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## **Measurements of Prompt Radiation Induced Conductivity in Teflon (PTFE)**

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# Measurements of Prompt Radiation Induced Conductivity in Teflon (PTFE)

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## Abstract

We performed measurements of the prompt radiation induced conductivity (RIC) in thin samples of Teflon (PTFE) at the Little Mountain Medusa LINAC facility in Ogden, UT. Three mil (76.2 microns) samples were irradiated with a 0.5  $\mu$ s pulse of 20 MeV electrons, yielding dose rates of 1E9 to 1E11 rad/s. We applied variable potentials up to 2 kV across the samples and measured the prompt conduction current. Details of the experimental apparatus and analysis are reported in this report on prompt RIC in Teflon.

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## 1. INTRODUCTION

We performed measurements of the prompt radiation induced conductivity (RIC) in thin samples of Teflon (PTFE) at the Little Mountain Medusa LINAC facility in Ogden, UT. Three mil (76.2 microns) samples were irradiated with a 0.5  $\mu$ s pulse of 20 MeV electrons, yielding dose rates of 1E9 to 1E11 rad/s. We applied variable potentials up to 2 kV across the samples and measured the prompt conduction current. Details of the experimental apparatus and analysis are reported in this report on prompt RIC in Teflon.

## 2. TEST SUMMARY

Three different Teflon RIC cells were used, each containing an upper RIC cell (URC) and a lower RIC cell (LRC). The sample number is labeled as TFEX, where X is 1-3. The specific test series is labeled as indicated in the table below.

**Table 1 Test Summary**

Date	Sample / Series	TLD type	Shot Numbers	Nominal Dose Rate (rad/s)	Nominal Pulse Width (ns)
June 2005	TFE1	LiF	1211-1257	3.5E10	500
July 2007	TFE3a-1	Si	1061-1077	2.2E9	500
	TFE3a-2	Si	1078-1094	4.1E9	500
	TFE3a-3	SI	1095-1107	8.4E9	500
	TFE2-1	Si	1237-1249	2.5E9	500
	TFE2-2	Si	1250-1262	4.4E9	500
	TFE2-3	SI	1263-1275	8.5E9	500
December 2008	TFE3b	SI	2247-2307	1.1E11	35

The ratios between the dose in the Teflon layers and the measured dose in the TLD's, as computed by MCNP, is 1.05 (URC) and 1.04 (LRC) for the LiF TLD, and 0.99 (URC) and 1.00 (LRC) for the Si Calorimeter. All dose rates reported are scaled to the dose in Teflon.

### 3. EXPERIMENTAL APPARATUS AND TEST CHAMBER

Figure 1 shows a side view cross-section of the RIC test fixture for the dielectric samples. This configuration is a stack of two separate cells which are irradiated together. Each cell consists of a center electrode, two dielectric layers, and ground planes on the outer surface of each dielectric. The RIC cell nearest the electron beam is called the upper RIC cell (URC), and the cell below it the lower RIC cell (LRC).

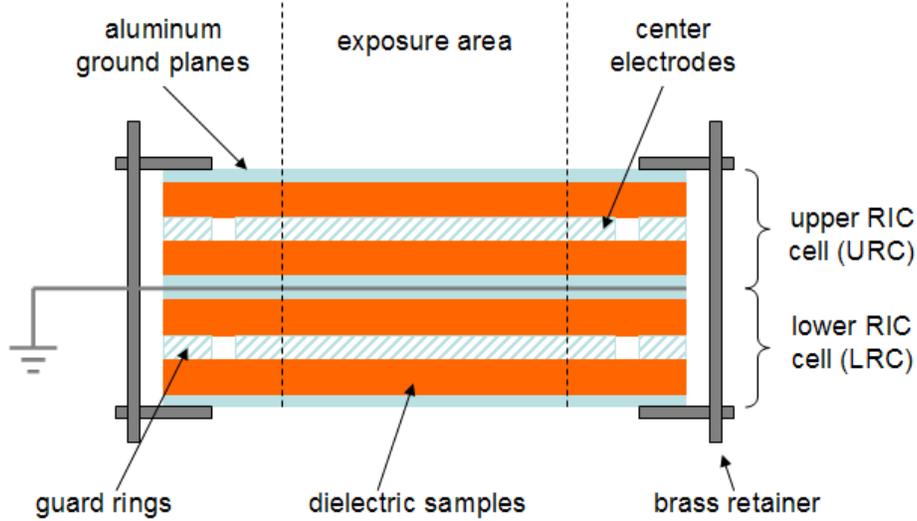


Figure 1 A RIC cell test fixture.

The Teflon layers are formed from 76.2 micron thick discs, about 2.5 centimeters in diameter, and are placed on either side of a 30 micron center aluminum electrode. Two 15 micron outer aluminum electrodes serve as the cell ground planes. The guard rings minimize the electric field distortion at the edge of the center electrodes. Bias voltages were applied to the center electrodes and the guard rings. The bias of the lower cell was made equal to that of the upper cell, with opposite polarity.

Current is driven through the dielectric layers from their conductivity and the applied bias, and directly from the attenuation and divergence of the electron beam. The conductivity consists of the dark or static conductivity  $\sigma_0$ , the prompt RIC  $\sigma_p$ , and the delayed RIC  $\sigma_d$ . The net current is the sum

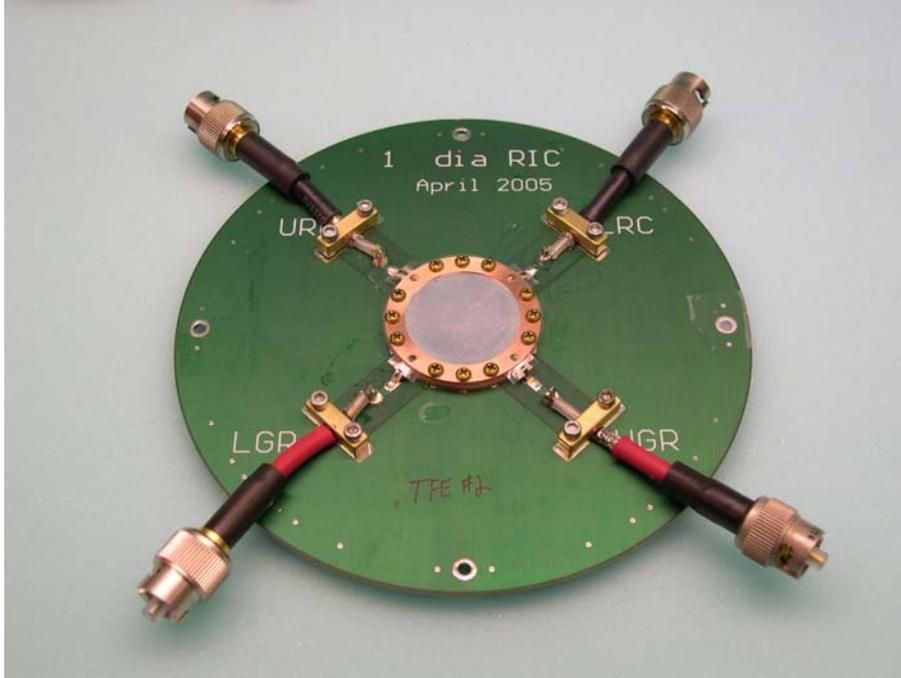
$$I = Vd(\sigma_0 + \sigma_p + \sigma_d) + I_{dd} \quad (1)$$

where  $V$  is the bias, and  $d$  the sample thickness. The delayed conductivity may contain several terms with different decay constants, representing traps of different depths. In addition, there is a direct drive current  $I_{dd}$  produced by the electron beam in the absence of bias.

This cell design, including dielectric layers above and below a center electrode, greatly reduces the direct drive current,  $I_{dd}$  by balancing the charge lost from the center electrode on either side.

Even with this technique, the direct drive current is a substantial part of the total, and it can be difficult to determine the contribution of the prompt RIC for polymers.

A typical RIC cell test fixture is pictured in Figure 2. The busses for applying the guard ring voltages (LGR and UGR) and the center electrode biases (URC and LRC) are labeled.



**Figure 2 A typical RIC cell.**

The properties of the Teflon samples under test are given below.

**Composition** (weight fractions): C 0.240183, F 0.759818

**Density:** 2.25 g/cm<sup>3</sup>

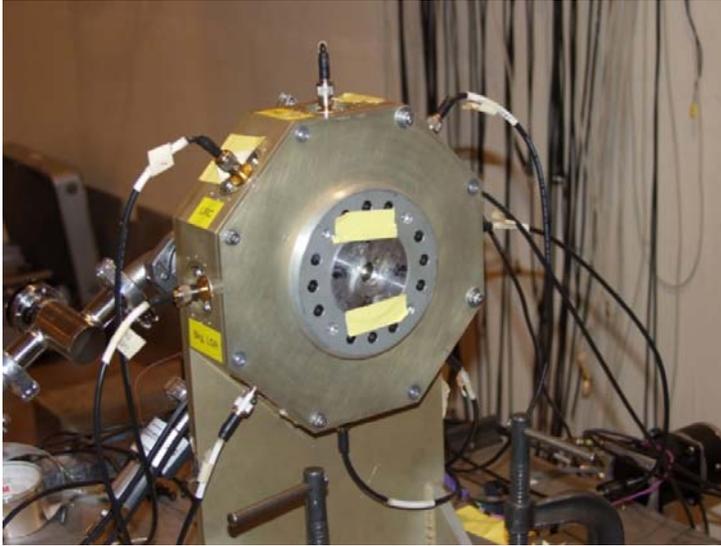
**Dielectric constant:** 2.02

**Sample thickness:** 3.00 mils = 76.2 microns

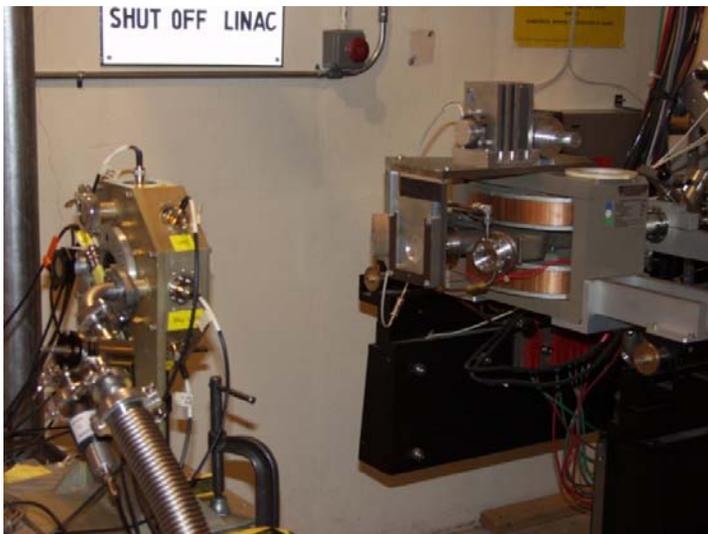
The measured capacitance of the RIC cells containing Teflon is 2.48E+02 pf with a standard deviation of 6.05pf. This is for one two- sided cell, either the URC or the LRC. The area of the center electrode is  $A_{tot} = 5.06 \text{ cm}^2$ , but the irradiated area was collimated to  $1.98 \text{ cm}^2$ . The measured capacitance closely agrees with a one-dimensional calculation:

$$C = \frac{2A_{tot}k\epsilon_0}{d} = \frac{2(5.06 \times 10^{-4} \text{ m}^2)(2.02)(8.9 \times 10^{-12} \text{ F / m})}{76.2 \times 10^{-6} \text{ m}} = 239 \text{ pF} . \quad (2)$$

The test chamber that housed the RIC (radiation induced conductivity) cell was evacuated to  $2E-4$  Torr to eliminate any effects due to air ionization. Radiation entered the test chamber through a collimated aperture. Figure 3 shows the front side of the test chamber and the aperture hole in the center of the fixture. The aperture was smaller in diameter than the dielectric samples, assuring that only the central area of the dielectric was struck by radiation, and that the guard rings did not receive radiation exposure. Figure 4 shows the side view of the test chamber with the front of the LINAC visible to the right.



**Figure 3 The vacuum experimental chamber. It shown in the foreground with high voltage cables exiting through vacuum feed-through connectors.**



**Figure 4 The experiment chamber with high voltage cables. In the background is the front of the Little Mountain Medusa LINAC facility.**

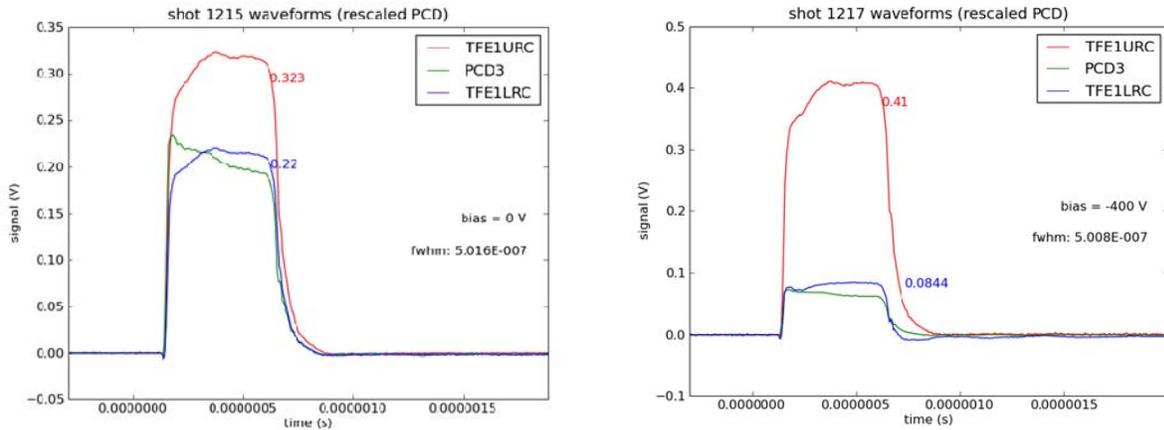
### **Electron Beam Characteristics**

If a radiation source is not capable of providing consistent or repeatable output, including its spectrum, pulse width, and fluence, then the difficulty of performing repeatable and interpretable experiments is greatly magnified. We chose the Medusa LINAC at the Little Mountain Test Facility (LMTF) because it is capable of producing repeatable and predictable radiation output over long periods of time (such as reproducible pulsing over a week of experiments). We found through repeated testing that our dosimetry consisting of silicon calorimeter, PIN diode and PCD diamond detectors gave consistent repeatable readings shot to shot for the same conditions such as fixed distance from the source and fixed pulse width. The variation at the same conditions was approximately 1% shot to shot.

The nominal electron energy for the LINAC is 20 MeV, and the radiation pulse can be varied from 10 ns to 50  $\mu$ s. For most of these experiments the radiation pulse width was about 0.5  $\mu$ s FWHM. The dose rate range for this experiment was about 1E9 to 1E10 rad(Si)/s. For electron beam dosimetry, silicon calorimeters were supplemented with TLDs, PIN diodes, and PCDs. Measurement accuracy at the LINAC, including dosimetry and recording instruments, is estimated to be about  $\pm 10\%$ .

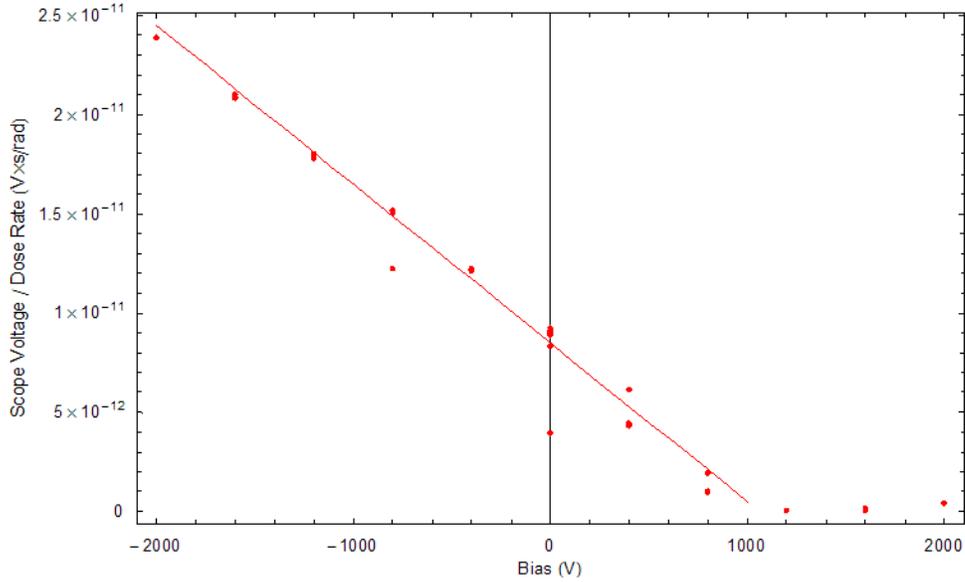
## 4. TFE1

Typical waveforms for the TFE1 series are shown in figure 5. The direct drive signal is about 0.2 to 0.3 Volts and the biased signal (at 400 V) is about 0.4 V, so the RIC current is producing about a 0.1 V difference. The positively biased cell has its signal reduced from the 0.2 V present from the direct drive to about 0.1 V, as expected. You can see the delayed RIC driving a slight negative voltage in the positively biased cell after the pulse, when the direct drive contribution is removed.



**Figure 5 Typical unbiased (a) and biased (b) waveforms from the TFE1 series.**

The URC data for the TFE1 series is shown in figure 6. There is a problem with the data for positive bias above 800 V, so these are excluded from the fit. A few other outlying points were also excluded. The mean dose rate was used. Unlike other material samples (like Pyralux), there is no change in slope or intercept going from negative to positive bias.



**Figure 6 The RIC coefficient fit for the TFE1 URC.**

## 5. TFE2

The TFE 2 cells had highly asymmetric responses as seen in figure 7. The URC direct drive response is about half the LRC direct drive response. At low bias, there is the expected asymmetry in the signals due to direct drive, but at high bias, the positively biased cell shows a larger response.

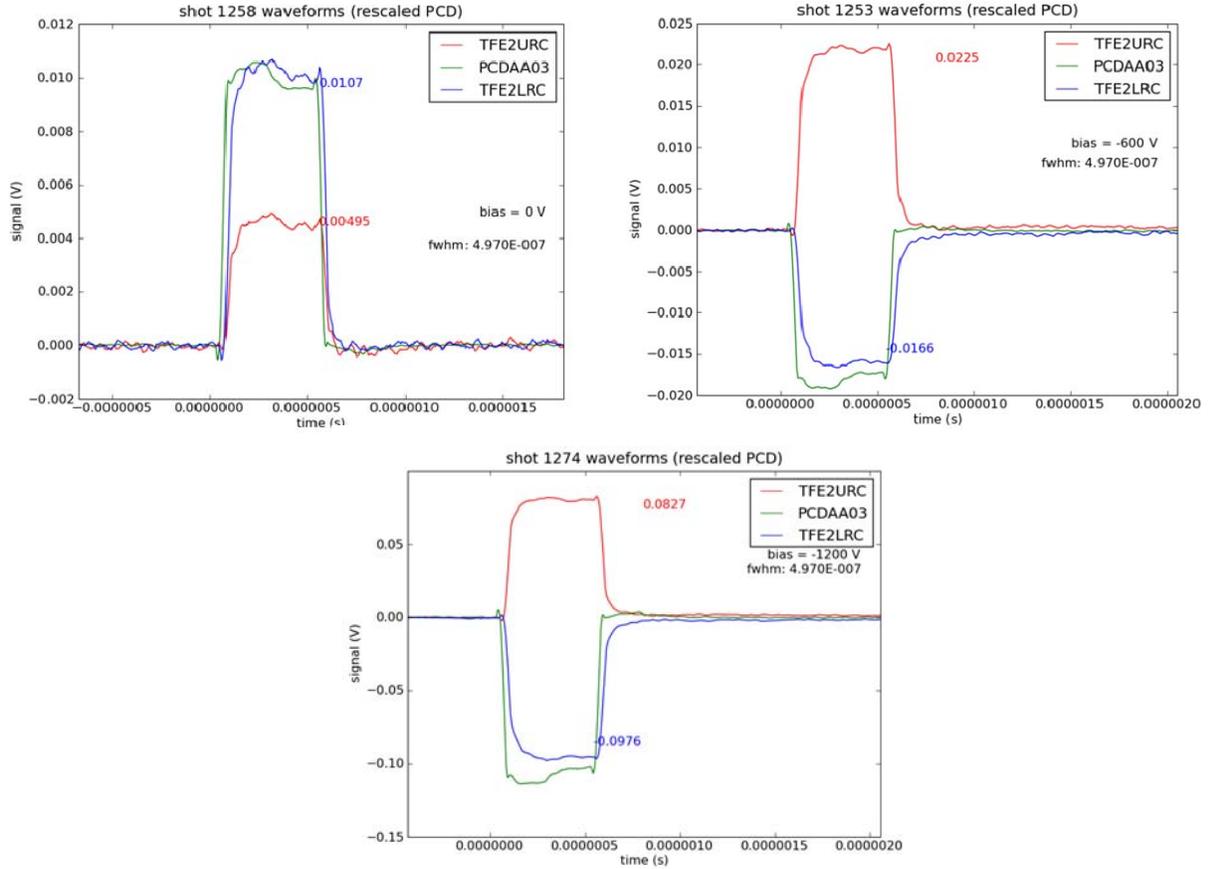
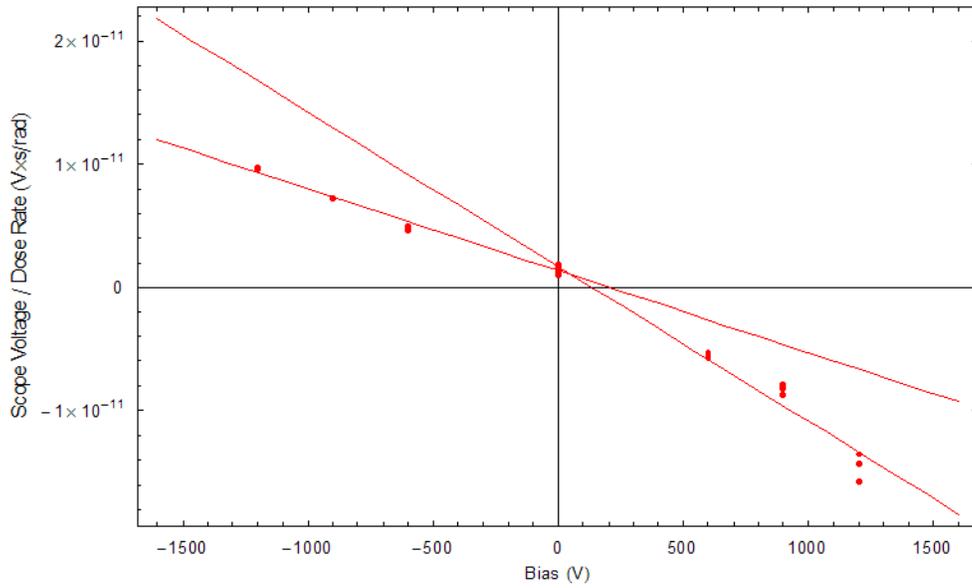


Figure 7 Unbiased, low biased, and high biased waveforms from the TFE2 series.

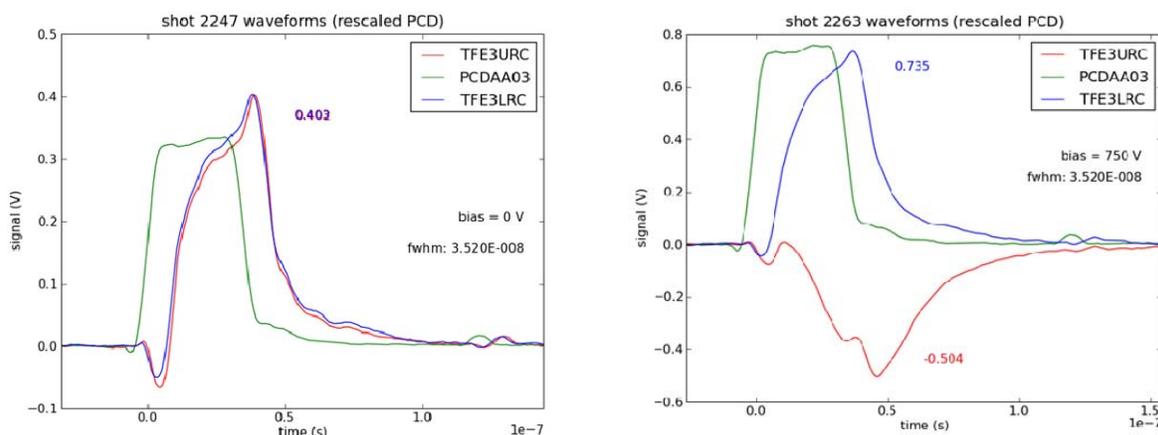
The resulting RIC coefficient fit (figure8) shows a small discontinuity at zero, but a larger slope for positive bias. This behavior has been observed for most other materials we studied. For consistency, the negative bias data are again used to determine the RIC coefficient.



**Figure 8 RIC coefficient fit for the TFE2 URC.**

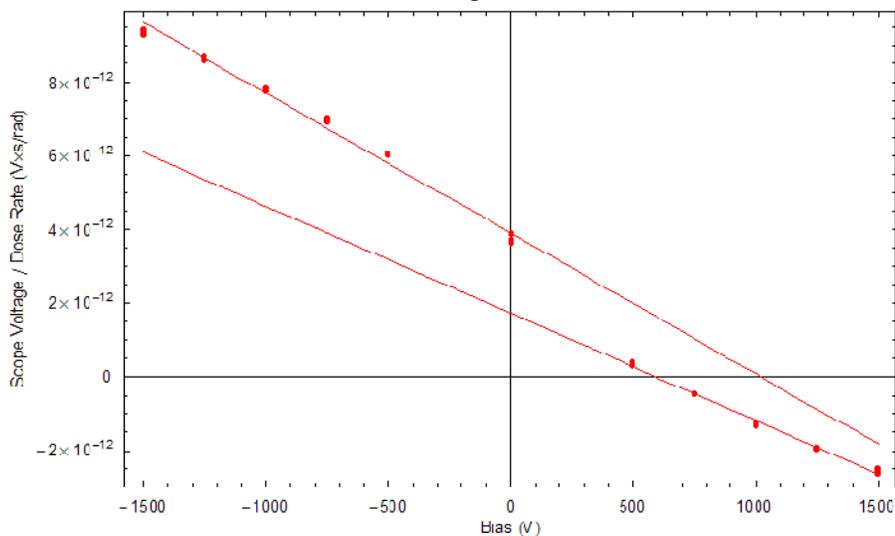
## 6. TFE3B

This series was performed with a narrow pulse width around 35 ns. Typical waveforms from this series are shown in figure 9.



**Figure 9 Typical unbiased and biased shots from the TFE3b series.**

In these narrow pulses, neither the direct drive nor the RIC current reach equilibrium during the pulse, as can be seen from the ramping behavior. The interpretation of these signal features is discussed in the report on RIC in Pyralux. In order to avoid measuring just the delayed RIC, the values for the fit are taken at the time determined by 90% FWHM into the pulse. The RIC coefficient fit is shown in Figure 10.



**Figure 10 RIC coefficient fit for the TFE3b URC.**

The shallower slope for positive bias is a feature not seen in any other series. As usual, the negative bias fit is used to determine the RIC coefficient. The measured conductivity is less than would be predicted at this dose rate from the other data, but this is expected due to the narrow pulse width.

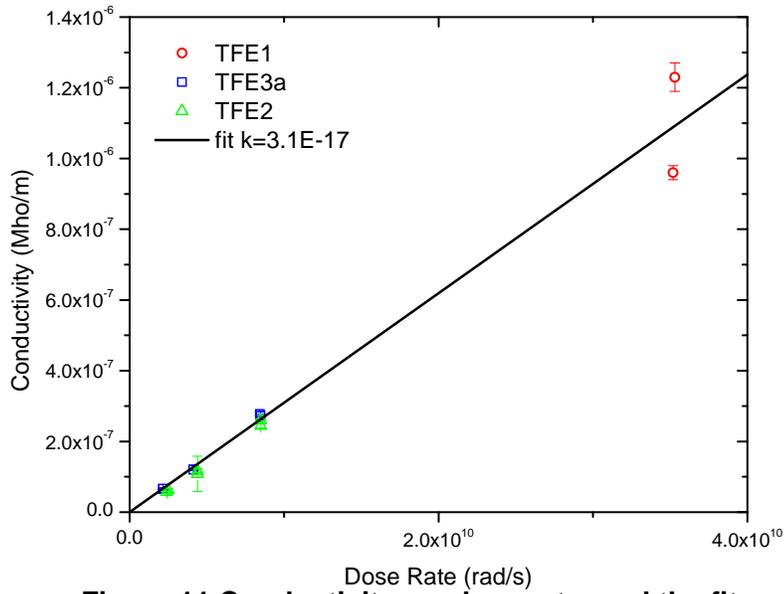
## 7. SUMMARY

The resulting fits for the RIC coefficient and conductivity are summarized in the table below. The parentheses indicate the standard error in the slope fit in the last digit.

**Table 2 Fits for the RIC Coefficient and Conductivity**

Series	Cell	Dose rate (rad/s)	k (Mho/m/(rad/s))	$\sigma$ (Mho/m)
TFE1	URC	3.5E10	3.1(1)E-17	1.23(4)E-6
TFE1	LRC	3.5E10	2.75(6)E-17	9.6(2)E-7
TFE3a-1	URC	2.2E9	3.0(1)E-17	6.5(2)E-8
TFE3a-1	LRC	2.2E9	3.1(1)E-17	6.7(2)E-8
TFE3a-2	URC	4.1E9	2.96(6)E-17	1.21(2)E-7
TFE3a-2	LRC	4.1E9	2.90(5)E-17	1.20(2)E-7
TFE3a-3	URC	8.4E9	3.30(6)E-17	2.78(5)E-7
TFE3a-3	LRC	8.5E9	3.22(4)E-17	2.73(4)E-7
TFE2-1	URC	2.5E9	2.6(1)E-17	6.3(4)E-8
TFE2-1	LRC	2.4E9	2.3(1)E-17	5.7(3)E-8
TFE2-2	URC	4.4E9	2.6(1)E-17	1.17(6)E-7
TFE2-2	LRC	4.4E9	2.4(1)E-17	1.08(5)E-7
TFE2-3	URC	8.5E9	3.07(5)E-17	2.60(4)E-7
TFE2-3	LRC	8.5E9	2.87(7)E-17	2.44(6)E-7
TFE3b	URC	1.086(5)E11	1.73(3)E-17	1.87(7)E-6
TFE3b	LRC	1.086(5)E11	1.73(6)E-17	1.87(7)E-6

The conductivities are plotted versus dose rate in figure 11.



**Figure 11 Conductivity vs. dose rate, and the fit.**

The best fit is purely linear, with a RIC coefficient of  $3.1 \times 10^{-17}$  Mho/m/(rad/s).

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