August 1976.

4. R. L. Fitzwilson, M. J. Bernstein, and T. E. Alston, IEEE Trans. Nucl. Sci. NS-21, 276 (1974).

5. E. P. Chivington, L. E. Shaw, and T. E. Alston, IEEE Trans. Nucl. Sci. NS-23, 1952 (1976).

6.

DISTRIBUTION LIST

DEPARTMENT OF DEFENSE

Director
Defense Communications Agency
ATTN: NMR

Defense Documentation Center
Cameron Station
12 cy ATTN: TC

Director
Defense Nuclear Agency
ATTN: DDST
ATTN: TISI, Archives
2 cy ATTN: RAEV
3 cy ATTN: TITL, Tech. Library

Commander
Field Command, Defense Nuclear Agency
ATTN: FCPR
ATTN: FCLMC

Director
Interservice Nuclear Weapons School
ATTN: Document Control

Chief,
Livermore Division, Field Command, DNA
Lawrence Livermore Laboratory
ATTN: FCPRL

National Communications System
Office of the Manager
ATTN: NCS-TS

Under Secretary of Def. for Rsch. & Engrg.
ATTN: S&SS (OS)

DEPARTMENT OF THE ARMY

Director
BMD Advanced Tech. Ctr.
Huntsville Office
ATTN: RDMH-O

Dep. Chief of Staff for Rsch. Dev. & Acq.
ATTN: DAMA-CSM-N

Commander
Harry Diamond Laboratories
ATTN: DRXDO-TI, Tech. Lib.
ATTN: DRXDO-RCC, John A. Rosado
ATTN: DRXDO-RCC, Raine Gilbert
ATTN: DRXDO-NP

Commander
Picatinny Arsenal
ATTN: SMUPA
ATTN: SARPA

Commander
Redstone Scientific Information Ctr.
U.S. Army Missile Command
ATTN: Chief, Documents

DEPARTMENT OF THE ARMY (Continued)

Chief
U.S. Army Communications Sys. Agency
ATTN: SCCM-AD-SV, Library

Commander
U.S. Army Electronics Command
ATTN: DRSEL

DEPARTMENT OF THE NAVY

Chief of Naval Research
ATTN: Henry Mullaney, Code 427

Director
Naval Research Laboratory
ATTN: Code 5565, P. Ulrich
ATTN: Code 7750, Jack Davis

Officer-in-Charge
Naval Surface Weapons Center
ATTN: Code WA501, Navy Nuc. Prgms. Off.

Director
Strategic Systems Project Office
ATTN: NSP

DEPARTMENT OF THE AIR FORCE

AF Geophysics Laboratory, AFSC
ATTN: Charles Pike

AF Materials Laboratory, AFSC
ATTN: Library

AF Weapons Laboratory, AFSC
ATTN: SUL
2 cy ATTN: NTS
2 cy ATTN: DYC

Hq. USAF/RD
ATTN: RDQSM

Commander
Rome Air Development Center, AFSC
ATTN: Edward A. Burke

SAMSO/DY
ATTN: DYS

SAMSO/MN
ATTN: MNNG
ATTN: MNNH

SAMSO/SK
ATTN: SKF

SAMSO/XR
ATTN: XRS

Commander in Chief
Strategic Air Command
ATTN: NRI-STINFO, Library
ATTN: XPFS

DEPARTMENT OF ENERGY

University of California
Lawrence Livermore Laboratory
ATTN: Tech. Info., Dept. L-3

Los Alamos Scientific Laboratory
ATTN: Doc. Con. for Reports Lib.

Sandia Laboratories
Livermore Laboratory
ATTN: Doc. Con. for Theodore A. Dellin

Sandia Laboratories
ATTN: Doc. Con. for 3141, Sandia Rpt. Coll.

OTHER GOVERNMENT AGENCY

NASA
Lewis Research Center
ATTN: N. J. Stevens
ATTN: Carolyn Purvis
ATTN: Library

DEPARTMENT OF DEFENSE CONTRACTORS

Aerospace Corporation
ATTN: Frank Hai
ATTN: V. Josephson
ATTN: Julian Reinheimer
ATTN: Library

Avco Research & Systems Group
ATTN: Research Lib. A830, Rm. 7201

The Boeing Company
ATTN: Preston Geren

University of California at San Diego
ATTN: Sherman De Forest

Computer Sciences Corporation
ATTN: Alvin T. Schiff

Dr. Eugene P. DePlomb
ATTN: Eugene P. DePlomb

Dikewood Industries, Inc.
ATTN: Tech. Lib.
ATTN: K. Lee

EG&G, Inc.
Albuquerque Division
ATTN: Technical Library

Ford Aerospace & Communications Corp.
ATTN: Donald R. McMorrow, MS G30
ATTN: Library

General Electric Company
Space Division
ATTN: Joseph C. Peden, VFSC, Rm. 4230M

General Electric Company
TEMPO-Center for Advanced Studies
ATTN: DASIAC
ATTN: William McNamara

DEPARTMENT OF DEFENSE CONTRACTORS (Continued)

Hughes Aircraft Company
ATTN: Tech. Library

Hughes Aircraft Company,
El Segundo Site
ATTN: Edward C. Smith, MS A620
ATTN: William W. Scott, MS A1080

Institute for Defense Analyses
ATTN: IDA Librarian

IRT Corporation
ATTN: Dennis Swift
ATTN: Technical Library

JAYCOR
ATTN: Library
ATTN: Eric P. Wenaas

JAYCOR
ATTN: Robert Sullivan

Johns Hopkins University
Applied Physics Laboratory
ATTN: Peter E. Partridge

Kaman Sciences Corporation
ATTN: Library
ATTN: W. Foster Rich
ATTN: Jerry I. Lubell

Lockheed Missiles & Space Co., Inc.
ATTN: Dept. 85-85

McDonnell Douglas Corporation
ATTN: Stanley Schneider

Mission Research Corporation
ATTN: Roger Stettner
ATTN: Conrad L. Longmire

Mission Research Corporation-San Diego
ATTN: V. A. J. Van Lint
ATTN: Library

R&D Associates
ATTN: Leonard Schlessinger
ATTN: Technical Library

Rockwell International Corporation
ATTN: Technical Library

Science Applications, Inc.
ATTN: William L. Chadsey

Spire Corporation
ATTN: Roger G. Little

Systems, Science & Software, Inc.
ATTN: Andrew R. Wilson
ATTN: Technical Library

TRW Defense & Space Sys. Group
ATTN: Tech. Info. Center/S-1930
2 cy ATTN: Robert M. Webb, R1-2410
4 cy ATTN: D. M. Clement/L. C. Nielsen/
T. J. Sheppard/C. E. Wuller