BaBar RPC story, from my perspective

(my log book #1…)

J. Va’vra

Content

1. Analysis of deposits found in a SLAC test chamber.

2. Attempt to see if RPC individual components can be damaged by heat cycling.

5. Imperfections on the surface of Layer 7.

6. Initial "unclear" thinking about what to do about this mess.

Aim of the chemistry study:

A plan is to do a FTIR (Infrared Absoption Spectrocopy) on the following five samples, which will be taken from two RPC chambers (one so called "good" and one "bad") by dissolving the samples with the ultra-pure acetone:

1. Reference Linseed oil from Italy.
2. A drop, which did not cross the gap ("bad" chamber).
3. A drop, which did cross the gap ("bad" chamber).
4. Oil from a good section of the same chamber.
5. Oil from "good" chamber which did not have this problem.
6. Gas tubing from the inlet side (piece of BaBar tubing).

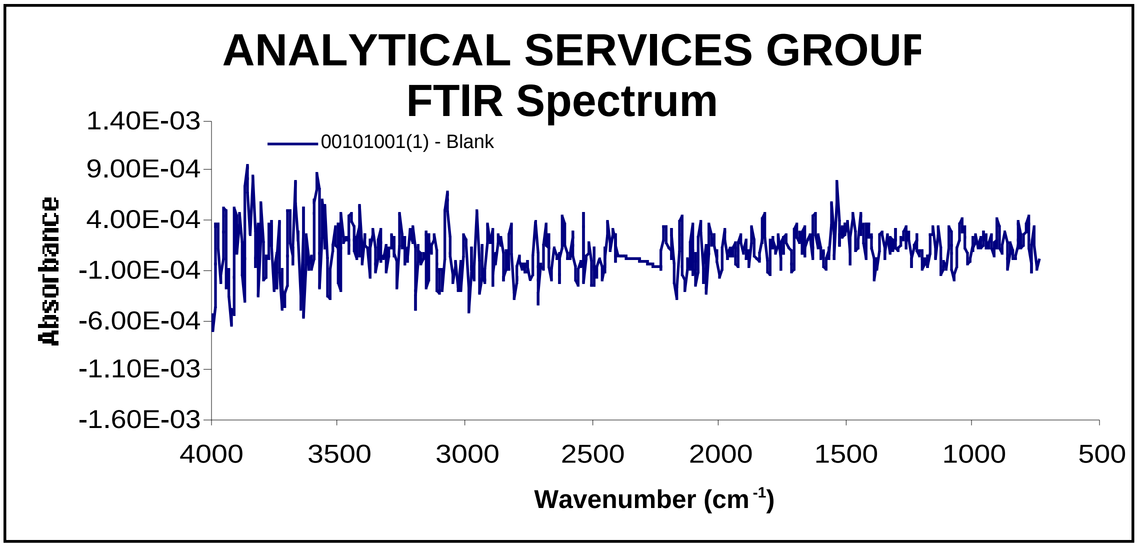
The "bad" chamber was a chamber, which Aron subjected to high temperature (~35°C), i.e., the Linseed oil had a chance to come out of the button. The "good" chamber was a chamber with the "popped" buttons, i.e., not used in the BaBar and not subject to high temperature.

The idea is to do a relative analysis, which will determine that the excess of oil found in the RPC chamber:

(a) is not oil originating from tubing coming from the Freon gas,
(b) is not a result of a chemical reaction with Freons, and instead it
(c) came from an improperly drained chamber during the construction at the factory, and was trapped by the buttons and came out into the active region during initial high temperature operation at BaBar (reaching 30-35°C).

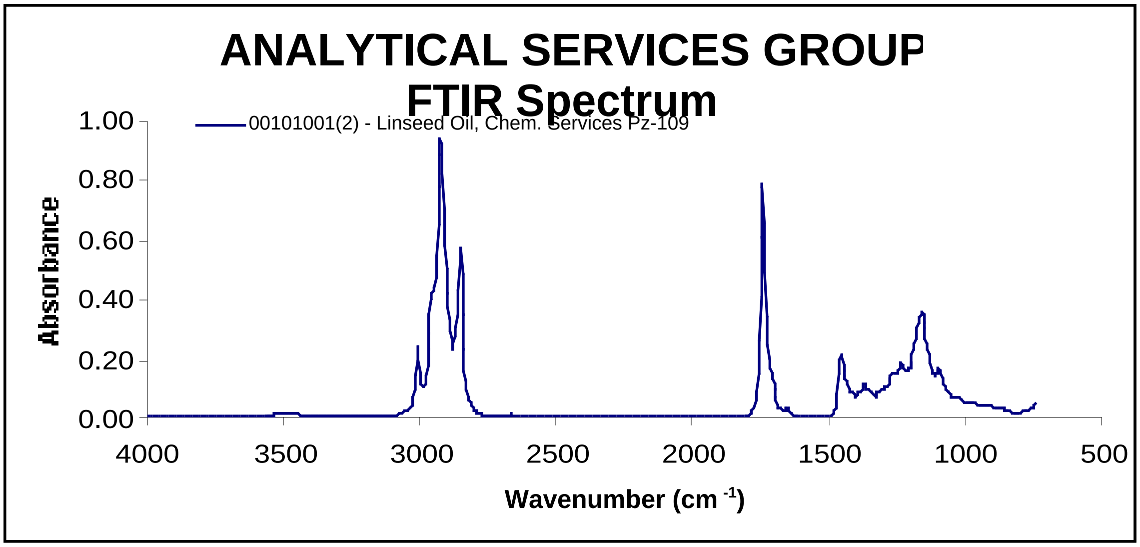
The chemical analysis of the samples was done by Dr. Gotts.

Calibration:



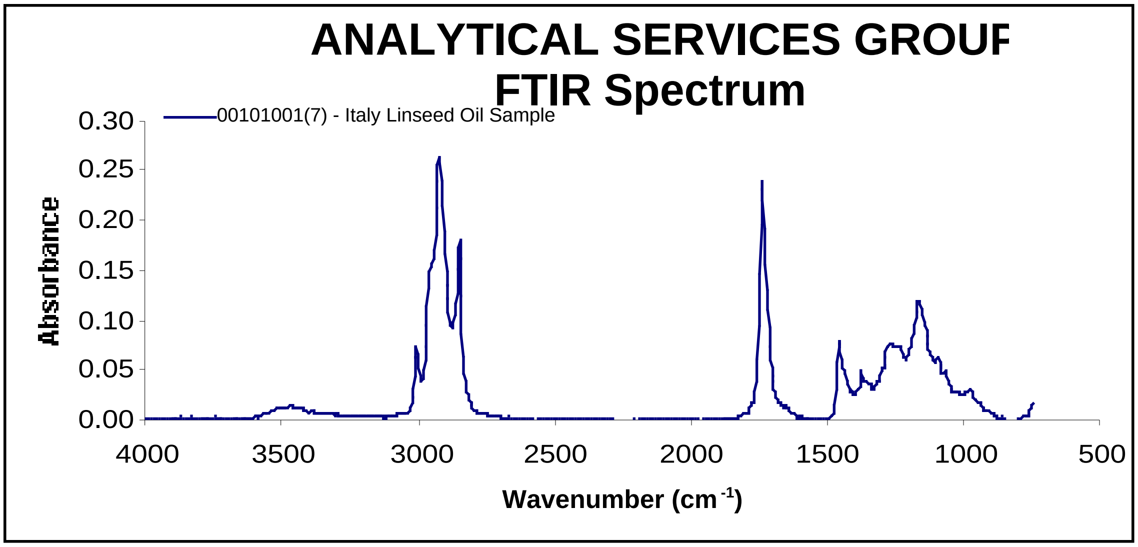
Note: A solvent blank does not contain any pollution

Library Linseed oil:



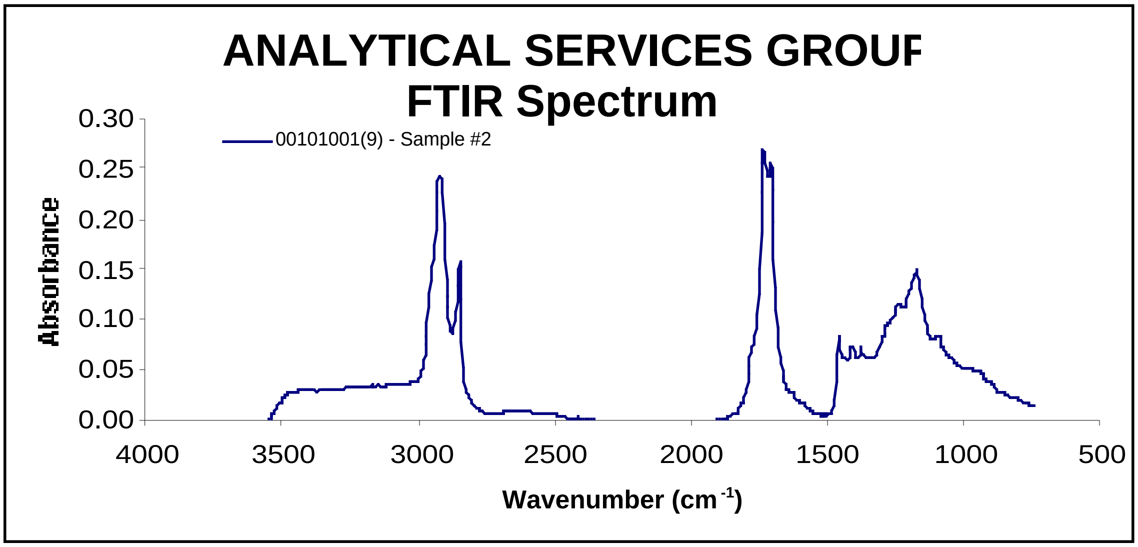
Note: This is not the BaBar linseed oil, instead it is a reference library's oil.

Italian Linseed oil:



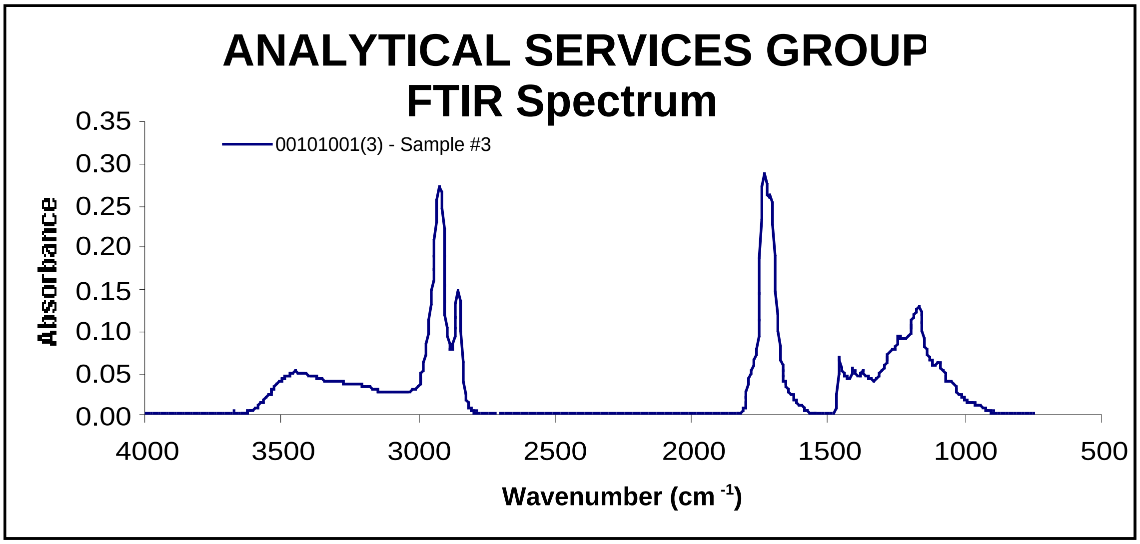
Note: The Italian Linseed oil is practically identical to the reference library’s oil.

Sample 2 (“bad” chamber - a drop which did not cross the gap):



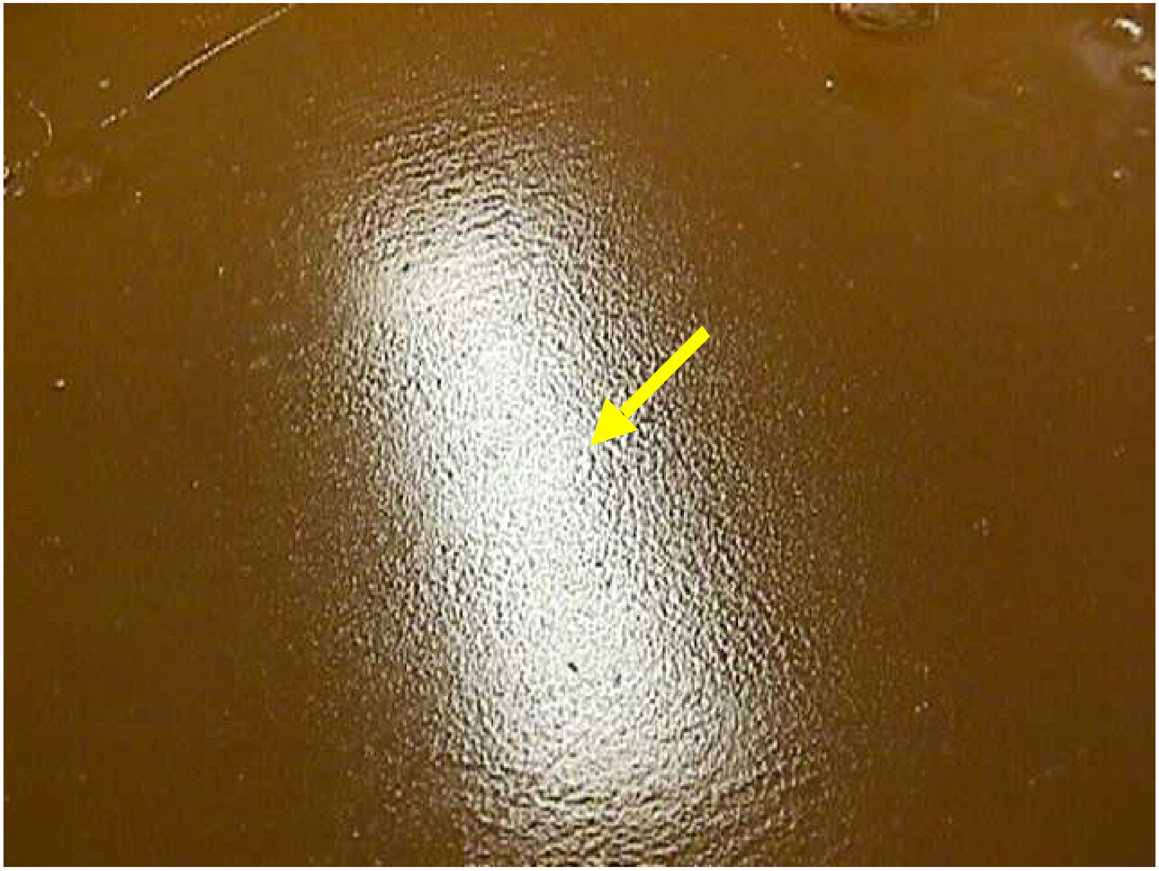
Note: A large amount of the linseed oil. Some indication of the oxidation of the linseed oil and the formation of an organic acid

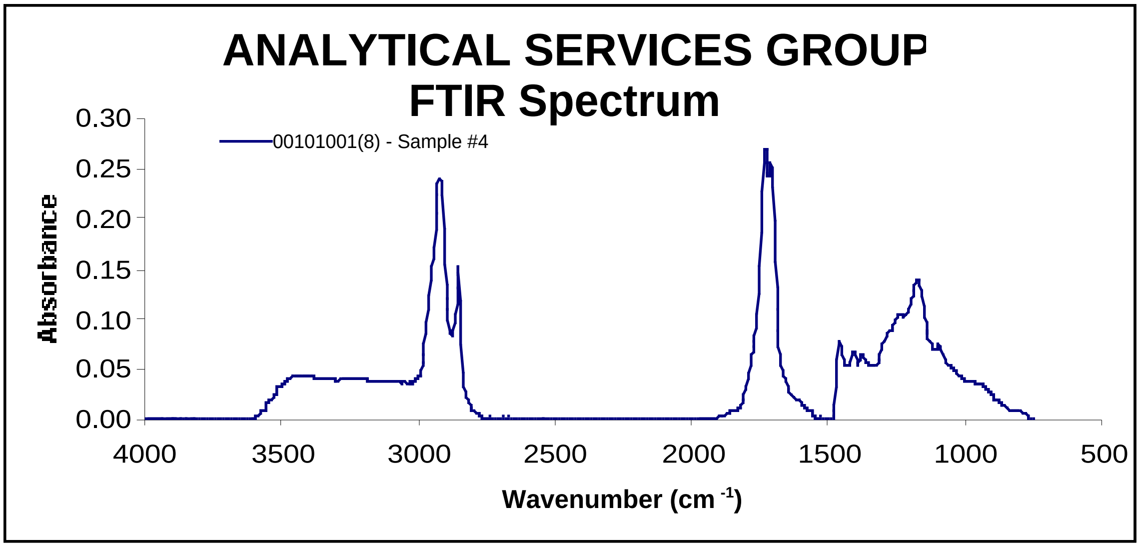
Sample 3 ("bad" chamber - a drop which crossed the gap):



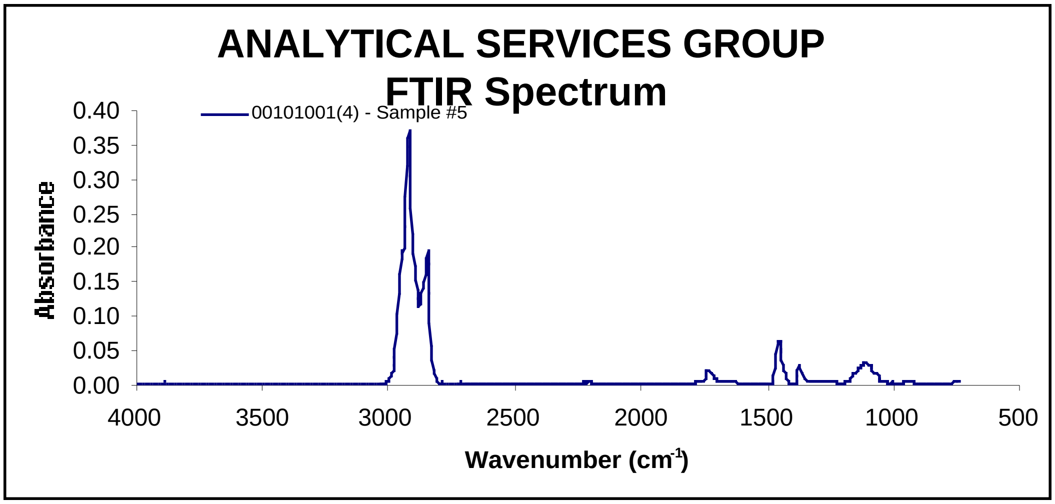
Note: A large amount of the Linseed oil. Some indication of the oxidation of the Linseed oil and the formation of an organic acid.

Sample 4 (“bad” chamber – “good” section):



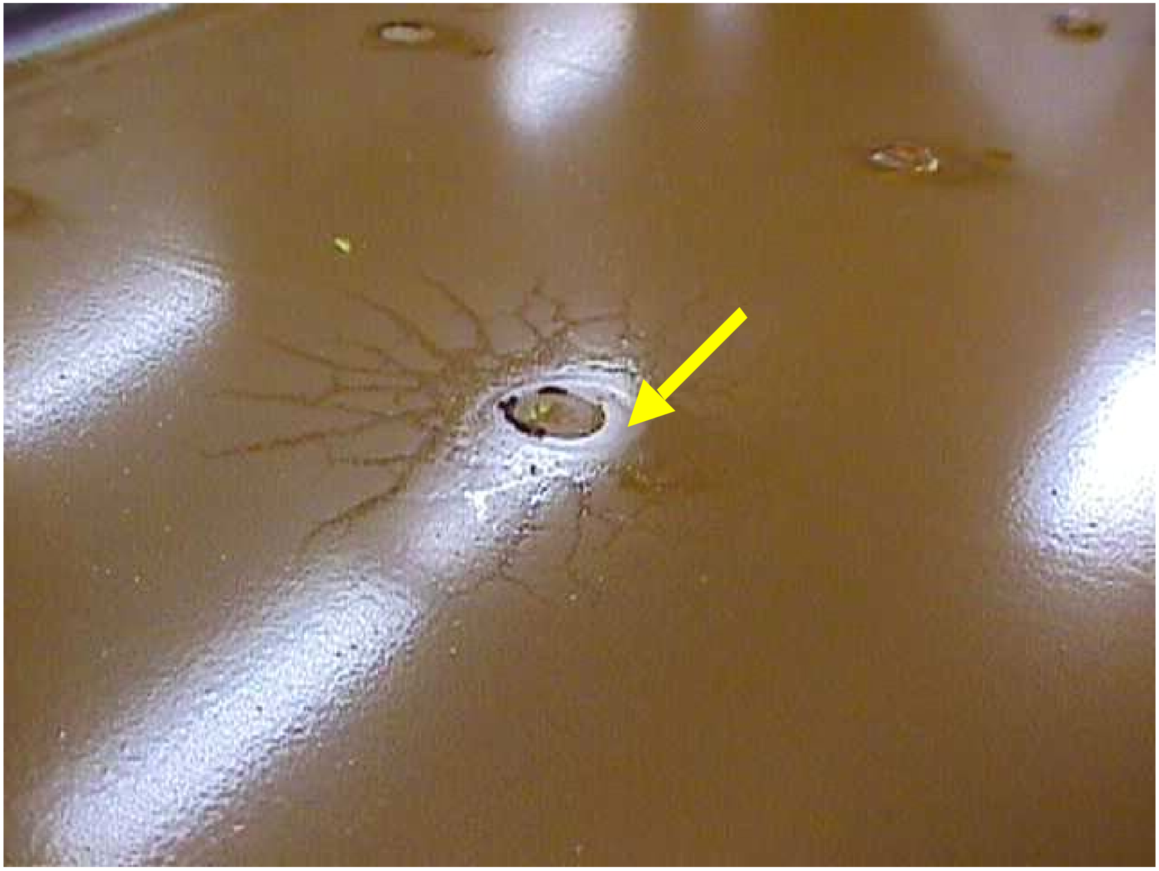


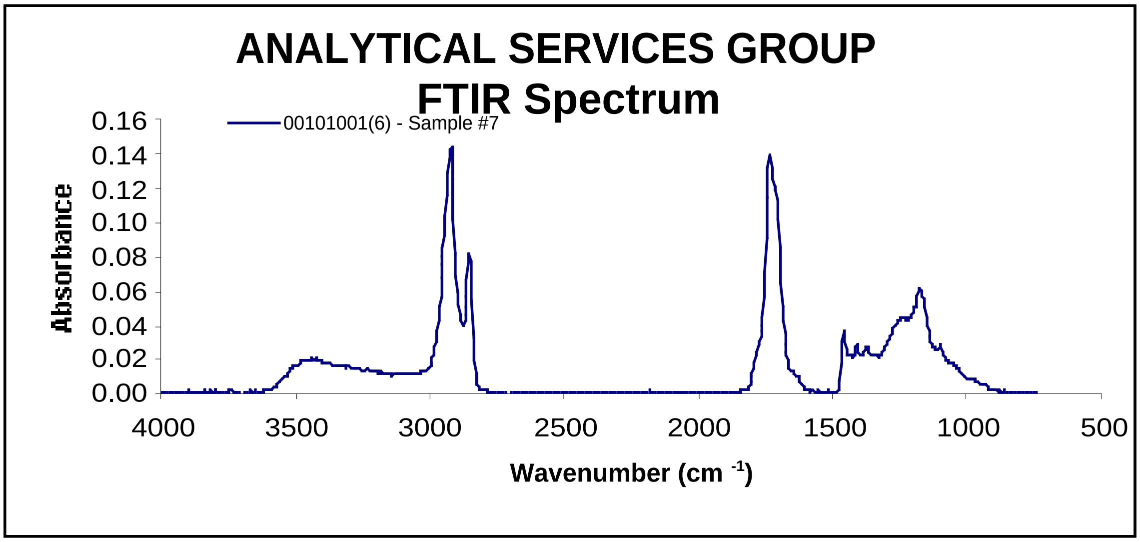
Sample 5 ("good" chamber – far from the buttons):



Note: Away from the button, there is a smaller proportion of the Linseed oil compared to the level we have seen in the "bad" chamber.

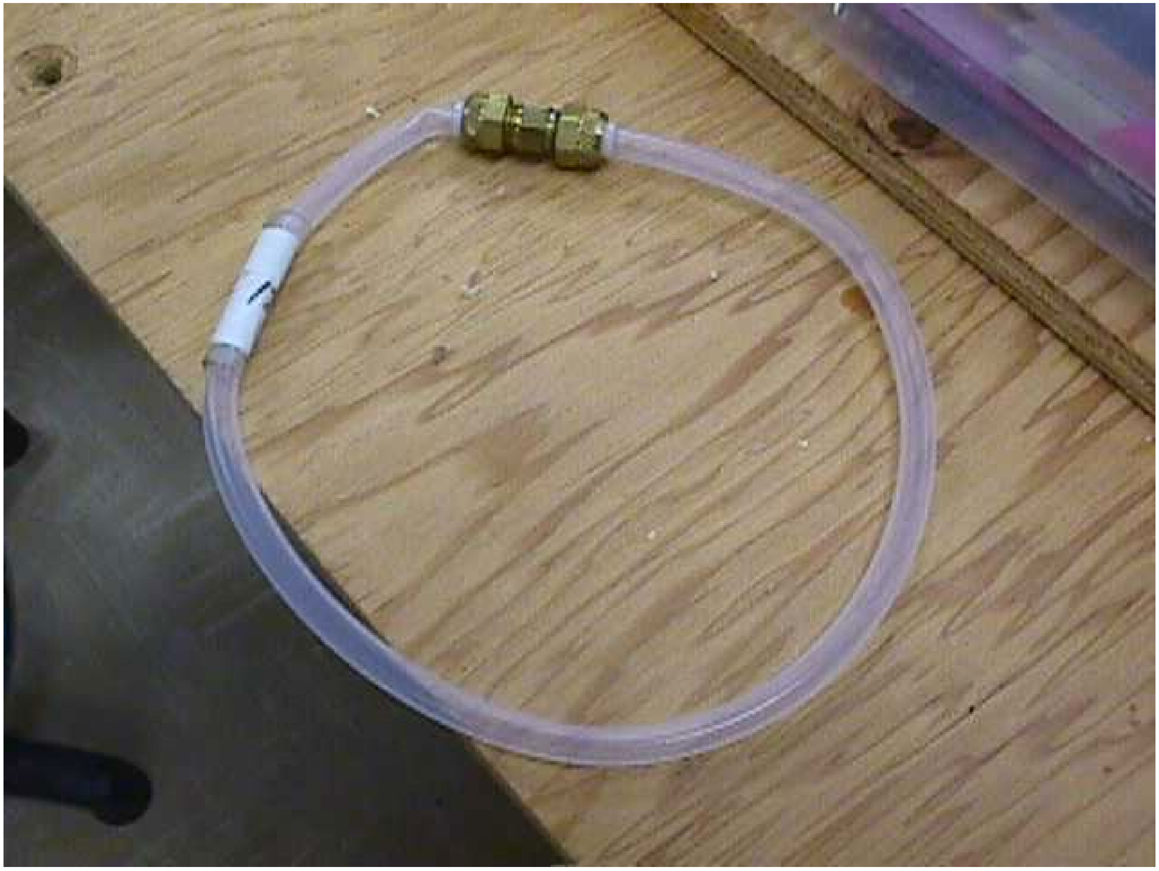
Sample 7 (“good” chamber – a “star” pattern near the button):

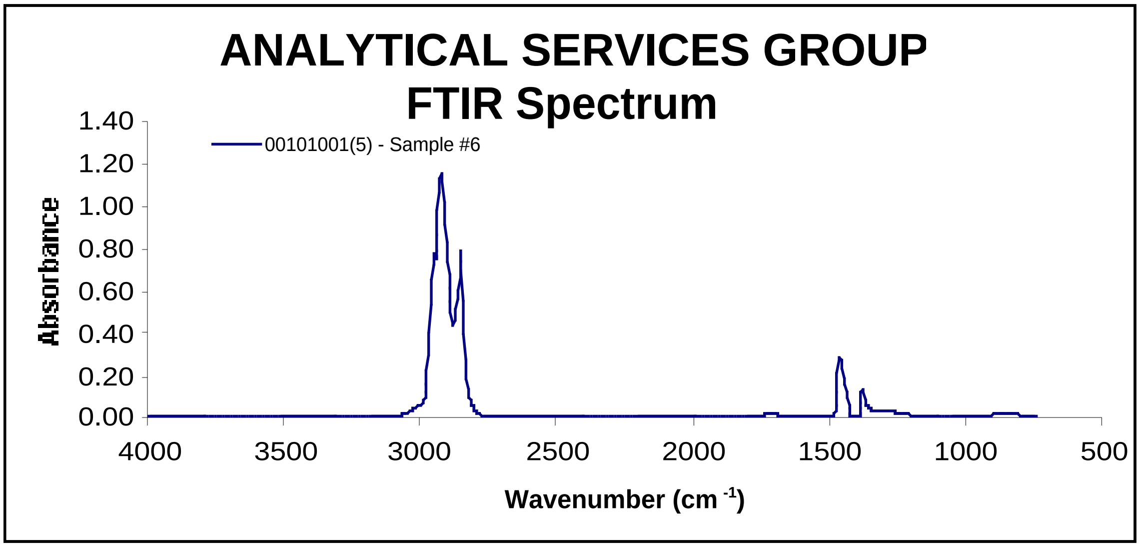




Note: A large amount of the Linseed oil. Some indication of the oxidation of the linseed oil and the formation of an organic acid. Near the button, we see larger proportion of Linseed oil.

Sample 6 (inlet gas tubing from BaBar RPC detector):





Note: The tubing has traces of the hydrocarbon oil. This is how any oil signature would look like. The oil may have come from the Freon gas, possibly. There is no sign of the Linseed oil though.

Conclusion:

1. We see large areas in the active region full of Linseed oil. Some droplets bridged the gap. All surfaces are very sticky.
2. The Linseed oil samples may be partially oxidized and possibly contaminated with an organic acid. The organic acid could come, for example, from the UV light during the operation.
3. There is no sign of a "gross" chemical reaction with the Freon inside the "bad" chamber, which would produce this amount of extra droplets.
4. Inlet tubing has traces of oil, which is not the Linseed oil. It is not possible to determine exactly what type of oil. Could be coming from the Freon gas.
5. The Italian Linseed oil appears identical to the FTIR reference library Linseed oil.
6. The Linseed oil droplets can be easily dissolved by simply pouring acetone on the electrode. The surface becomes very smooth and completely dry. This would invite a possible fix, unfortunately, there is no easy way to do this in BaBar.

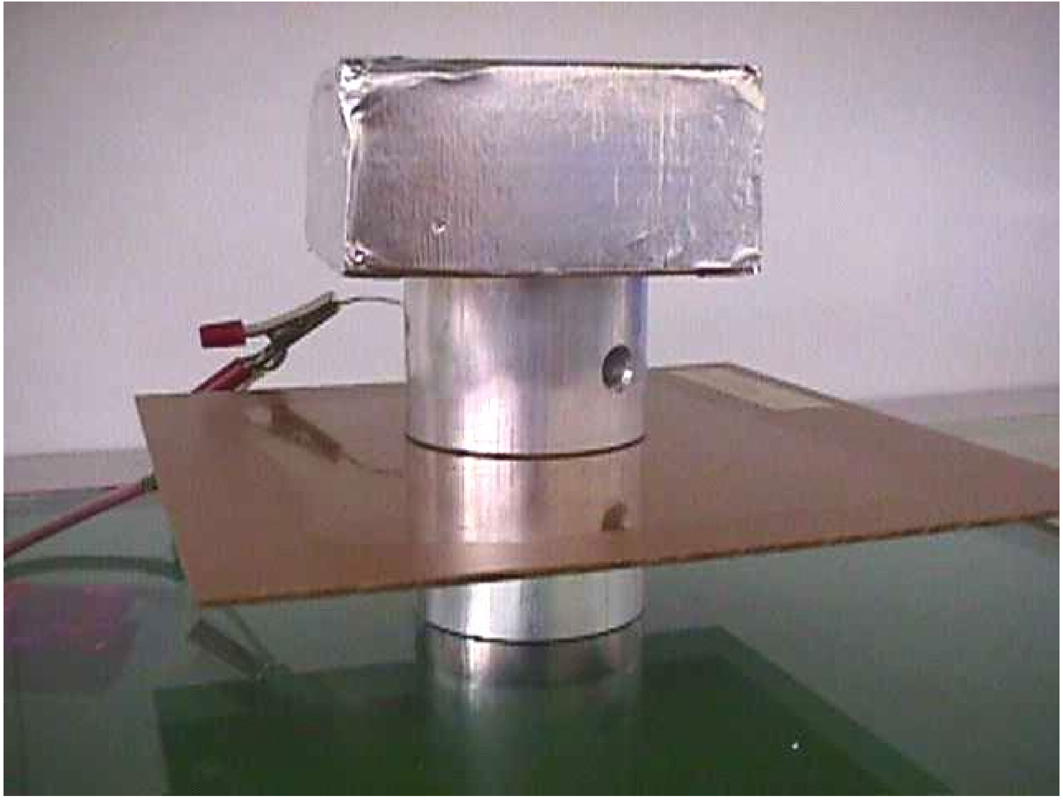
July 29, 2000

Volume and surface resistivity of Bakelite, Linseed oil, Lexan buttons and G-10 spacers

Aim of this study:

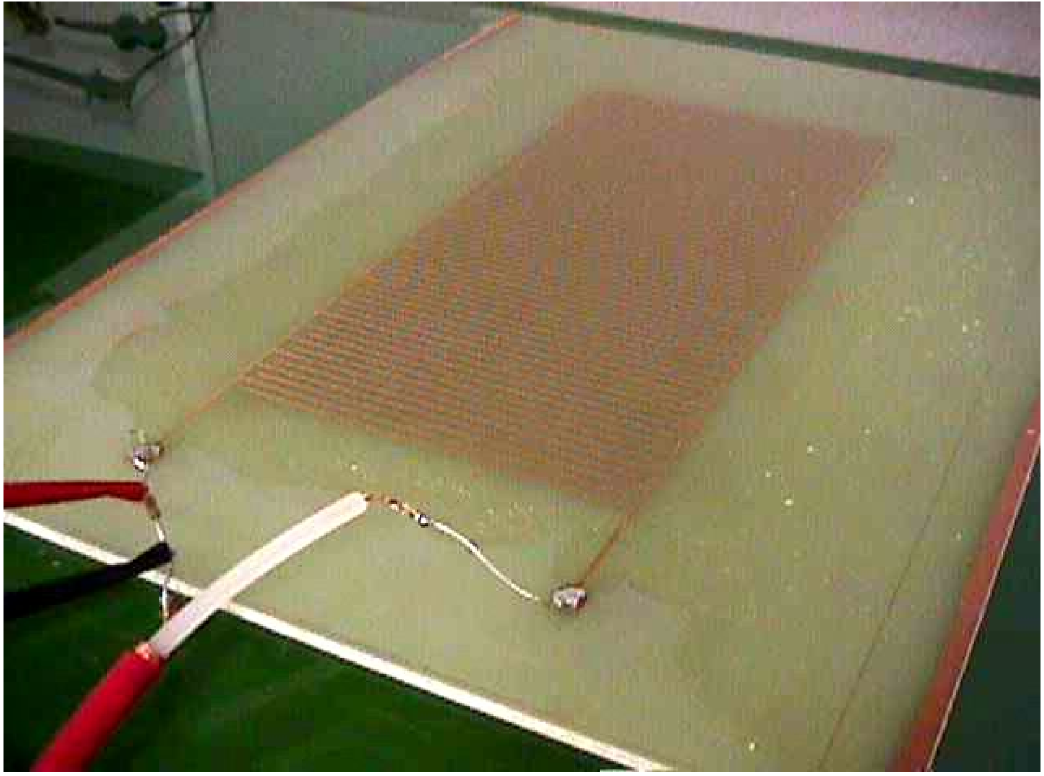
A plan is to see if individual components, such as G-10 and Lexan spacers, or Bakelite electrodes, can be damaged by temperature cycling.

Setup to measure the Bakelite sheet volume resistivity:



- **Conditions:**
  - Setup is in air, which has controlled temperature.
  - Linseed oil is from Orchard Hardware Store.
  - Bakelite is painted with the Linseed oil.
  - There is no graphite paint on the Bakelite.
  - Electrodes are made from aluminum.
  - All time histories were obtained under a "current on" condition.
  - Voltage across the Bakelite is -1000V.
  - Bakelite has NO graphite !!

Setup to measure the Linseed oil surface resistivity:



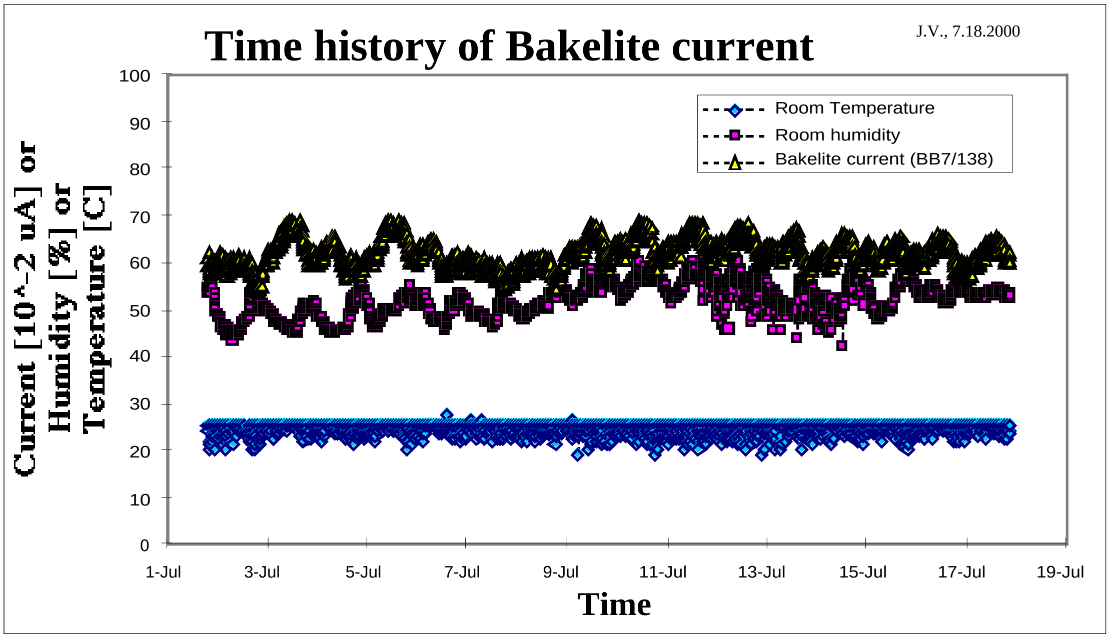
Conditions:

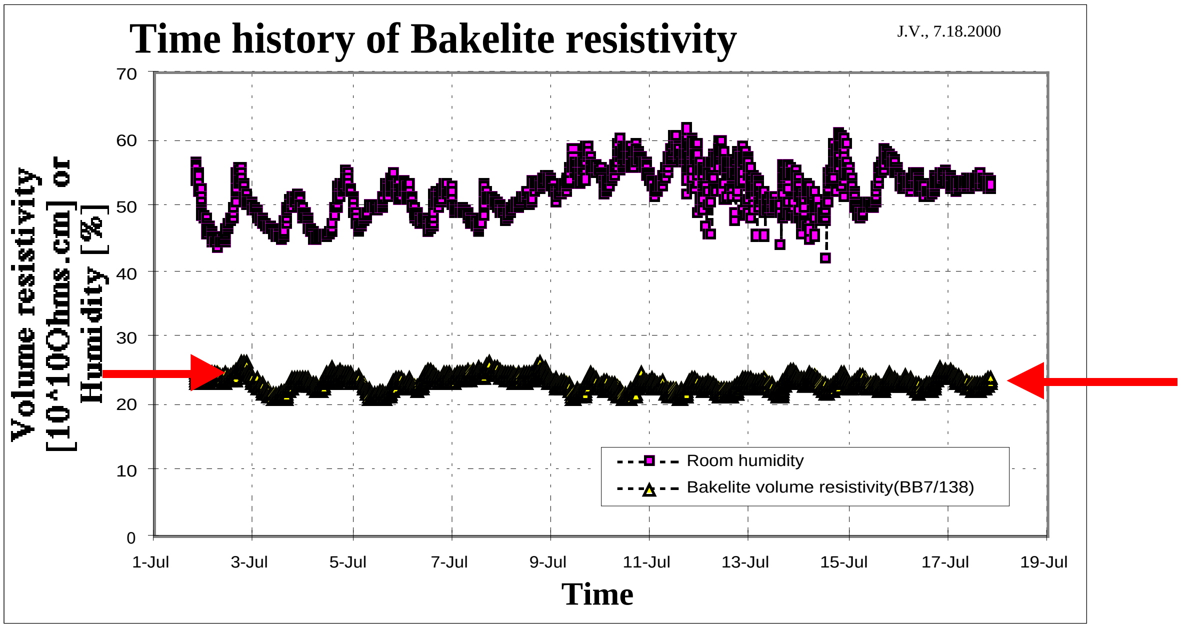
- Copper finger pattern has on G-10 surface 2.7*10^3 squares.
- Setup is in air, which has controlled temperature.
- Linseed oil is from Orchard Hardware Store. Applied with a brush, cured for ~60 hours.
- G-10 is painted with the Linseed oil. G-10 alone has more than 10 times higher resistance than Linseed oil.
- Time history were obtained under a "current on" condition.
- Voltage across the finger pattern is -5000 V.

Overall setup is placed in the oven, which controls temperature within ~1^{o}C:

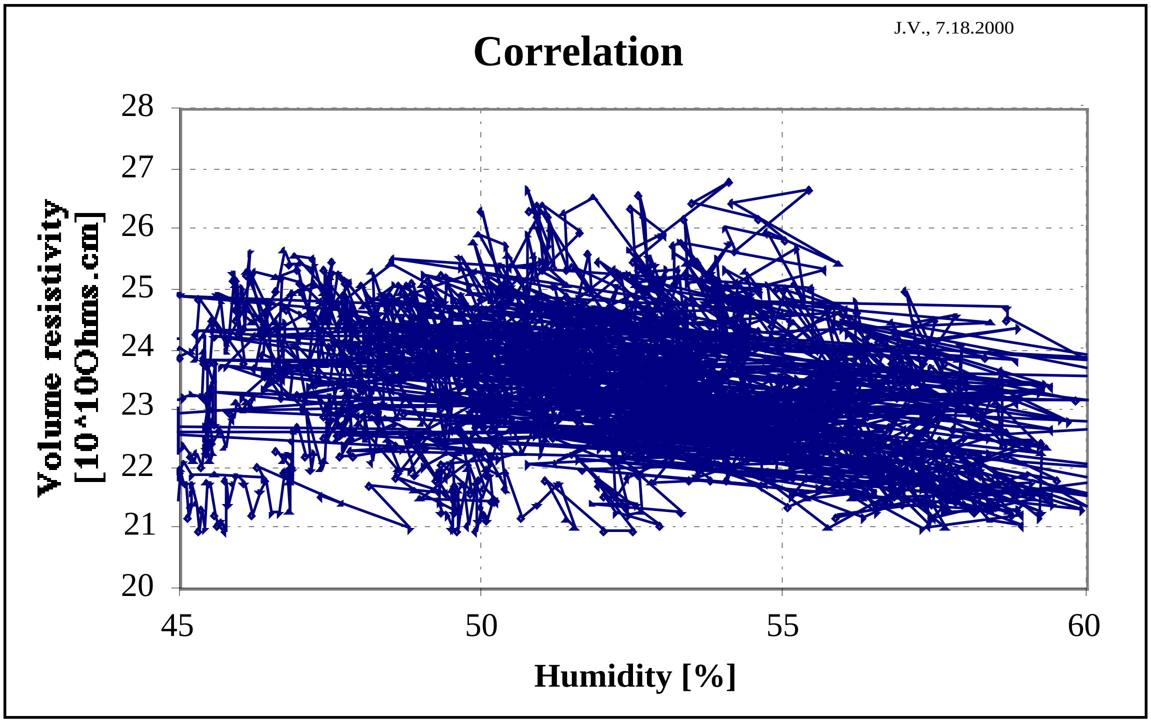
- **Conditions:**
  - Cycle temperature between 20 and 40^{o}C.
  - Monitor temperature, humidity and current.
  - Humidity is introduced by blowing a humid air into oven.

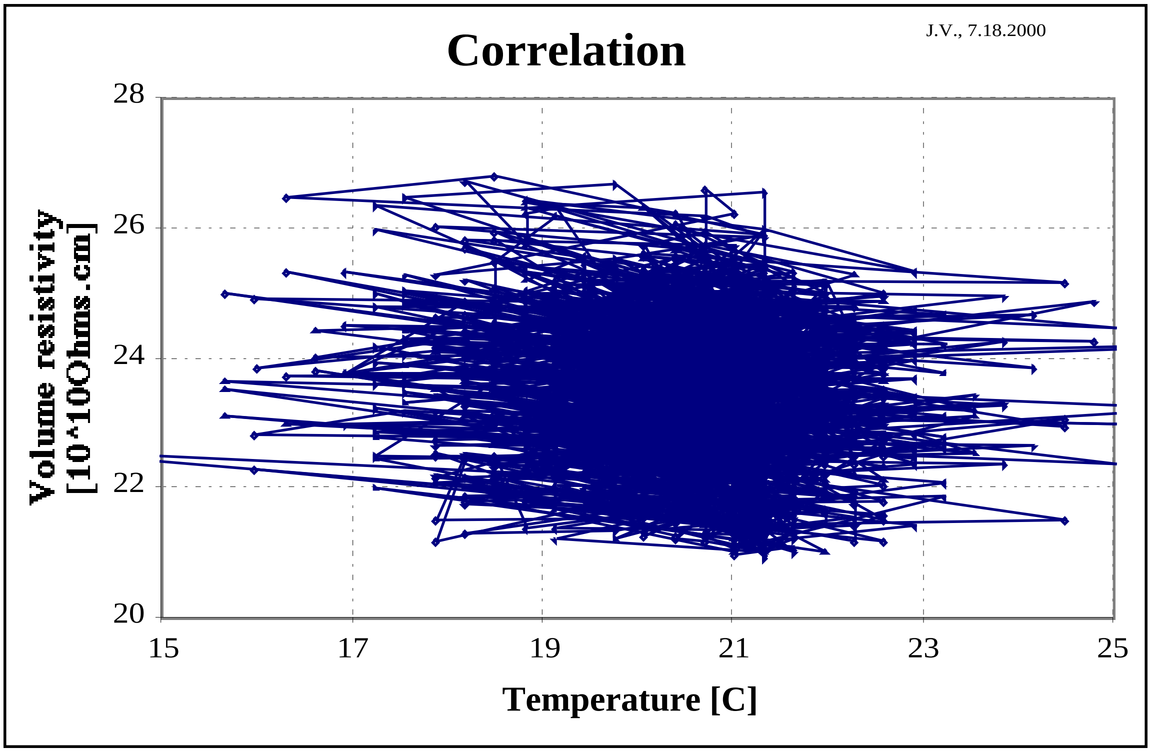
1. A long term behavior of the volume resistance of the Bakelite sheet, covered with Linseed oil, at room temperature and humidity (samples are outside oven in this particular test):





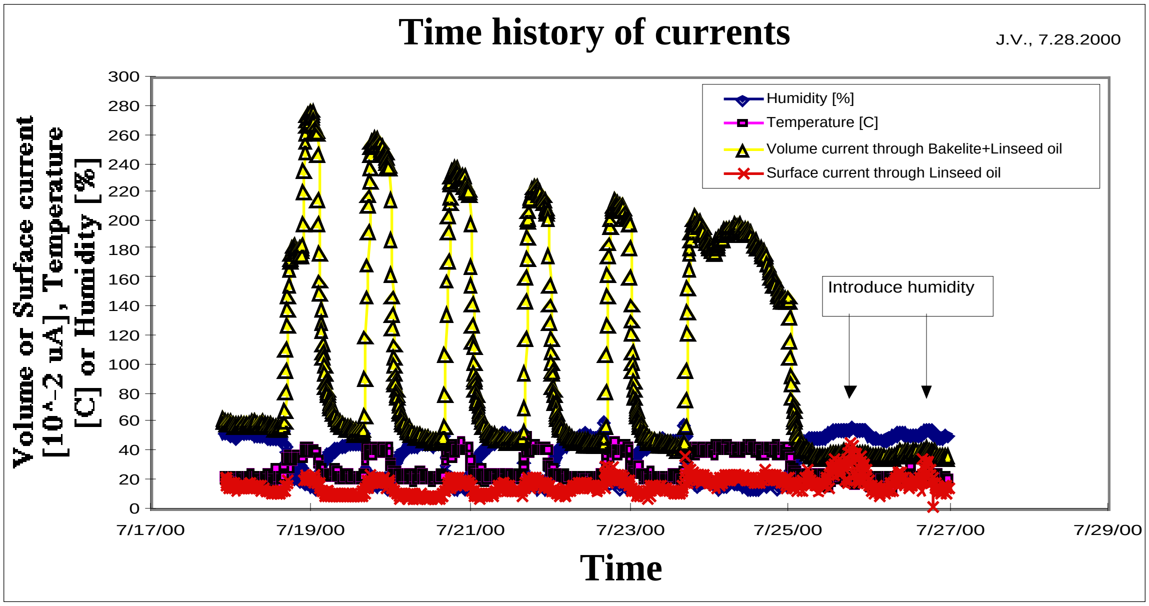
- Volume resistance of Bakelite did not change after ~0.3 C, while at room temperature.

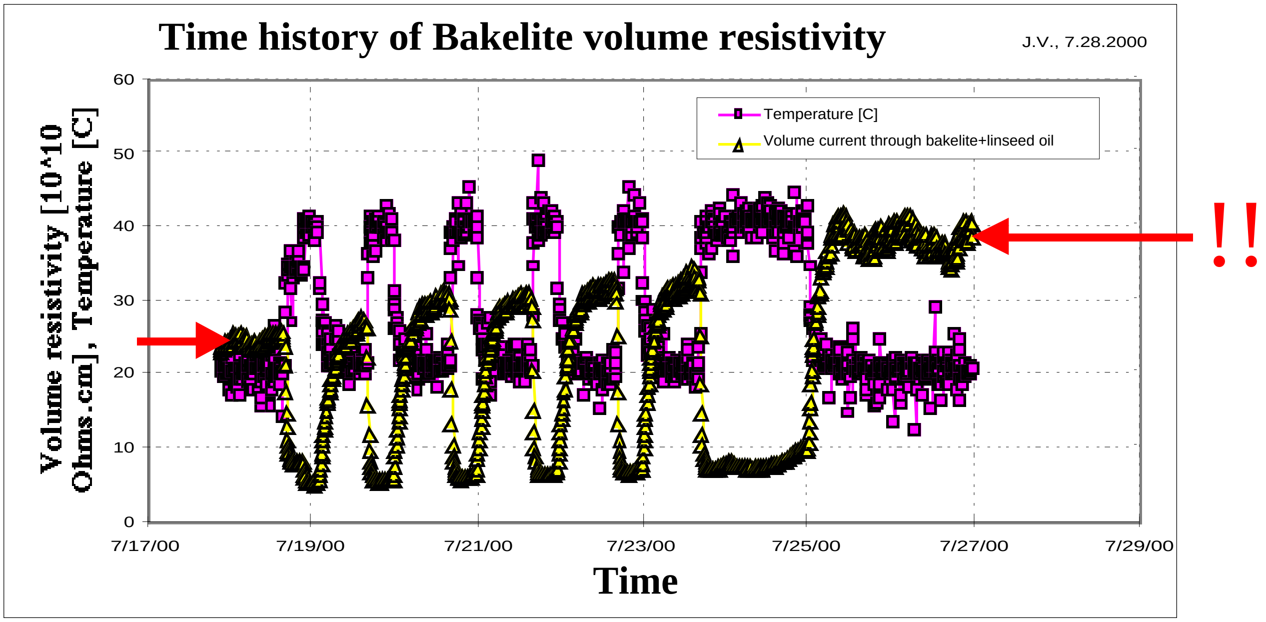




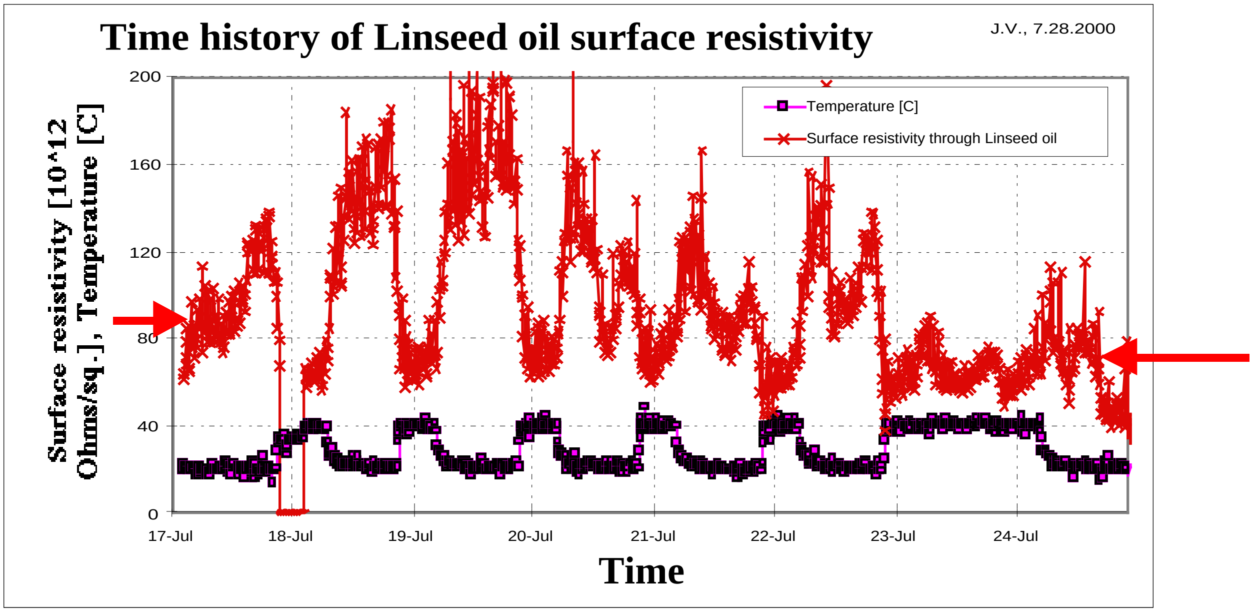
- Volume resistance of Bakelite sheet, covered by Linseed oil, seems to correlate more strongly with humidity. Based on later measurements, this is due to Linseed oil.

2. ρ_{Volume}(Bakelite+Linseed oil) & $\rho_{Surface}$(Linseed oil) = f (Time, Temperature - vary, Humidity):





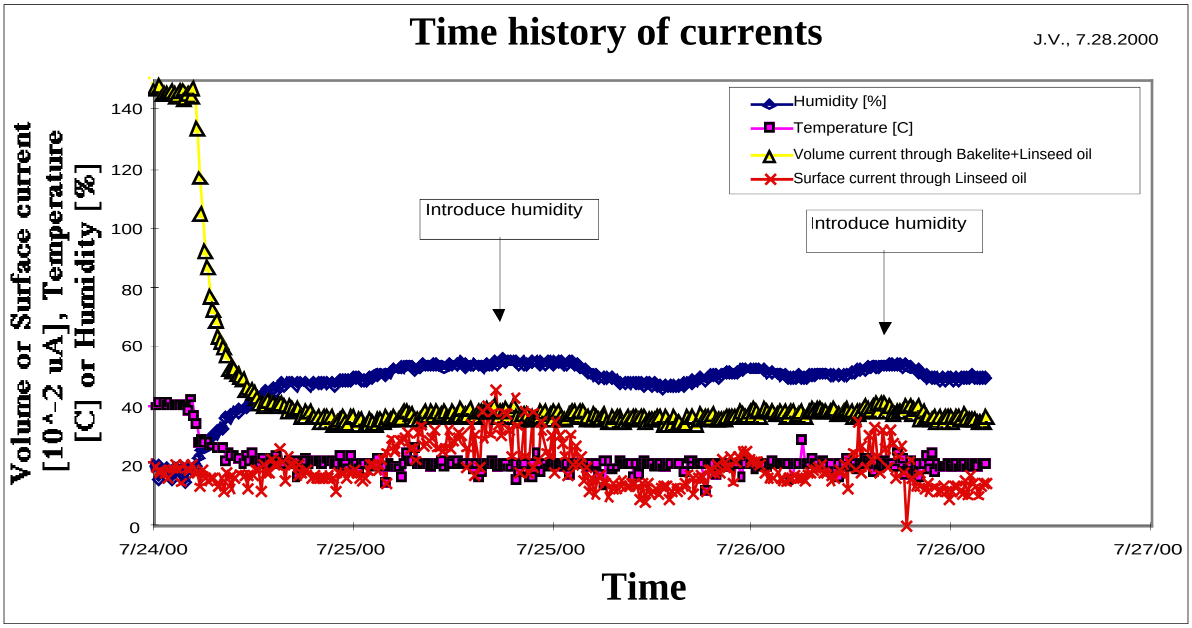
- Cycle temperature in the oven between 20 and 40°C. The Bakelite volume resistance increased by a factor of ~2.

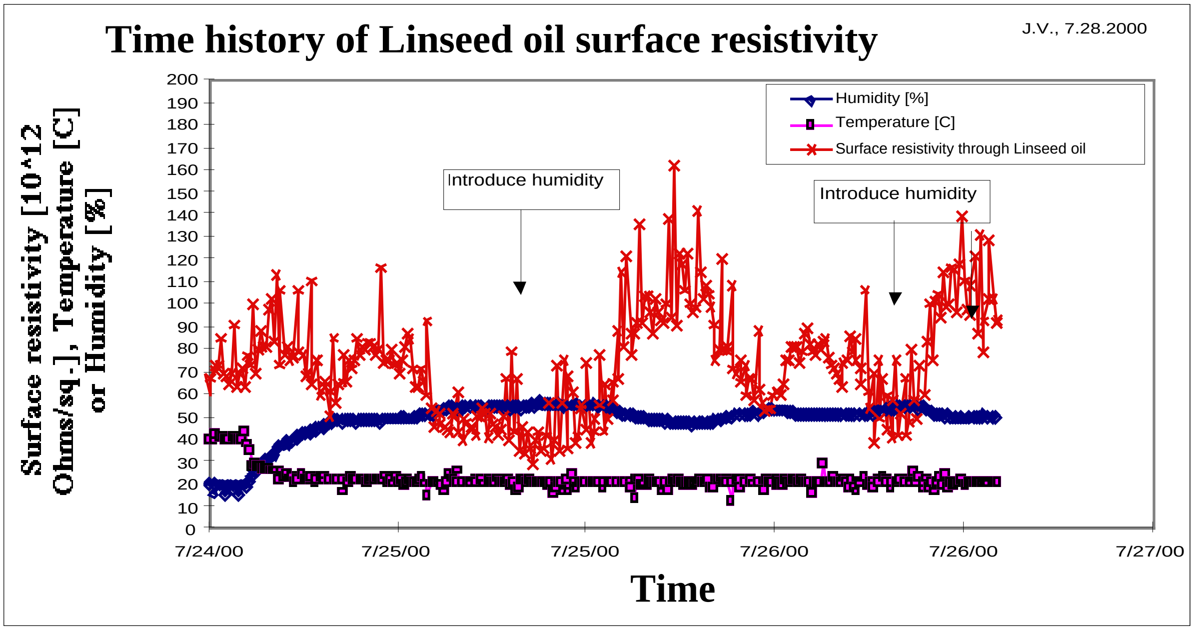


- Total charge in this experiment: ~0.5 Coulombs.
- Total charge density is: ~0.015 Coulombs/cm^2.

- The Linseed oil surface resistance did not change after ~15 mC/cm^2, while at room temperature.

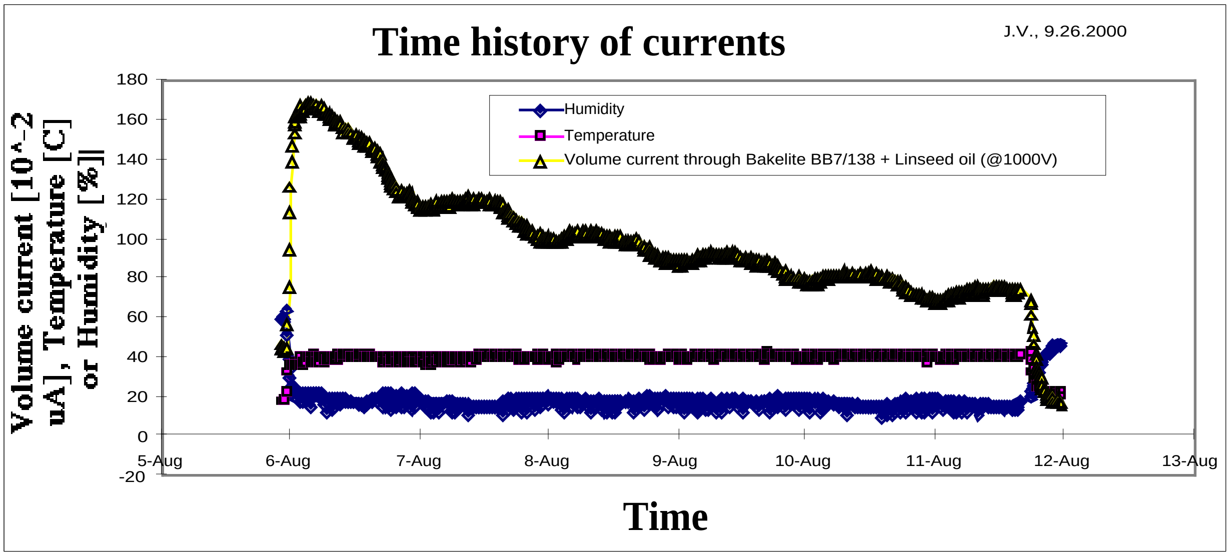
3. ρ_{Volume}(Bakelite + Linseed oil) & $\rho_{Surface}$(Linseed oil) = f (Time, Temperature, Humidity - vary):

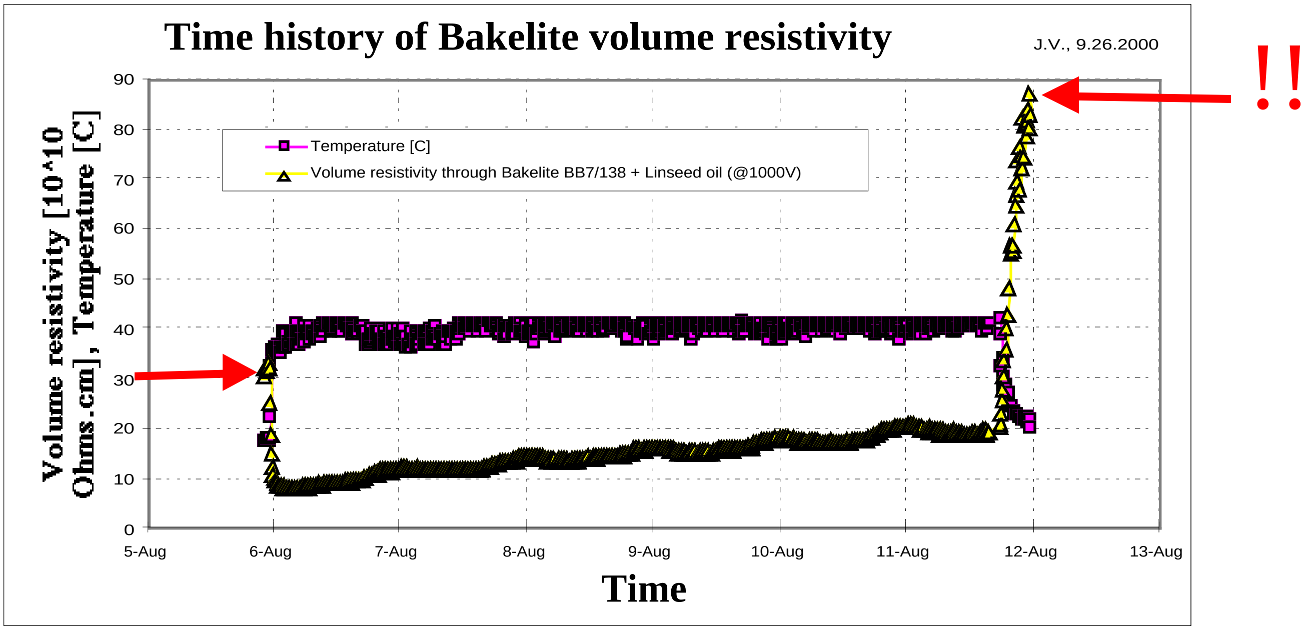




- One can generate a factor of 2-3 reduction in the surface resistance by introducing a humid air (a change of ~5% rel. humidity) from outside of the Linseed oil surface. It recovers to original value after the humidity is removed.

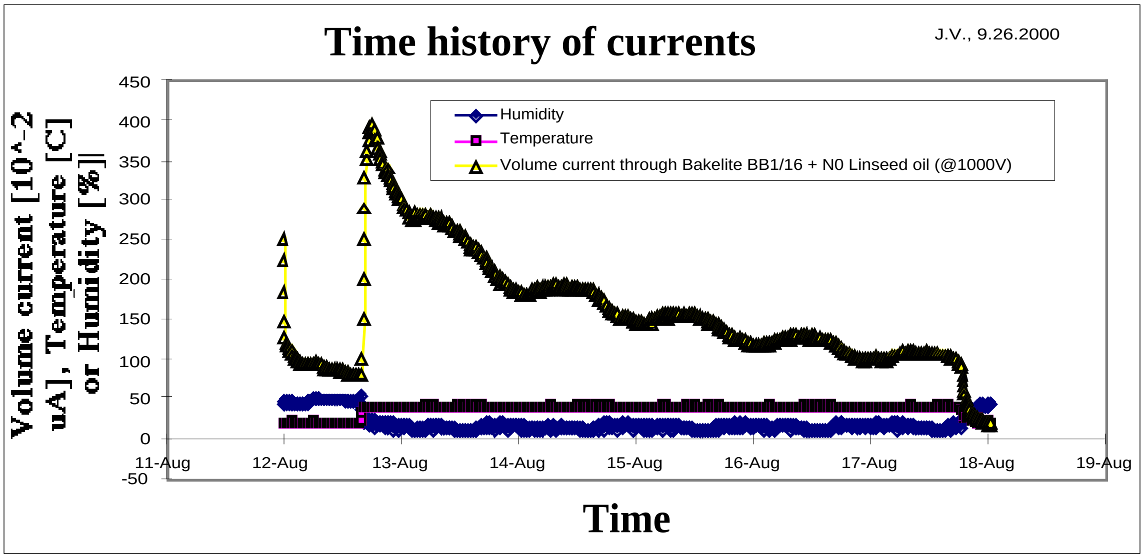
4. ρ_{Volume}(Bakelite + Linseed oil) =
= f (Time, Temperature ~ 40^{o}C, Humidity):

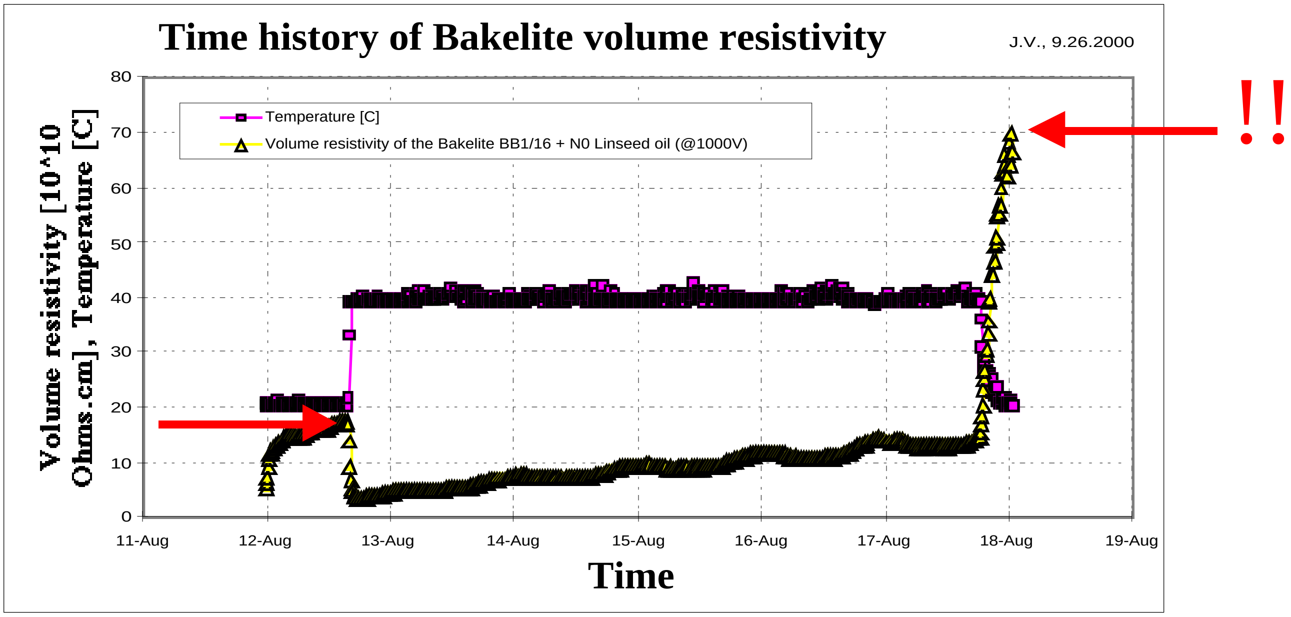




- Bakelite has no graphite on the surface !!
- Volume resistance of Bakelite, covered by the Linseed oil, increased by a factor of ~3, after ~15 mC/cm^{2} at 40^{o}C.

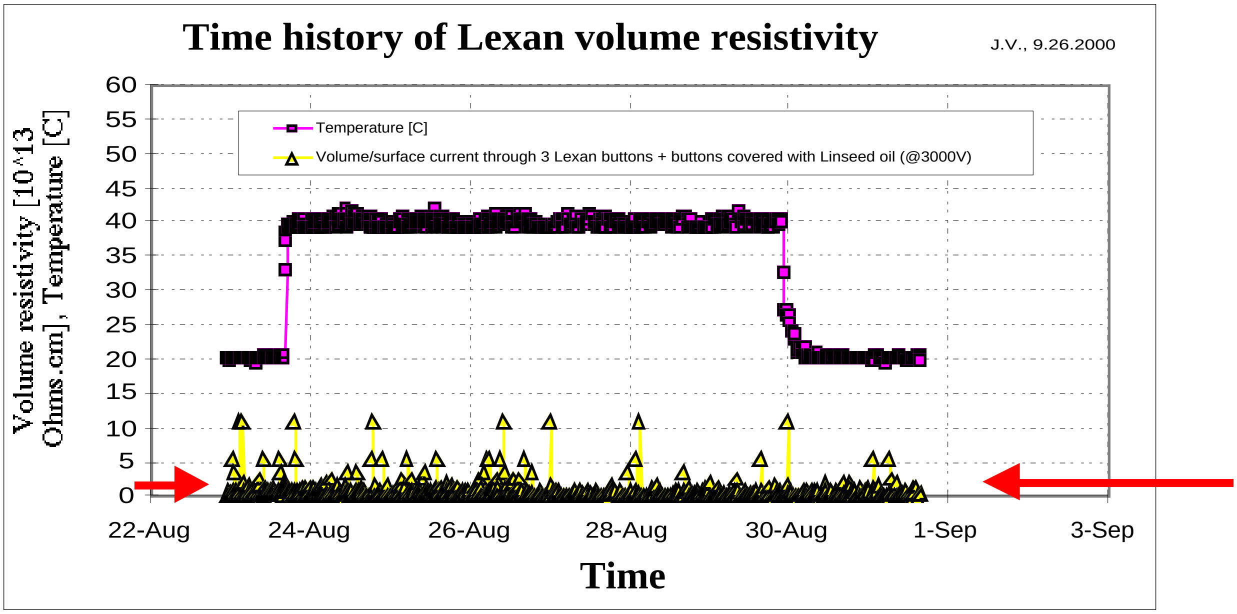
5.ρ_{Volume}(Bakelite + NO Linseed oil) = = f (Time, Temperature ~ 40°C):





- Bakelite has no graphite on the surface !!
- Volume resistance of Bakelite, covered by the Linseed oil, increased by a factor of ~3, after ~25 mC/cm^2 at 40°C.

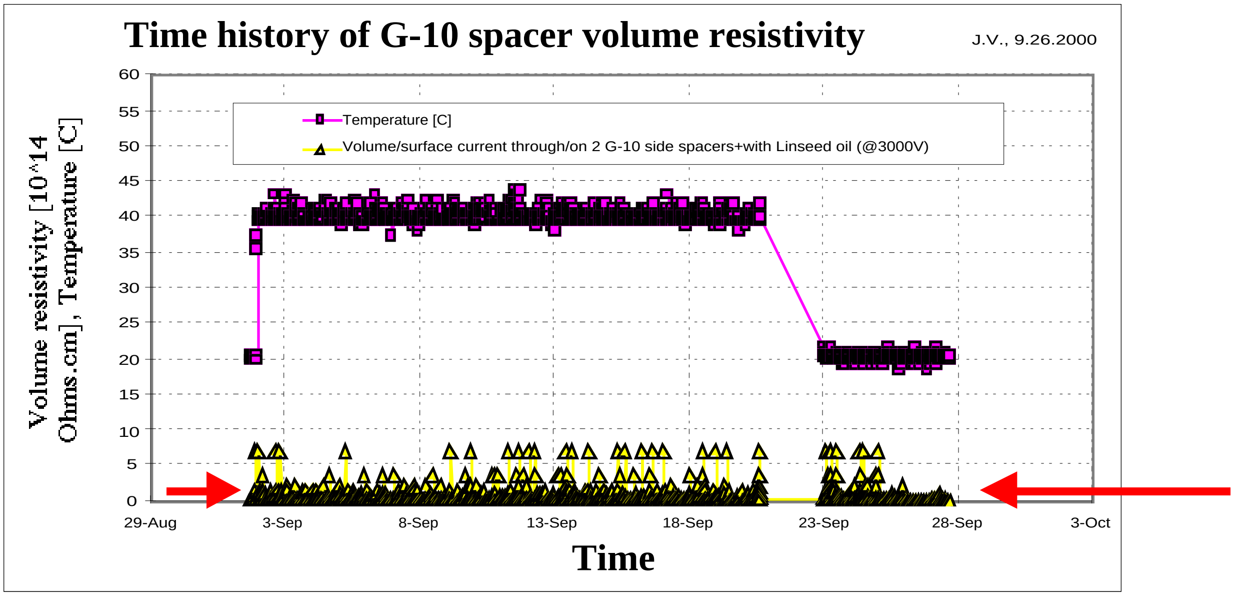
6.$\rho_{Vol/Surf.}$(Lexan button + Linseed oil) = = f (Time, Temperature ~ 40°C):



- Total charge in this experiment: ~0.003 Coulombs.

- There are three Lexan buttons placed between the electrodes shown on page 3. The Lexan buttons covered with the Linseed oil. The current goes either through the volume of the button or along the surface. Because of this ambiguity, I do not calculate the resistance.
- The Lexan button resistance did not change after ~3mC, while at room temperature.

7.$\rho_{Vol/Surf.}$(G10 side + Linseed oil) = = f (Time, Temperature ~ 40°C):



- There are two G-10 spacers placed between the electrodes shown on page 3. The G-10 side pieces are covered with the linseed oil. The current goes either through the volume of the G-10 or along the surface. Because of this ambiguity, I do not calculate the resistance.
- The G-10 side spacer resistance did not change after ~8mC, while at room temperature.

Conclusion:

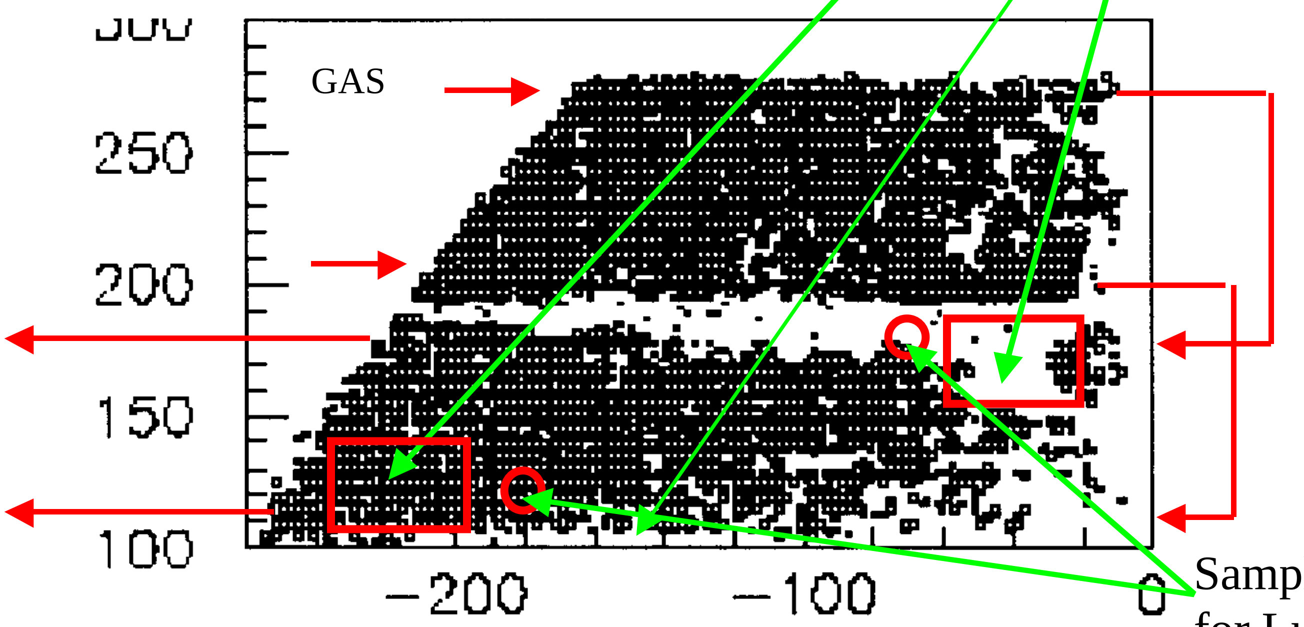
- Was not able to inflict an obvious permanent damage to any RPC component until this point, which would result in an increase of current when returning to "nominal" conditions.
- All tests were done with current on all the time.
- The Bakelite volume resistance is sensitive to temperature.
- The Linseed oil surface resistance seems to be sensitive primarily to humidity.
- Perhaps, one could speculate that by cycling temperature to 40°C, for some very wet Bakelite pieces (which were perhaps sitting in water in the factory) we drive water from Bakelite interior into the Linseed oil inner-most layer, thus changing its resistance, which does not want to change back quickly. If this theory would be right, one would be talking about a very long time constant to cure it. More tests are needed to prove this model.
- The Bakelite volume resistance is not a constant, when subject to a long term exposure to 40°C; it seems to drop by a factor of 2-3 in a week.

Volume and surface resistivity of Bakelite, and Linseed oil in the BaBar RPC EC FWD Top West Layer 7, and their comparison to the New Chamber

Choice of sections of chamber for the study

EC FWD WEST TOP – LAYER 7:

Radiography of the RPC made by Davide:



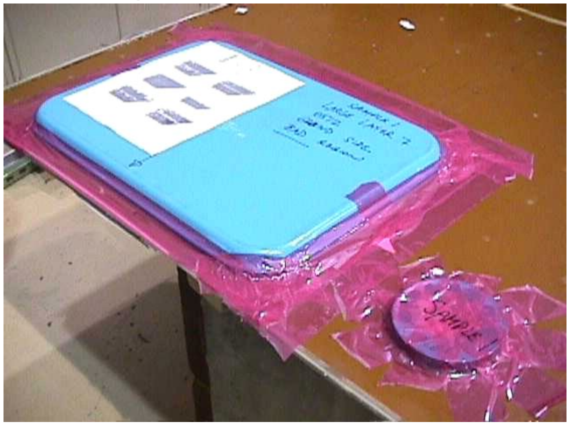
A lot of polymerized oil found here

Good section

Bad section

Samples for Lu

Cut four pieces altogether: (a) from anode & cathode, (b) good & bad section:

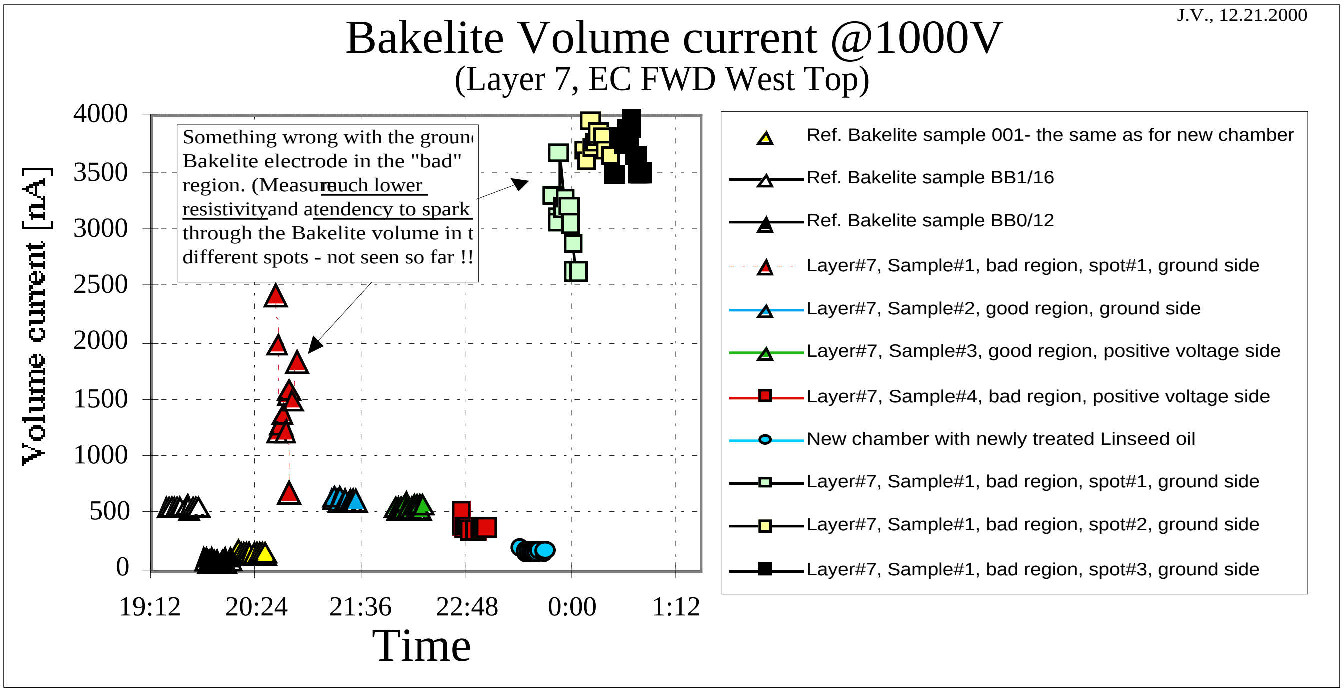


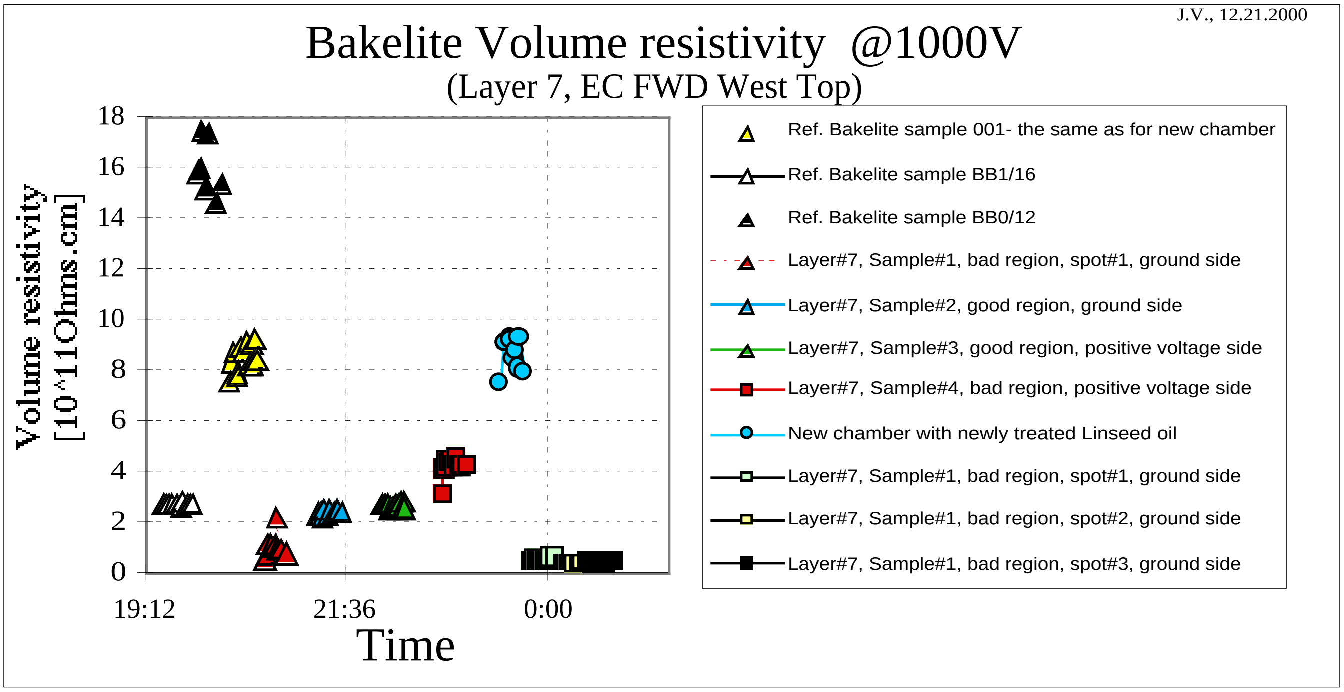
Volume resistivity of Bakelite pieces from EC FWD WEST TOP Layer 7

Volume resistivity setup:

RPC electrode is placed between Al electrodes, loaded by lead bricks:

Bad electrode was measured at several different locations:





- Take always a reference run between two measurements involving a sample with the Linseed oil.
- Instability in the current of the sample#1 was caused by a breakdown through Bakelite at 1000Volts.

Results quoting the average values:

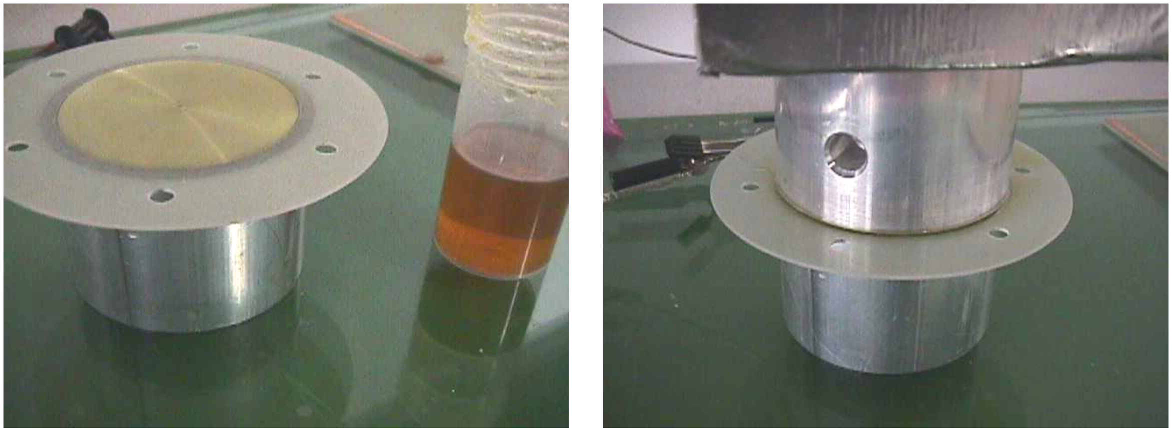
Bakelite sample (at room temperature of ~ 22degC)	Volume resistivity [10^11 Ohms.cm]
Ref. Bakelite sample BB1/16 - the same as old BaBar chamber	2.8 +- 0.1
Ref. Bakelite sample BB0/12 - the same as old BaBar chamber	15.7 +- 0.4
Ref. Bakelite sample 001 - the same as new chamber	8.0 +- 0.6
Layer7,sample#1, bad region, ground side (cathode)	**0.5 +- 0.2**
Layer7,sample#2, good region, ground side (cathode)	2.5 +- 0.1
Layer7,sample#3, good region,positive voltage side (anode)	2.7 +- 0.1
Layer7,sample#4, bad region,positive voltage side (anode)	3.9 +- 0.6
New chamber (with the newly treated Linseed oil)	**7.6 +- 0.5**

- Volume resistance of the new chamber is much higher than the samples from Layer 7.

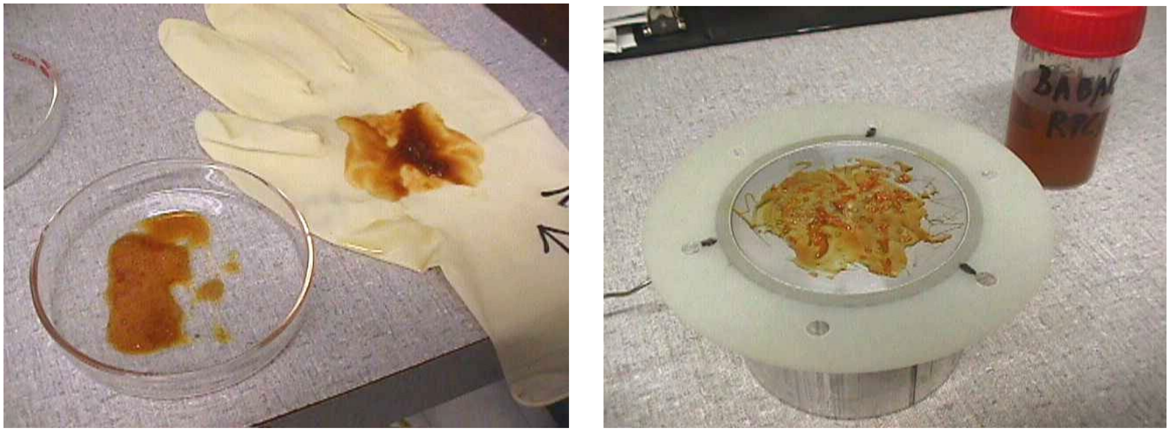
Volume resistivity of the Linseed oil

Liquid volume resistivity setup:

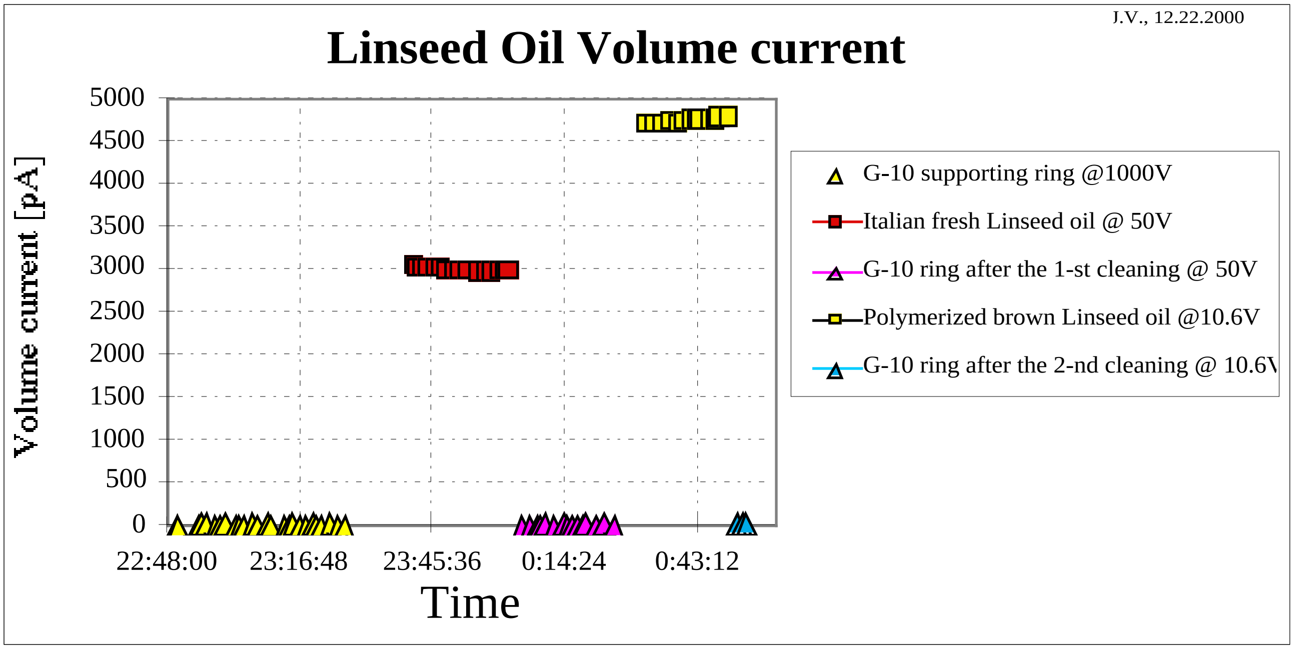
<u>1) Measurement of the fresh Italian Linseed oil:</u>
A G-10 ring, which is glued to aluminum electrode, defines the volume of liquid. The thickness of the Linseed oil is only ~0.032”~0.75mm:

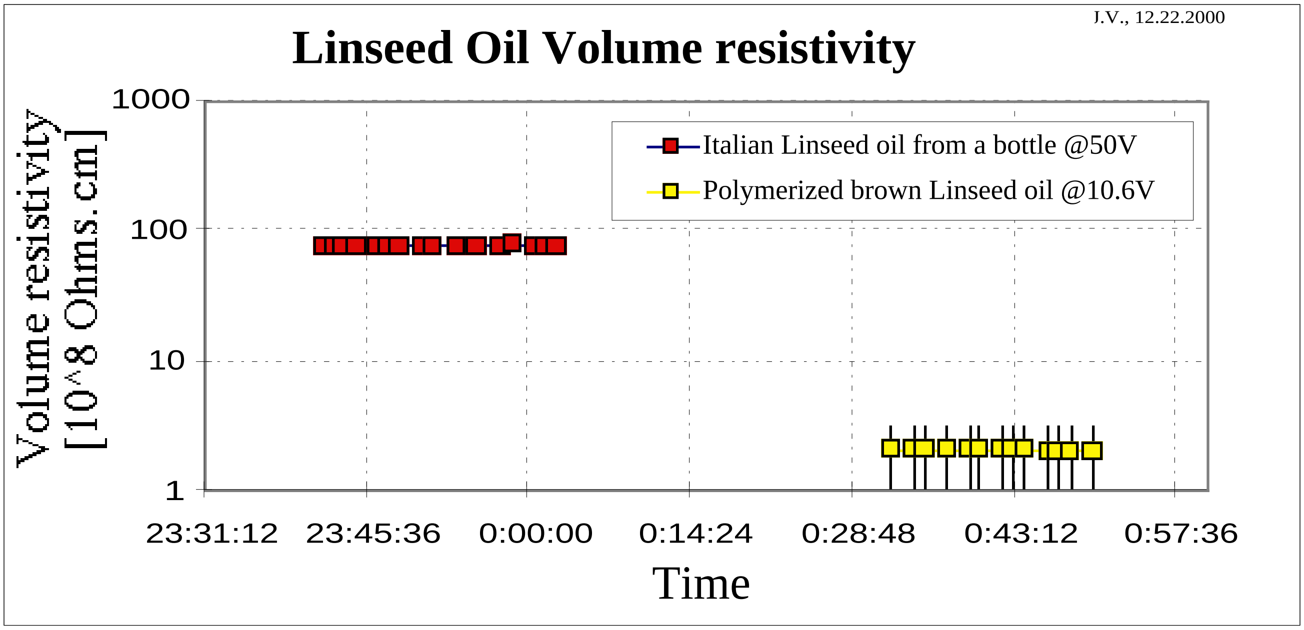


<u>2) Measurement of the brown polymerized Linseed oil:</u>
Semi-cured polymerized Linseed oil is placed on the electrodes:



Glue a G-10 ring on the aluminum electrode to create a leak-tight reservoir. Fill the volume with the Linseed oil up to the rim to ensure a good contact with the top electrode.





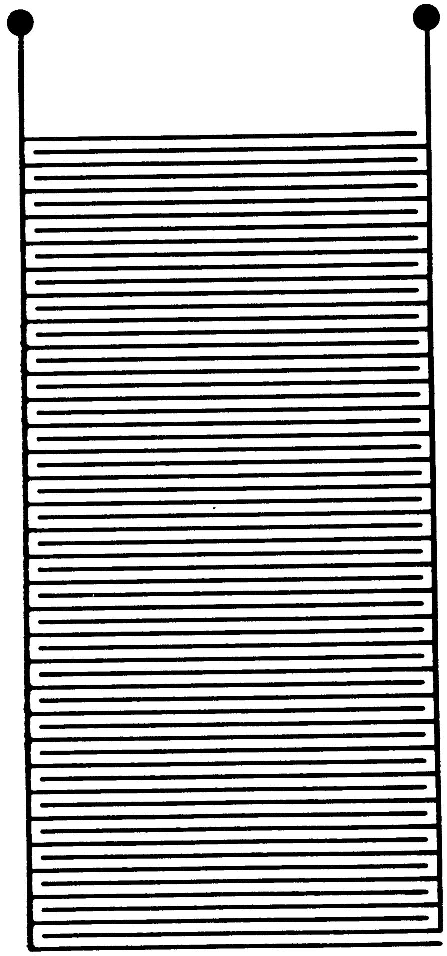
Average values:

Linseed oil sample (at room temperature of ~ 22degC)	Volume resistivity [10^8 Ohms.cm]
Fresh Italian Linseed oil (uncured)	**76.7 +- 1.0**
Brown Linseed oil taken from Layer7 (uncured)	**2.1 +- 1.0**

- The brown "gui" Linseed oil found along the edges of Layer 7 has an extremely low resistance.

Surface resistivity of Bakelite pieces from EC FWD WEST TOP Layer 7

The copper pattern on Mylar:



CRID DEGRADER TESTER
PC-735-505-58-0

$R = \frac{U}{I}$

$R_{\square} = n\,R$

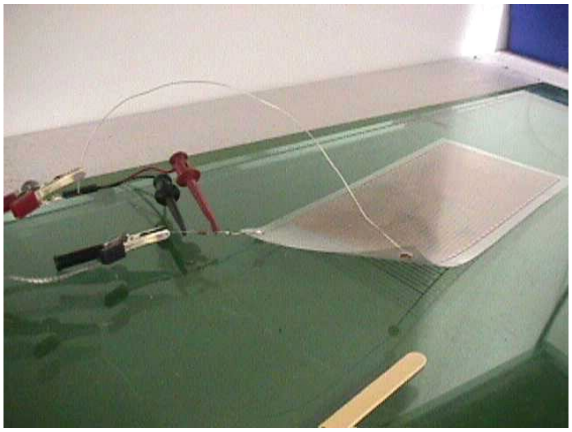
$n \sim 2.7 \times 10^3$

(NUMBER OF SQUARES)

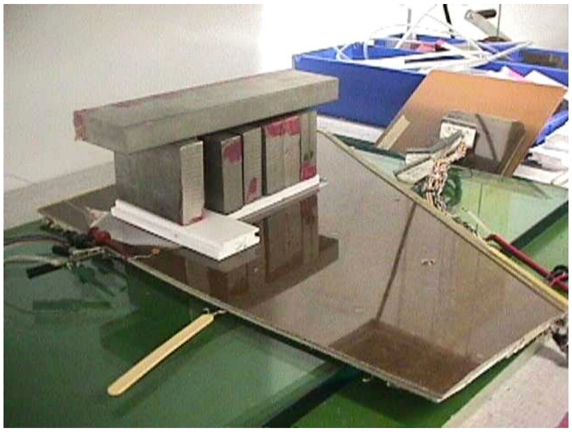
The patter is placed on the RPC electrode, copper facing the Linseed oil side, and loaded for a good adhesion. The method relies on the fact that the Mylar surface/volume resistance is much higher that the surface resistance of the Linseed oil. A typical voltage across the fingers was 500 Volts. The structure has 2700 squares. The base line current is always measured between each measurement.

Surface resistivity setup:

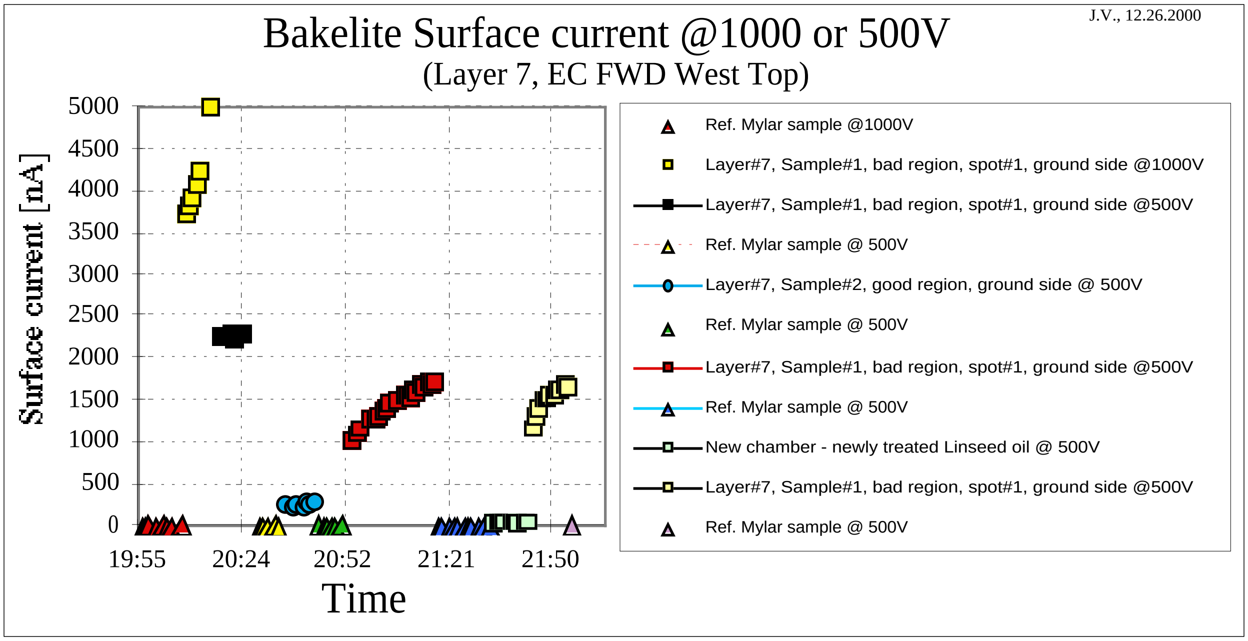
Mylar pattern is placed on the RPC electrode and loaded by weight for good adhesion:

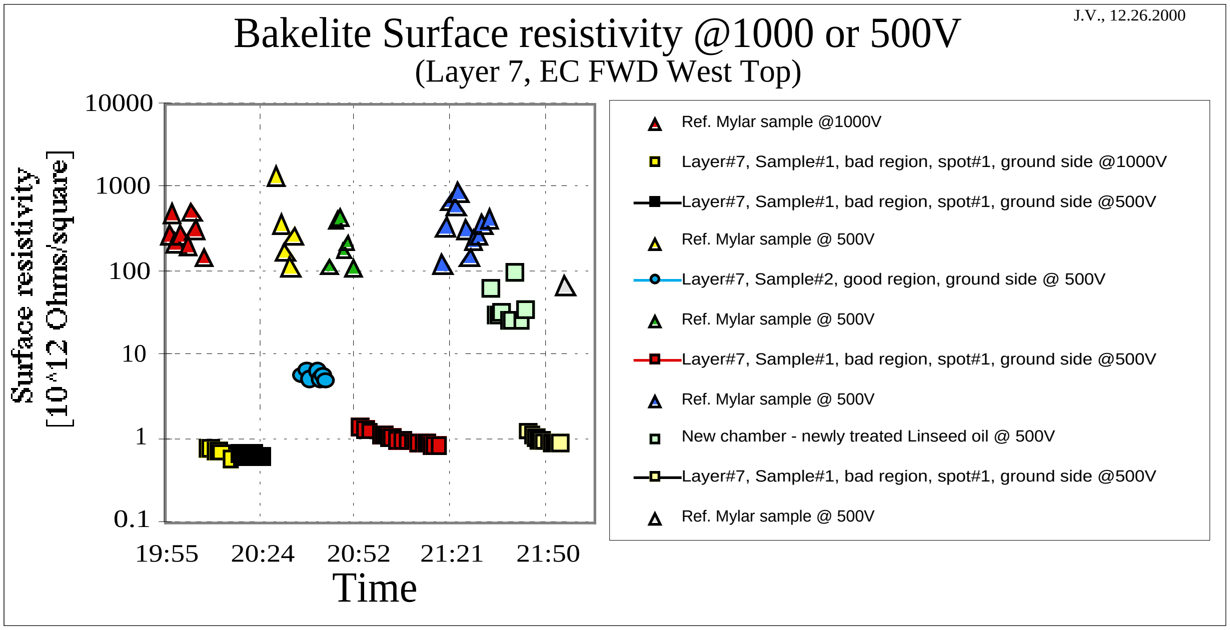


Test of brand new RPC electrode:

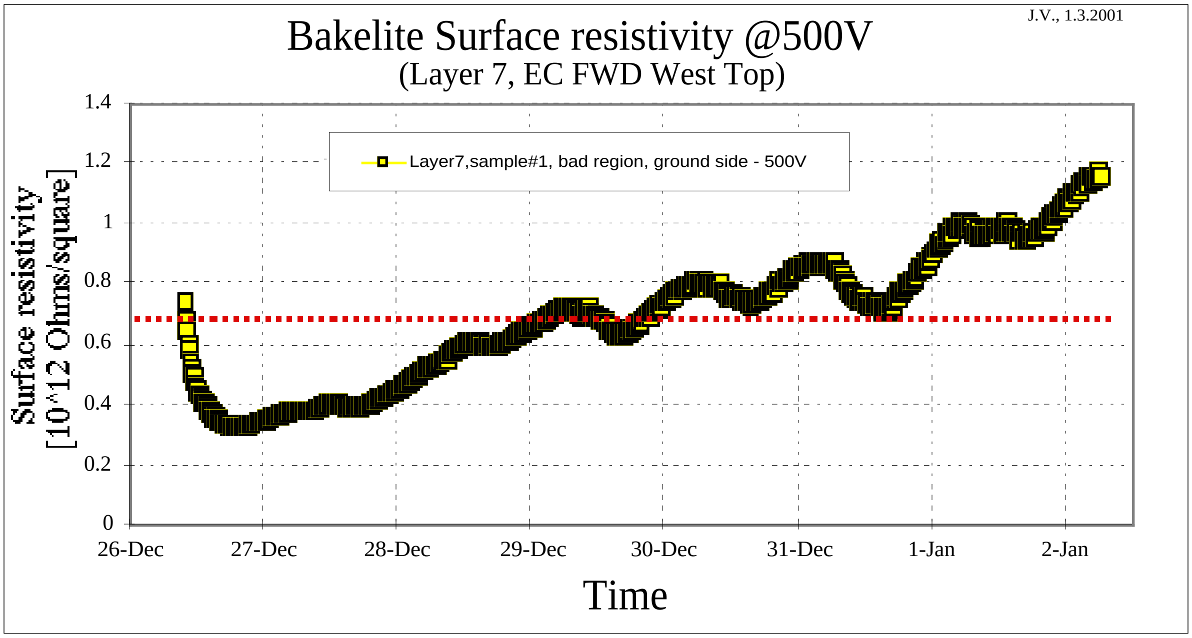


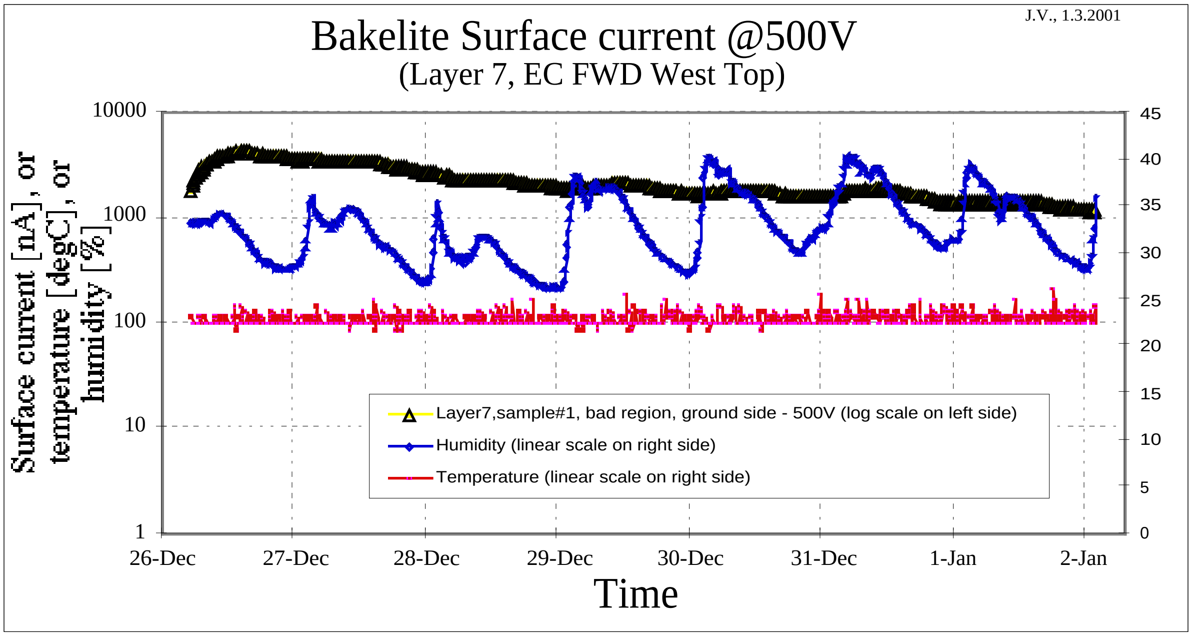
Press the copper finger side of the Mylar sheet towards the RPC electrode surface. Remove any bump on the electrode's surface and load it with a weight.



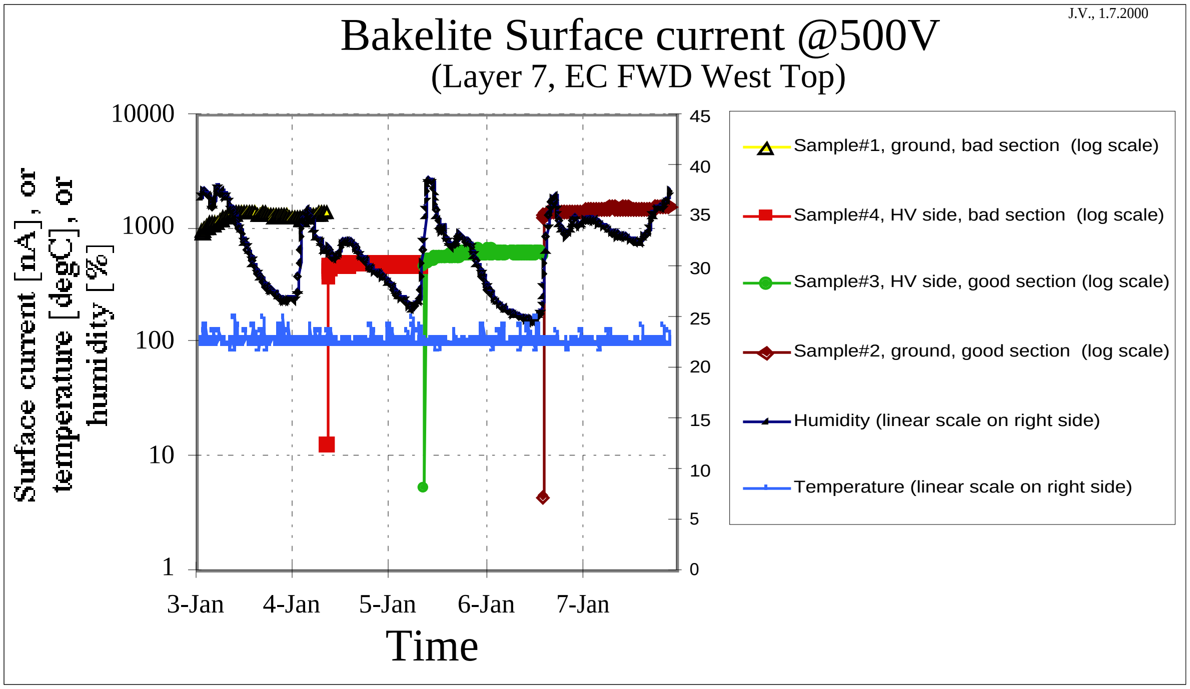


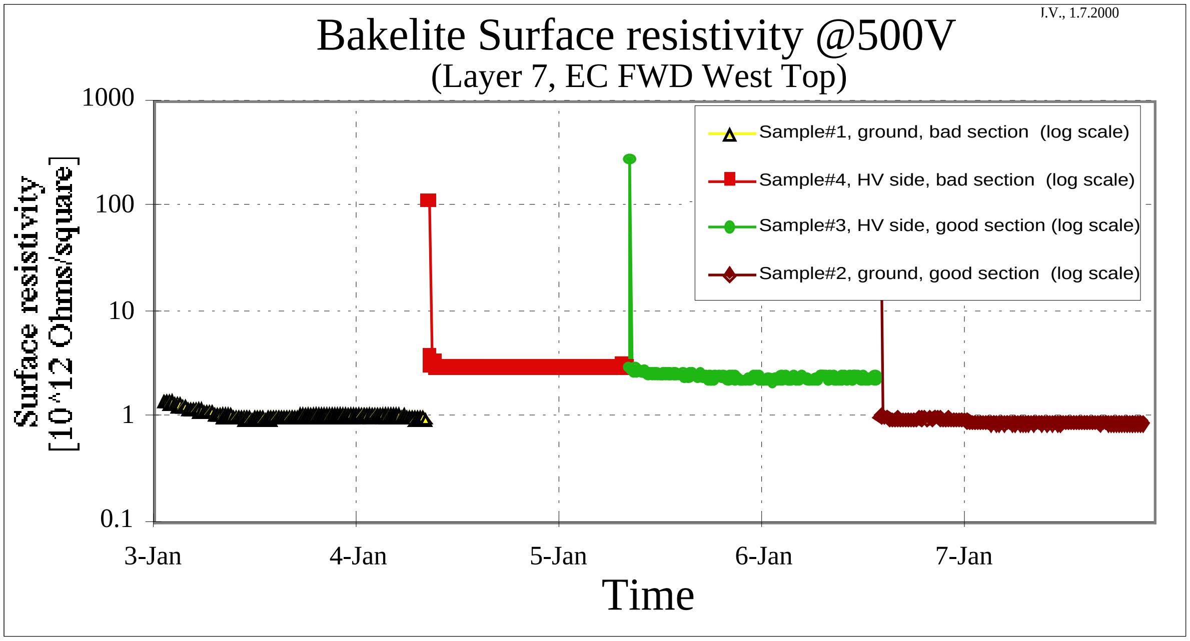
Always take a reference run between two measurements with samples involving the Linseed oil. To do this, peel off the Mylar foil from the Linseed oil (this was already enough to measure a negligible current).





A long term test of the surface resistance of the Bakelite piece from the bad section of the Layer 7. There seems to be a systematic shift in the surface resistance.





Repeat the long-term test with all four pieces from Layer 7. These values were then used for the final quote of the surface resistance.

Summary of all results so far:

Bakelite:

Sample	**Bakelite sample** (at room temperature of ~ 22degC)	Volume resistivity [10^11 Ohms.cm]	Surface resistivity [10^12 Ohms/sq.]
1	Ref. Bakelite sample BB1/16 - the same as old BaBar chamber	2.8 +- 0.1	
2	Ref. Bakelite sample BB0/12 - the same as old BaBar chamber	15.7 +- 0.4	
3	Ref. Bakelite sample 001 - the same as new chamber	8.0 +- 0.6	
4	Layer7,sample#1, bad region, ground side (cathode)	**0.5** +- **0.2**	**1.0 +- 0.4**
5	Layer7,sample#2, good region, ground side (cathode)	2.5 +- 0.1	1.0 +- 0.2
6	Layer7,sample#3, good region,positive voltage side (anode)	2.7 +- 0.1	2.5 +- 0.2
7	Layer7,sample#4, bad region,positive voltage side (anode)	3.9 +- 0.6	3.3 +- 0.5
8	**New chamber (with the newly treated Linseed oil)**	**7.6 +- 0.5**	**31.2 +- 3.7**

Linseed oil:

Sample	**Linseed oil** sample (at room temperature of ~ 22degC)	Volume resistivity [10^8 Ohms.cm]
1	**Fresh Italian Linseed oil (uncured)**	**76.7 +- 1.0**
2	**Brown Linseed oil taken from Layer7 (uncured)**	**2.1 +- 1.0**

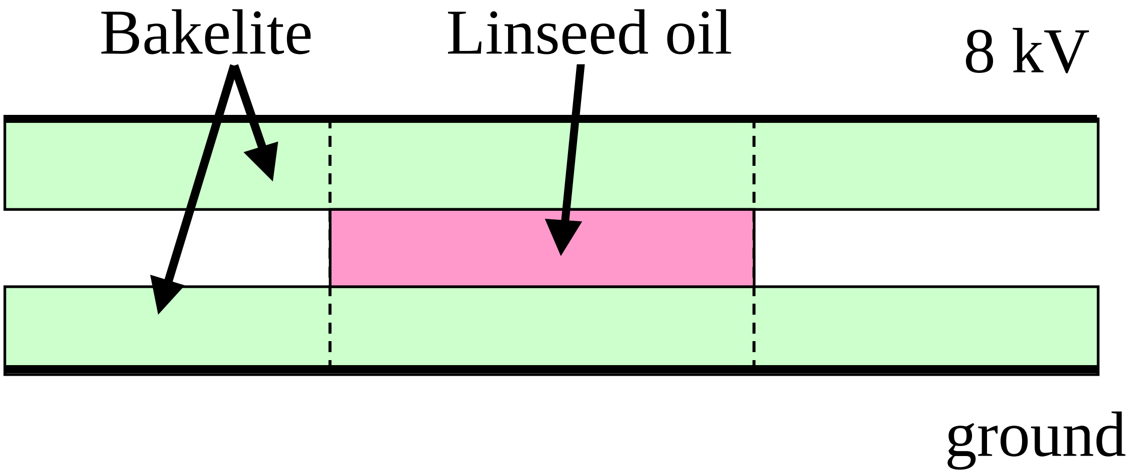
Comments:

1. A fresh Italian Linseed oil has the volume resistance about 3 orders of magnitude lower than that of Bakelite, which was used in the BaBar chambers. The resistance of the "brown" Linseed oil is even lower by another factor of 30-40 (this is the brown stuff found in the bad section of the BaBar chamber layer 7 in December 2000; presumably, it was created by allowing the large currents when running during the 1-st year).
2. The only major anomaly I have found among pieces from Layer 7 is a "bad" region from the grounded electrode, which has significantly lower volume resistance by a factor of 5-8. This has been verified by several measurements in different locations. This could be explained by:
   a) Variability in the resistance of the Bakelite material itself. Notice that the reference Bakelite pieces do have quite a variation in the volume resistance,
   b) Non-uniformly distributed porous Bakelite material in some locations, which has been impregnated either by a fresh uncured Linseed oil or simply a moisture in the storage of chamber parts at the factory.
   c) Unevenly cured Linseed oil due to variation in its thickness and insufficient exposure to air.
3. The bad region of layer 7 has not only abnormally low resistance, but during the tests I have observed a breakdown through the volume of Bakelite at 1000 Volts. This also indicates that the volume material has a defect of some kind, perhaps related to the above mentioned porosity.
4. The volume and the surface resistance of the new chamber is significantly higher compared to the old chamber design.

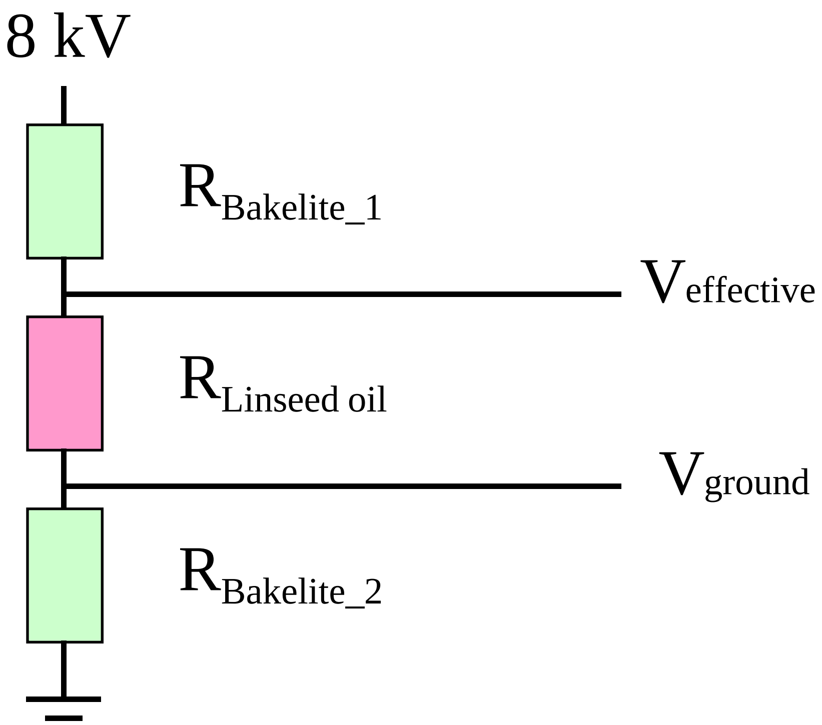
Simple equivalent models:

EXAMPLE #1

Let's assume a circular blob of the Linseed oil of about $1 cm^2$ in area shorting the anode-cathode gap (it is 2 mm thick):



An equivalent electrical circuit for this model:



It is clear if $R_{Linseed}$ oil is too low, we short the chamber.

1. Volume resistance of the Linseed oil blob:

1.1. The blob is made of the fresh Linseed oil:

$R_V(\text{Linseed}) = \rho_V\ (t_{gap}\ /\ \text{Area}) \sim 77 \times 10^8\ \Omega.\text{cm} \times (0.2\text{cm}/1\text{cm}^2) \sim 1.5 \times 10^9\ \Omega$

1.2. The blob is made of the "brown" Linseed oil:

$R_V(\text{Linseed}) = \rho_V\ (t_{gap}\ /\ \text{Area}) \sim 2 \times 10^8\ \Omega.\text{cm} \times (0.2\text{cm}/1\text{cm}^2) \sim 4 \times 10^7\ \Omega$

(Note: neglect the surface resistivity of the Linseed oil)

2. Volume resistance of the single Bakelite sheet:

3.1. "Nominal" resistance:

$R_V(\text{Bakelite}) = \rho_V\ (t_{gap}\ /\ \text{Area}) \sim 2.5 \times 10^{11}\ \Omega.\text{cm} \times (0.2\text{cm}/1\text{cm}^2) \sim 5\text{x}10^{10}\ \Omega$

3.2. Low resistance:

$R_V(\text{Bakelite}) = \rho_V\ (t_{gap}\ /\ \text{Area}) \sim 0.5 \times 10^{11}\ \Omega.\text{cm} \times (0.2\text{cm}/1\text{cm}^2) \sim 10^{10}\ \Omega$

Calculation anode and cathode voltages and current:

Top Bakelite	**Short**	Bottom Bakelite	1 cm^2 area	1 cm^2 area	1 cm^2 area
rho-bakelite_1 [10^11 Ohms.cm]	**rho-Linseed oil** [10^8 Ohms.cm]	**rho-bakelite_2** [10^11 Ohms.cm]	**V-effective** [kV]	**V-ground** [kV]	**Current** [uA]
3.9	**1.00E+08**	0.5	7.999688014	3.99982E-05	3.99982E-06
2.7	**1.00E+08**	2.5	7.999784011	0.00019999	3.99979E-06
3.9	**76.7**	0.5	1.030580562	0.893515313	0.089351531
3.9	**2.1**	0.5	0.912473592	0.908657232	0.090865723
2.7	**76.7**	2.5	3.906532492	3.790247693	0.075804954
2.7	**2.1**	2.5	3.847830684	3.844601219	0.076892024
0.5	**2.1**	0.5	4.008382397	3.991617603	0.39916176

Conclusion:

If the Linseed oil blob, either fresh or "brown", is shorting the gap, the region around it is definitely always inefficient due to the shorted gap voltage. This applies also to buttons full of oil, partially filled with oil, or even to whickers of oil.

EXAMPLE #2

Let's assume ~2 mm wide, 2 meter long bead of polymerized Linseed oil along the RPC edge (total area: ~40cm^2).

R_V(Linseed) = ρ_V (t_{gap} / Area) ~2 x 10^8 Ω.cm x (0.2cm/(0.2cm x 200cm)) ~ 10^6 Ω

Conclusion:

Clearly, this example will create a big problem, not only because the gap near by is shorted, but also this will start causing large current (for this particular example one obtains: ~3μA for 8kV).

EXAMPLE #3

Middle of the active region among four buttons does not have any oil touching two electrodes. However, I assume that buttons are full of Linseed oil, i.e., they are shorting the gap. This example would simulate reasonably well the bad region of the Layer 7, because in that region the active region is reasonable oil-free – see page 2 for the location of the bad region.

This problem has to be solved using more a sophisticated model with the distributed resistance. One can use values, which I have provided in this note as input.

Conclusions of all tests so far:

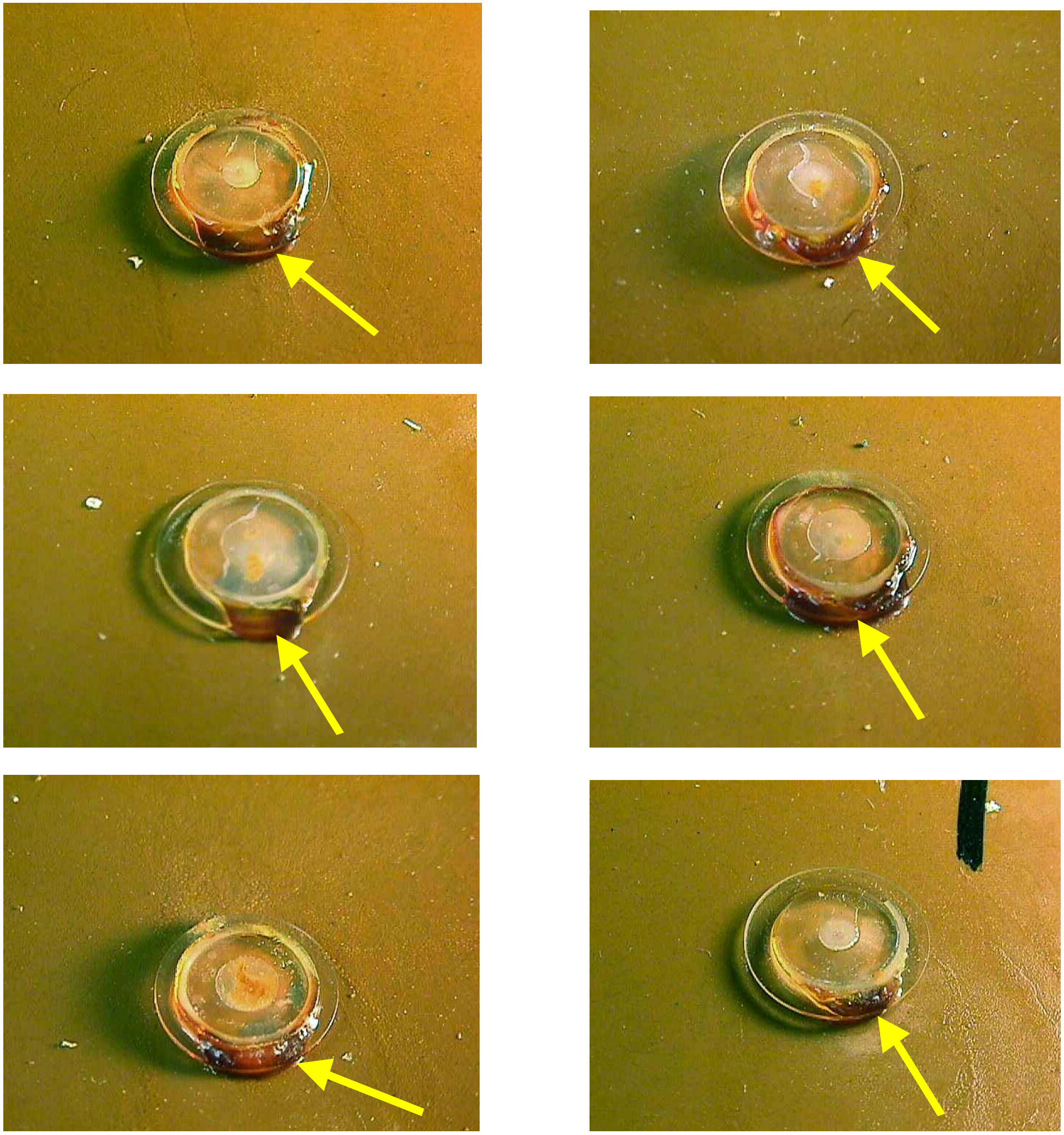
- The Bakelite volume resistance can increase by a factor of 2-3 in a week, when subject to a temperature of 40°C. This occurs even after a tiny charge dose of ~0.015 Coulombs/cm^2.
  On the other hand, if the sample is kept at room temperature, to increase the resistance increased by a factor of ~10, one needs ~1 Coulombs/cm^2.
- The Lexan button or G-10 side spacer volume resistance do not change as obviously when subject to 40°C for a week (of course, they could change over longer period of time).
- There is a hint that a brown "gui" Linseed oil taken from the BaBar RPC Layer 7 has >30x lower volume resistance than that of a fresh Italian Linseed oil.
- The volume resistance of the <u>new chamber</u> is 2-3x higher compared to the old chamber design. The surface resistance of the <u>new chamber</u> is 10x higher compared to the old chamber design (almost as high as the Mylar).
- Was not able to inflict an obvious permanent damage to any RPC component until this point, which would result in an increase of current when returning to "nominal" conditions.

However, we are still missing a crystal clear smoking gun based on the tests with the Layer 7.

A recent discovery on 12.20.2001:

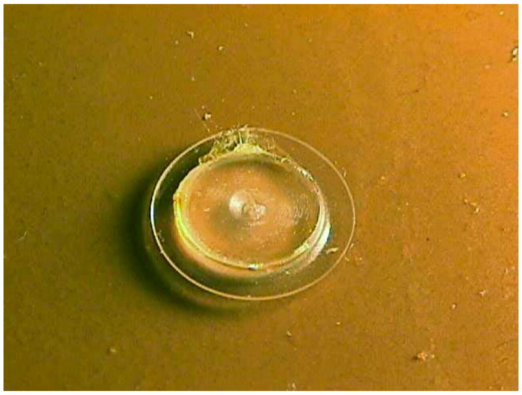
The buttons from a “bad” section are looking noticeably worse.

a) Buttons from a “bad” section of the RPC Layer 7:



- Practically every button has a “dark looking” bridge across.

a) Buttons from a “good” section of the RPC Layer 7:

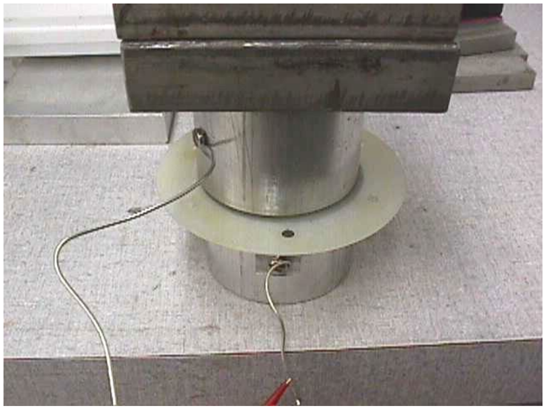


- Although there is some excess of Linseed oil, there is not as much of it, so it does not bridge the gap, and it is not as dark looking as in the “bad”section of RPC.

Let's measure the resistance of these buttons:

3 buttons from a "bad" section of RPC:

Setup to measure button resistance:



1) A button from a "good" section:

- Resistance of one such button: R=3xV/I~5.6x10^{10} Ω

. Volume resistance of the Lexan button coated with Linseed oil:

$$\rho_V = R\ (\mathrm{Area}/t_{gap}) \sim 1.7\mathrm{x}10^{11}\ \Omega.\mathrm{cm}$$

(a bare Lexan button resistance is $\rho_V \sim 10^{13}$ Ω.cm)

2) A button from a "bad" section:

- Linseed oil from the "bad" section is much darker
- Resistance of one such button: R=3xV/I ~3.5×10^{8} Ω !!!!

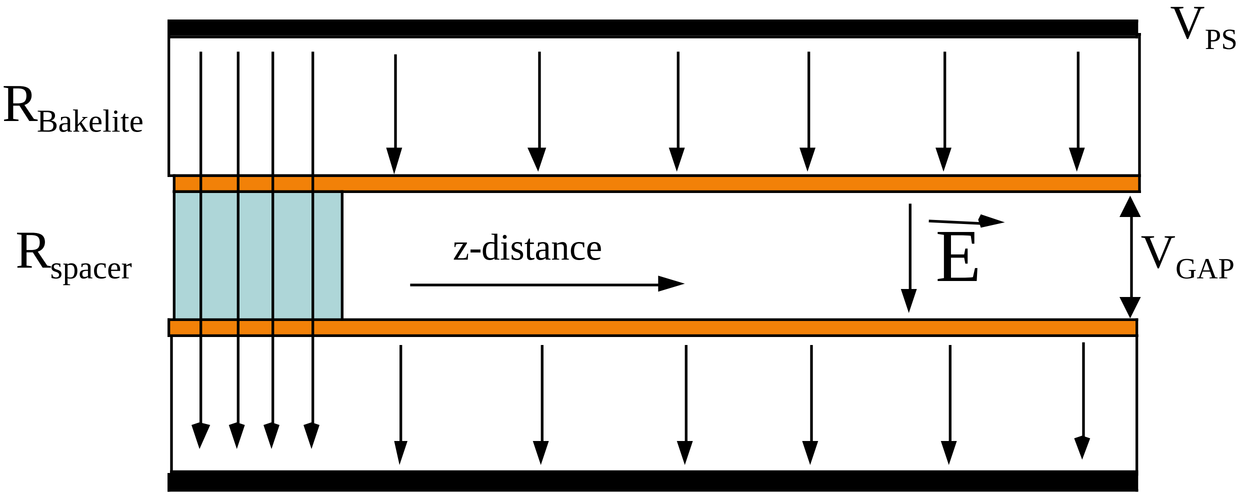
- Volume resistance of the "brown stuff":

$$\rho_V = R\,(\mathrm{Area}/t_{gap}) \sim 2.5\times10^{8}\ \Omega.\mathrm{cm}\quad !!!!!!$$

- This value is consistent with the value we got for the "gui" brown stuff taken from edges of the Layer 7.
- This is too small value, which will short the gap to a point that the RPC will not work.

We have a smoking gun !!!!!

1) Good region of Layer 7:



$$\mathbf{V_{GAP} = V_{PS} / (1+ 2\ R_{Bakelite}/R_{Lexan\ spacer}) \sim V_{PS}}$$

$$\mathbf{if\ \ R_{Lexan\ spacer} >> R_{Bakelite}}$$

- The current through the spacer should be small.

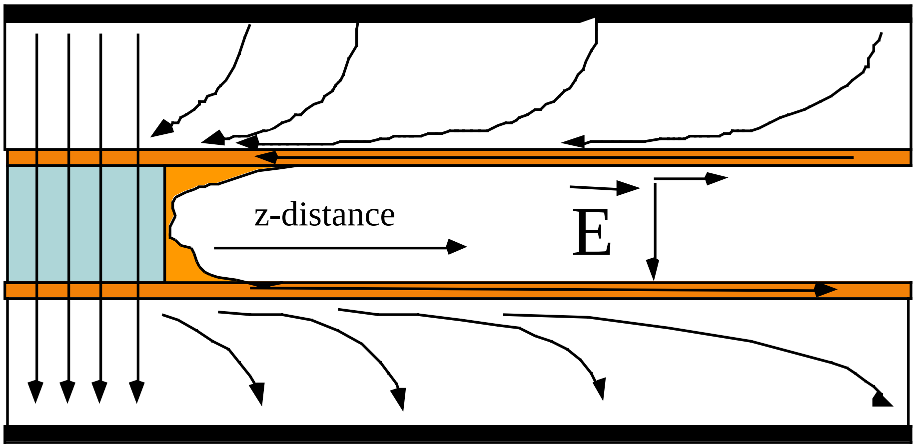
In this case, the chamber will work OK:

$R_{Bakelite} = \rho_V\ (t_{gap}\ /\ Area) \sim 2.5 \times 10^{11}\ \Omega.cm \times (0.2cm/100cm^2) \sim 5\times10^8\ \Omega$
$R_{Linseed\ oil\ blob} = \rho_V\ (t_{gap}\ /\ Area) \sim \mathbf{1.7\times10^{11}\ \Omega.cm} \times (0.2cm/0.1cm^2) \sim 3.4 \times 10^{11}\ \Omega$

$$\Rightarrow \mathbf{V_{GAP} = V_{PS} / (1+2*5*10^8 / 3.4\times10^{11}) \sim V_{PS}* 0.99}$$

2) Bad region of Layer 7:

Buttons are shorted by a "gui" Linseed oil:



A button is shorted by the "brown gui Linseed oil blob":

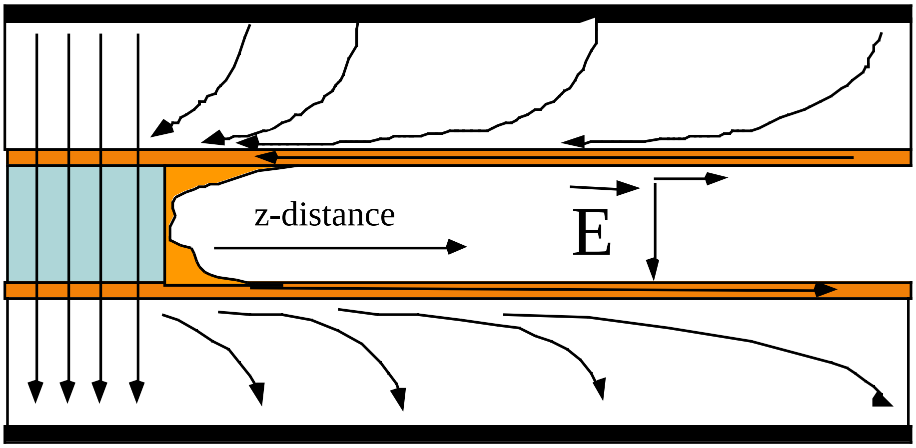
$R_{\text{Bakelite}} = \rho_V\,(t_{gap}$ / Area) ~ 2.5 x 10^{11} Ω.cm x (0.2cm/100cm^2) ~ 5x10^8 Ω

$R_{\text{Linseed oil blob}} = \rho_V\,(t_{gap}$ / Area) ~ **2.5*10^8 Ω.cm** x (0.2cm/0.1cm^2) ~ 5 x 10^8 Ω

=> **$V_{GAP} = V_{PS}$ / (1+2*5*10^8 / 5x10^8) ~ V_{PS}* 0.33 !!!!!!!!**

=> The chamber may not work with such buttons.

3) Once we get to such low button resistance range, a factor of 2-3 change of Bakelite resistance does indeed matter:



A button is shorted by the "brown gui Linseed oil blob" and the Bakelite resistance changed by a factor of 3x:

$R_{\text{Bakelite}} = \rho_V\,(t_{gap}$ / Area) ~ **3 x** 2.5 x 10^{11} Ω.cm x (0.2cm/100cm^2) ~ 1.5x10^9 Ω

$R_{\text{Linseed oil blob}} = \rho_V\,(t_{gap}$ / Area) ~ **2.5*10^8 Ω.cm** x (0.2cm/0.1cm^2) ~ 5 x 10^8 Ω

=> $V_{GAP} = V_{PS}$ / (1+3*2*5*10^8 / 5x10^8) ~ V_{PS}* 0.14   !!!!!!!!

It would appear that if one wants to cure a good fraction of the BaBar RPC problems, one should increase the resistance of the Linseed oil-covered buttons.

Surface imperfections

1. A sharp point, which would not go away by the acetone treatment - positive voltage electrode, bad region, sample#4.

A sharp point before acetone treatment:

The same point after the treatment:

A piece of dust still sticks out of the surface after the treatment.

2. Sharp point, which goes away by the acetone treatment – positive voltage electrode, good region, sample#3.

A sharp point before acetone treatment:

The same point after the treatment:

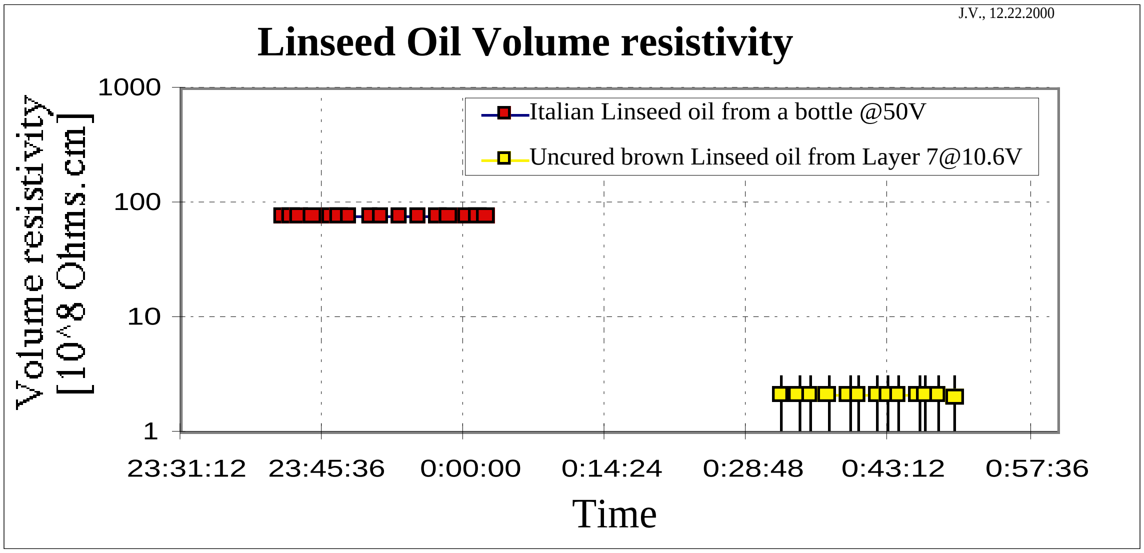
Linseed oil stalagmite, which was dissolved completely by the acetone, although the spot remains still visible.

Conclusions of this work:

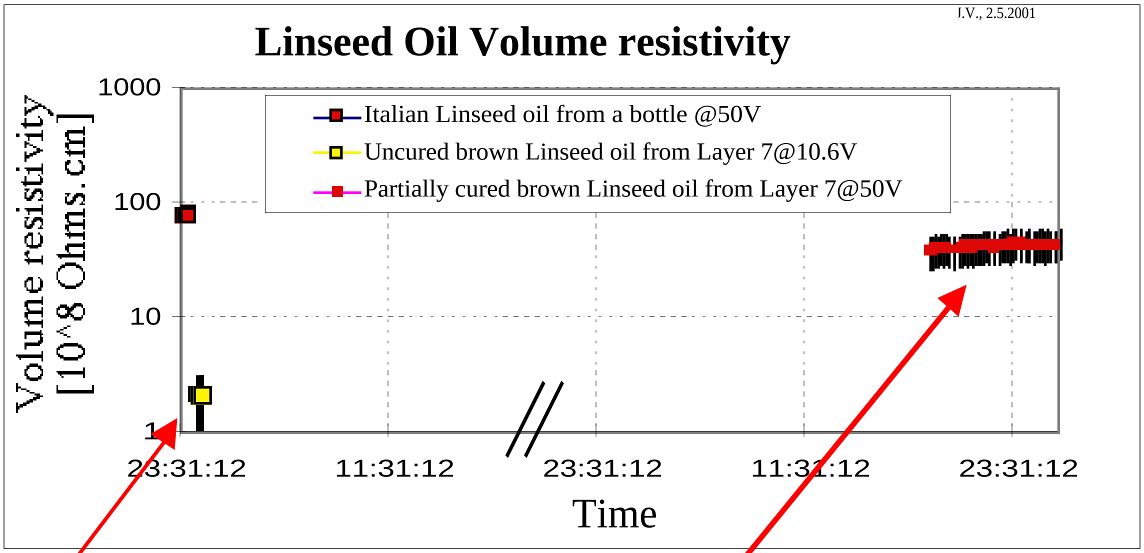
- The Linseed oil has a substantially lower volume resistance compared to Bakelite. Any contact between the anode and the cathode in a form of a droplet or partially filled button or even whisker will short the gap in that particular point, thus causing a local inefficiency.
- The "brown gui" Linseed oil has ~30 times lower resistance compared to the fresh Italian Linseed oil. Therefore a large accumulation of this type of oil along the bottom edge of the Layer 7 will not only cause the edge inefficiency, as we observe, but also a large current.
- I have measured volume and surface resistance of four samples taken from the Layer 7. This result can be used as a input into a calculation using the RPC model based on the distributed resistances. Among these samples, one was especially distinctive. Grounded electrode from the "bad" region of Layer 7 has 5-8 times lower volume resistance compared to other samples. Furthermore, initially, this sample had a difficulty to hold 1000 Volts across, which would indicate some internal problem, possibly a Bakelite porosity (it could have been be filled with either the Linseed oil at the factory, or water from an early storage of parts).
- The new chamber has Bakelite with substantially higher volume and surface resistance. However, I have certainly noticed that some buttons are still partially filled with the Linseed oil. I predict that such buttons may have local inefficiency due to shorting the gap voltage (I did not measure it directly, but I think that even new "cured" Linseed oil has still relatively "too low" volume resistance).

Can we save it all ?

a) J.V., 2.12.2001



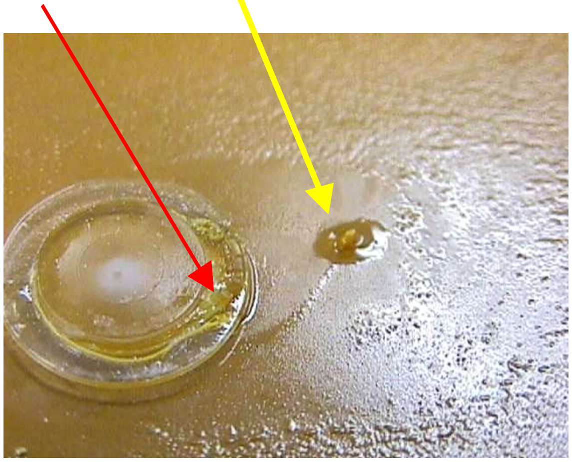
b)



"Brown stuff" fresh from the Layer 7

"Brown stuff" after 2 months in air at 60ºC

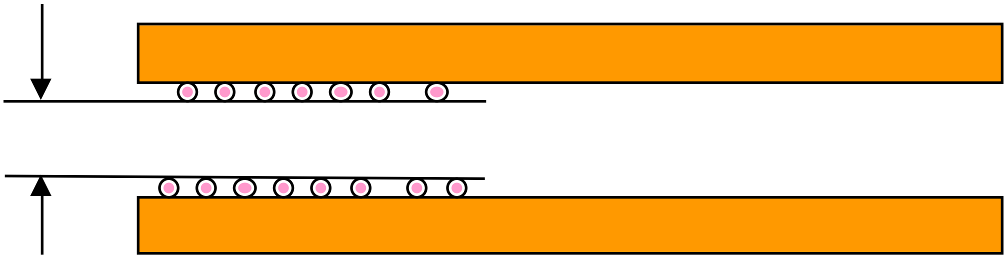
A number of stalagmites, which I managed to find is in sections taken from the Layer 7, is very small. However, every button looks like this:



Therefore, I think the buttons are the primary sources of trouble in RPCs, both from point of view of providing a source of the Linseed oil, and from point of view of actually shorting the gap every 10 cm.

I think we should consider changing them into L3 old design. I agree that the “new treatment” of the Linseed oil will remove much of this problem, but some buttons even in the new chamber have some deposits.

The electric field, acting on the “liquid” Linseed oil in early days, as Lu saw experimentally, could create local bumps as we see on the above picture, thus effectively reduce the gap size, and cause local inefficiencies.



There are two scenarios I can see:

a) <u>Optimistic one</u>:

Buttons are shorting the gap every 10 cm, and in between we have a layer of Linseed oil few mils thick, which is only partially cured, and it is the volume resistance of the “liquidy” oil, which propagates the short many centimeters into the active region. A similar argument applies to edges, where we have large amounts of the Linseed oil. In this case, an attempt to further cure the oil, for example with oxygen, should help. We should start with this treatment right away of some well selected chamber in BaBar (flow oxygen for a few months, then do radiography in a proper gas, then flow oxygen again, etc. All this would be at room temperature. Do not waste any time….

b) <u>Pessimistic one</u>:

The inefficiency is caused by the rough surface and the resulting gap changes, caused by an early application of the electric field acting on fresh uncured Linseed oil. In this case, the oxygen variable will not help.

Should we flow oxygen continuosly ?

If it is indeed true that the oxygen treatment helps only temporarily, if I understood Lu's measurements, perhaps, one could think of adding a small amount of oxygen permanently while we are running. There was an effort within the BELLE collaboration to develop the freon-less mix (S. Narita et al., IEEE NSS-MIC 2000, Lyon). Among other mixes they tried $20\%Ar+6\%iC_4H_{10}+69\%CO_2+5\%O_2$. It gave a bit higher noise rate, but the mix was stable. If one does not want to change the BaBar RPC gas mix drastically according to the above suggestion, perhaps one could add ~5% of O_2 and reduce correspondingly the Freon HFC-134A level.

Decomposition of the Linseed oil ?

Why the oxygen treatment is not stable?

The problem could be related to the ion migration within the surface film while running currents. Such effects have been observed very clearly in chambers coated with the CsI photocathode, or within the glass in the micro strip chambers.

As an example of what I meant is the ion migration in the CsI photocathode, under influence of a strong light causing large photocurrent. In this case the Cs(+) and I(-) ions move to their respective electrodes. The CsI film is, of course, on the cathode, and therefore Cs(+) ions will tend to migrate to the surface (towards anode). Once on the surface they may react with all sorts of impurities present in the chamber, which in turn causes a loss of quantum efficiency.

In case of BaBar RPCs, what is the equivalent process? We have a rather large current in the Linseed oil surface film, especially near the buttons and the edges, possibly more in the outer chambers.

I had a peak into the Encyclopedia Britanica, believe or not, and found the following definition of the Linseed oil: "The oil is a mixture of the glycerides of linolenic, linoleic, oleic, stearic, and palmitic acids with high degree of unsaturation of its fatty acid radicals".

Clearly this sentence needed a chemist to help to translate it. I called my old friend, J. Maly, a retired chemist, and I should say a non-expert in the Linseed oil, and he immediately clarified a lot and actually confirmed that my thought are possibly correct:

1. The molecule has unsaturated double-bonds, which means that it will want to react with the oxygen, which will tend to stabilize it and finish the polymerization process, and also probably increase the resistance.
2. He thought that the oil is really not hydrocarbon oil, as I thought naively judging from its name, but it is a fat instead, which is a molecule formed from reaction of glycerine and acids. Under the influence of voltage, coupled probably with a presence of water, the glycerine and the fatty acids will separate from each other. Once the fatty acids (R-COOH) are produced, they will be subject of electrolytic splitting into ionic groups H^+ and $R\text{-}COO^-$, under influence of a current. This would increase the conductivity of the film (I liked to hear that). Longer you

run the current lower resistance (I liked to hear that also).

3. The current action, with no oxygen present, would split the fat molecule, and would make it appear as never curing (I liked to hear that too).

Searching for some experimental evidence that the Linseed oil volume resistance will decrease as we run the current through it, I found it in my own data (see page 36 of this document). The brown stuff scraped from the bottom edges of Layer 7 RPC had significantly lower volume resistance (~2.1×10^8 Ohm.cm) compared to a fresh Linseed oil (76.7×10^8 Ohm.cm), which was not understood at that time. It is clear that the brown stuff had a large current going through it for a long time when the chamber was operating in BaBar. In view of this model, the Linseed oil, due to its internal chemical changes outlined in the previous message, is slowly lowering its volume resistance as we run the current through it. The frequent shorts due to button and edges within the RPC design are then expanding into the active area when the Linseed oil resistance lowers. Do we have any experimental evidence for this? Again, this speaks for the radiography inside the BaBar RPC system. Can we have some special "radiography" trigger and run with it all the time while the BaBar collects the data? I would judge it as very important.

The Linseed oil does contain water, of course. The pure water is not conducting much by itself, as we know, but a presence of acids from the Linseed oil decomposition, may also contribute to a decrease of the volume resistance while we are running current. Probably, the same thing applies to Bakelite.

Perhaps this speaks for a simple electrolytic test. Setup a bath with the Linseed oil, put in two electrodes and connect them to a battery. Then chemically analyze excess of elements on the respective electrodes. If the electrodes have a flat shape, one could measure, perhaps, the surface resistance of the film on the electrode surface. If one is significantly higher than the other, this may provide a clue. For example, if the anode surface resistance is much lower, than one could argue that this process lowers of the surface resistance near buttons and near edges once we start running, thus expanding the local inefficiency and causing a long term degradation of efficiency.

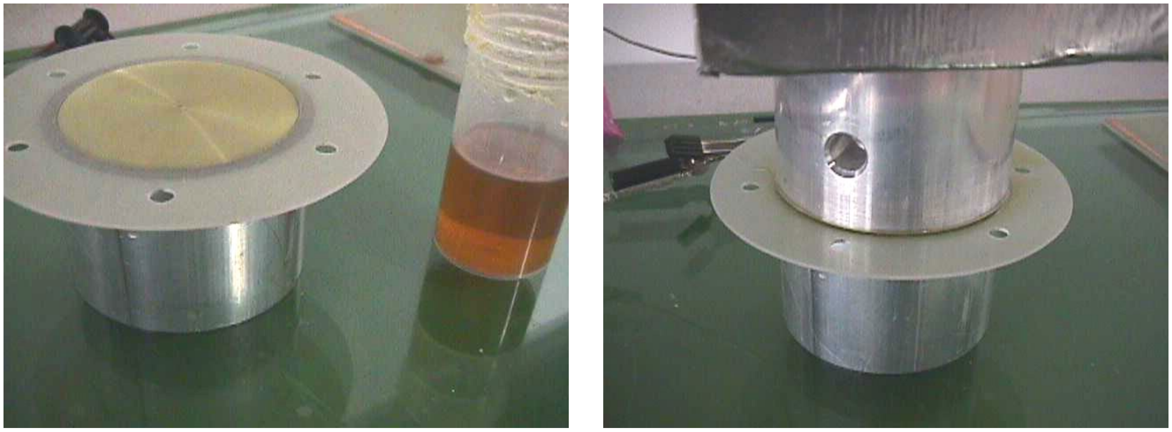
The fact that the outer chambers deteriorate more rapidly, especially near the edges, may also be consistent with the model of the decomposition of the Linseed oil. If, due to a higher background, there is large rate, or perhaps even repetitive sparking near the edges of the outer chambers, then there is a larger current through the Linseed oil in that area. That would speed up the decomposition of the oil, resulting in the lower resistance, and in turn in the efficiency drop near edges (a simple resistor divider argument).

Experimental proof that the Linseed oil can be decomposed

Use the same setup as on page 35:

7.16.2001

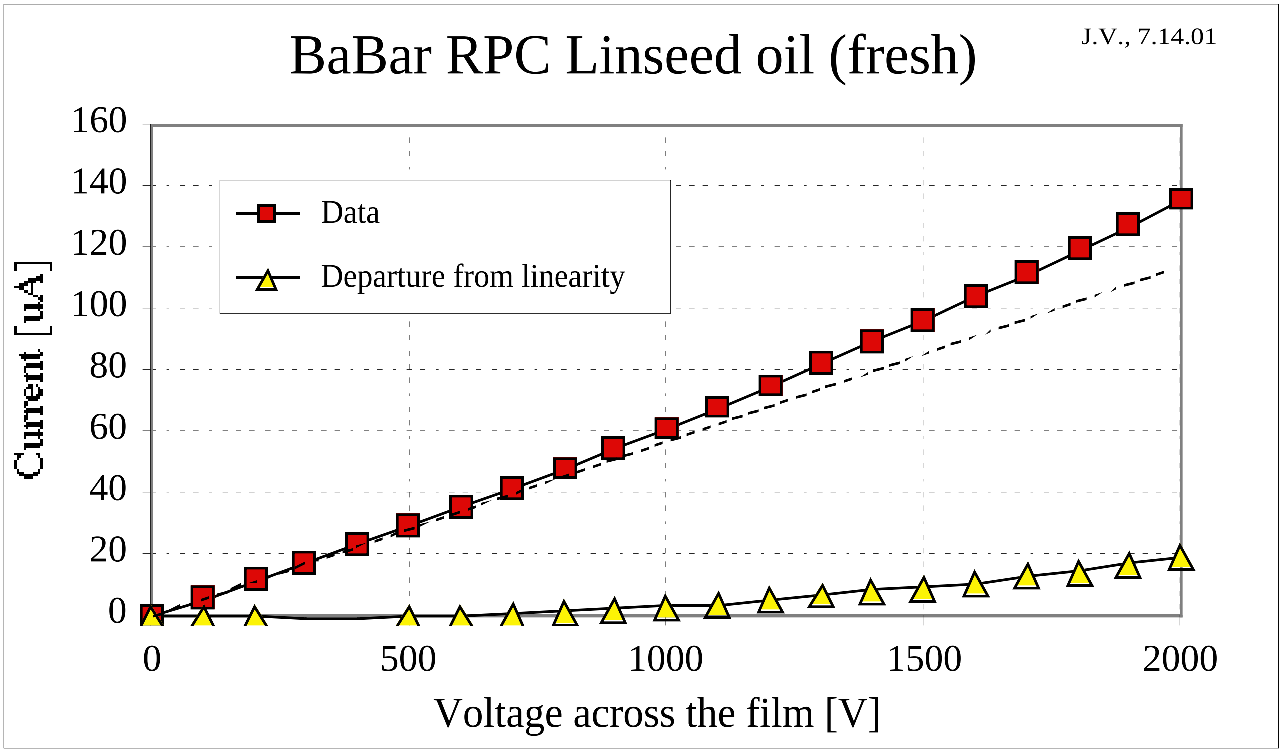
A G-10 ring, which is glued to aluminum electrode, defines the volume of liquid. The thickness of the Linseed oil is only ~0.032”~0.75mm, i.e., dealing with a thin sheet:



What to expect?

The Linseed oil has some fraction of the fatty acids already present at the start, which explains its rather high conductivity. If a large current flows, a further decomposition of Linseed oil occurs (see pages 58-60), resulting in a further build up of the fatty acids. This will increase the conductivity further. Therefore, one would expect that the current-to-voltage relationship is not linear. This is what we seem to be observing:

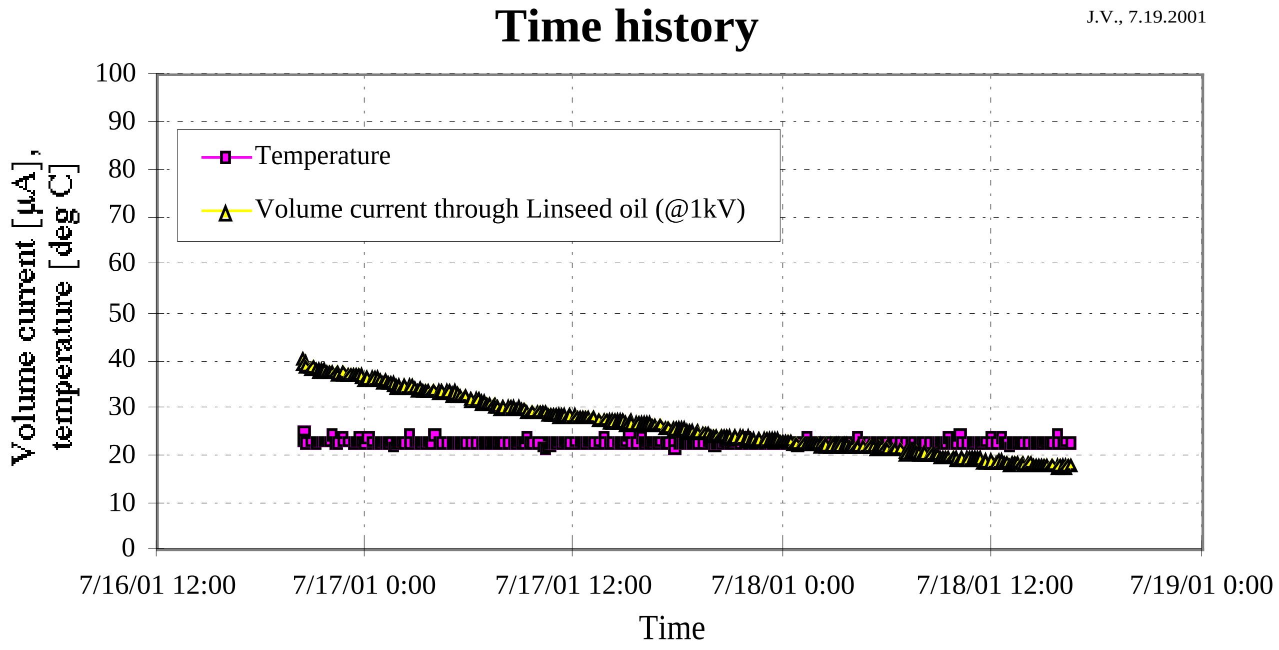
The result clearly proves a non-linear dependency of I = f(V):



Long term test with high voltage on:

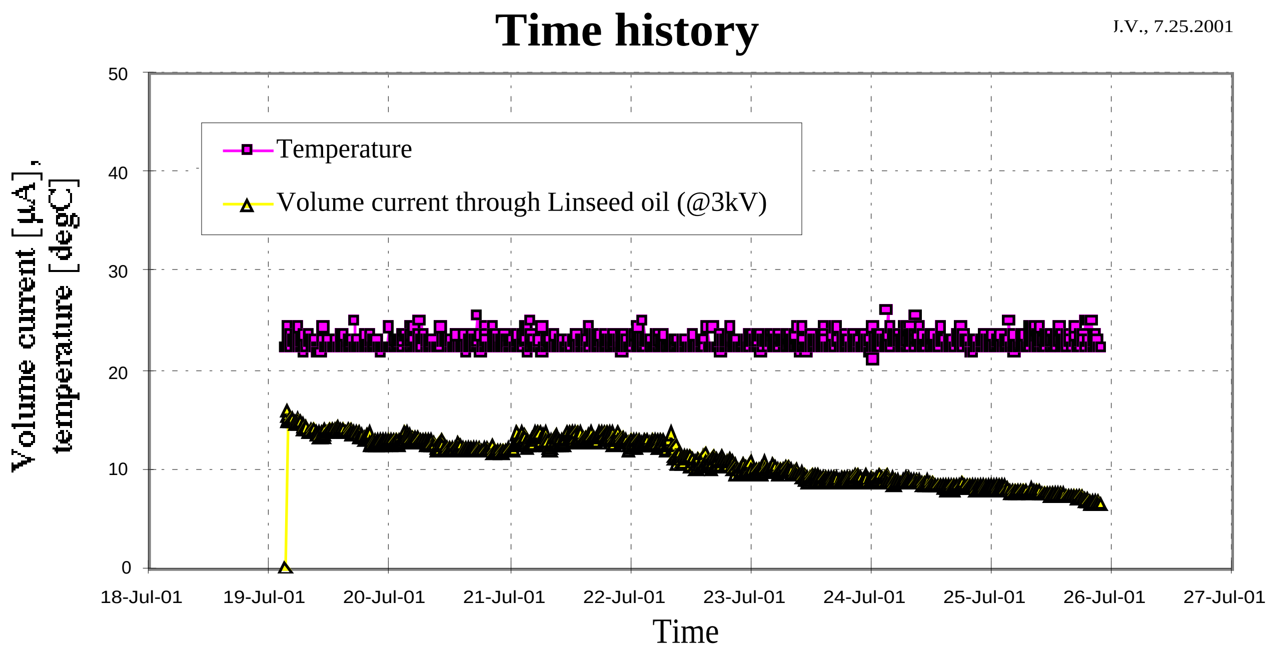
7.19.2001

An obvious next step is to make a long-term test in the same setup depicted on previous page, and show that the current continues to rise as the Linseed oil decomposition continues. However, a spark occurred after about an hour when running at 2kV. The setup could not hold the voltage at 2kV any more after that. After a separation of the electrodes, I noticed several large bubbles in the Linseed oil, which were not present initially (assuming that I did not create it when separating the electrodes). Therefore, lower the voltage to 1kV and do a long term test there. To my surprise the current was NOT increasing but it was steadily decreasing:



To remove a possibility that a large bubble is forming and thus separating the oil from the electrodes, I changed the setup. The metal part of the electrodes is just about submerged in oil, and there is actually a little gap just above the liquid to allow for any possible gas to escape. The electrolytic setup is shown on next picture:

Running a constant voltage of 3kV across ~1mm gap between electrodes with metal size of ~10mm x ~30mm created a current of ~16 µA. Again, I observe a steady decrease of the current as a function of time. Temperature of the experiment was kept at room temperature and was very constant throughout both measurements.



What to do now ?

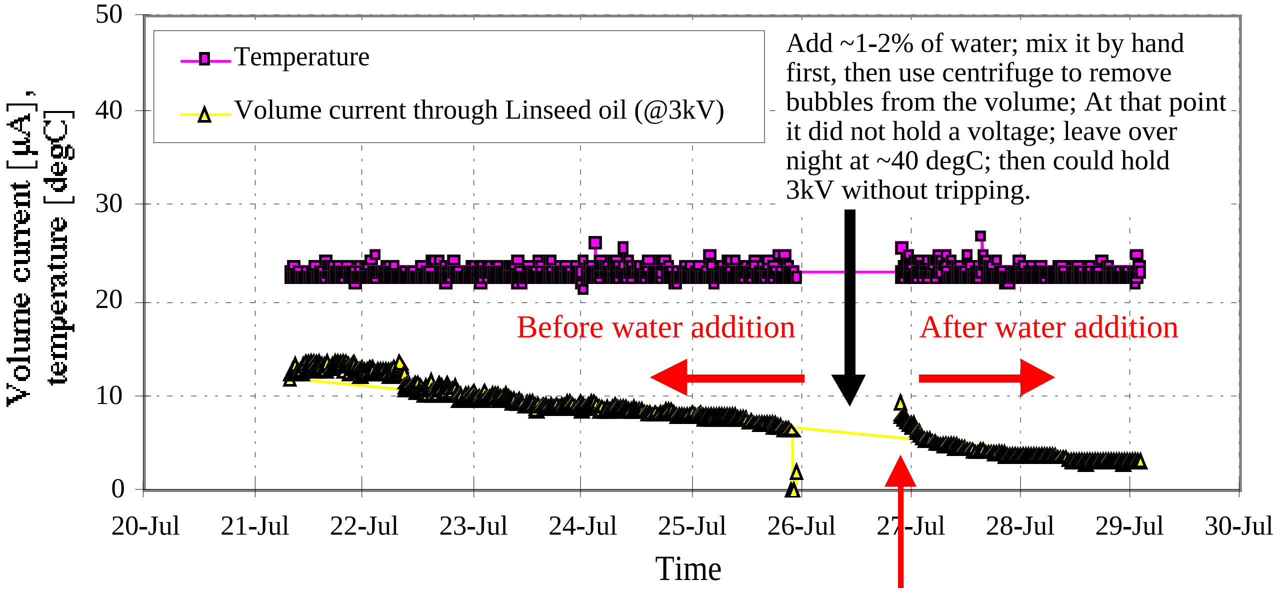
7.26.2001

The experiment is a classical electrolytic measurement, and therefore one does expect a H_2 gas formation at the cathode (a fatty acid R-COOH decomposes into H^+ and R-COO$^-$ ions). If there is water in the liquid, R-COO$^-$ will form the fatty acid again R-COOH with O_2 gas escaping at anode. R-COOH will split again into H^+ and R-COO$^-$ and the circle will continue. It is crucial to have water to keep going. However, if water is not present, R-COO$^-$ will just return the charge into the circuit and will stay in the solution (may slowly polymerize). In that case, the current would slowly becoming lower. So, the crucial test is what happens if I add a small amount of water into the Linseed oil.

The Figure on next page shows the result after adding de-ionized water in quantity of about 1-2% by volume to the Linseed oil shown on previous page. The water was clearly separated from the oil and therefore it was necessary to mix it well. After manual mixing I had too many bubbles. I decided to remove them by centrifuge. However, a high voltage test performed immediately after would show that I could not hold any voltage across a 1mm gap. Leave this mix at 40^{o}C over night. Next day, it would hold 3kV. Clearly, because of the treatment to remove the bubbles, I probably have much less than the initial amount of 1-2%. Start a long-term test, which is shown on next page. There is a portion of an old run taken previously and run after the water addition. Clearly, the current was initially high, but after a few hours it would get close to values before water addition. The slope of the current curve is the same as it was before the water addition.

J.V., 7.29.2001

Time history



Add ~1-2% of water; mix it by hand first, then use centrifuge to remove bubbles from the volume; At that point it did not hold a voltage; leave over night at ~40 degC; then could hold 3kV without tripping.

Current increases only temporarily

What is it telling us ?

7.29.2001

We can modulate the volume Linseed oil current by moisture. This is confirms my earlier results shown on pages 19, 22 and 27, and also more recent tests by Lu. By adding a small amount of water, all existing fragments R-COO, left from the previous electrolysis done up to that point, would immediately combine with added water to form the new fatty acid R-COOH molecules. These molecules would start immediately splitting into H^+ and $R\text{-}COO^-$ ions, which are responsible for the current increase. However, once the added water is consumed, the current came to the old level and slope, continuing to "live" off the existing concentration of the fatty acid molecules. The H^+ and $R\text{-}COO^-$ ions keep delivering charge, but R-COO fragment will do nothing without water (it may polymerize).

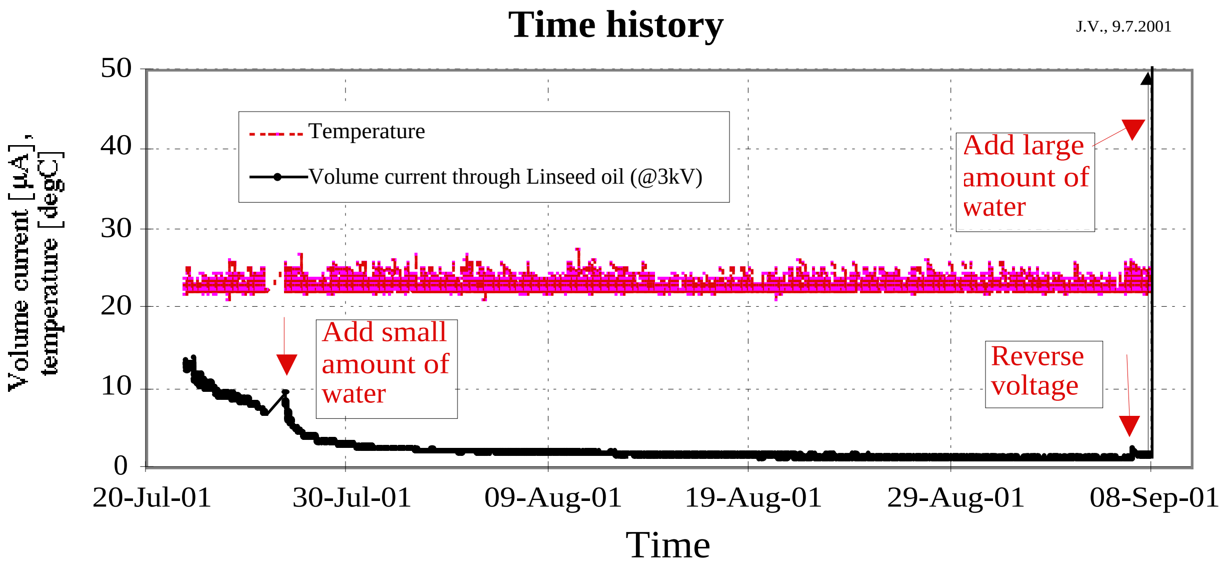
This gives a recipe what to do in the BaBar:

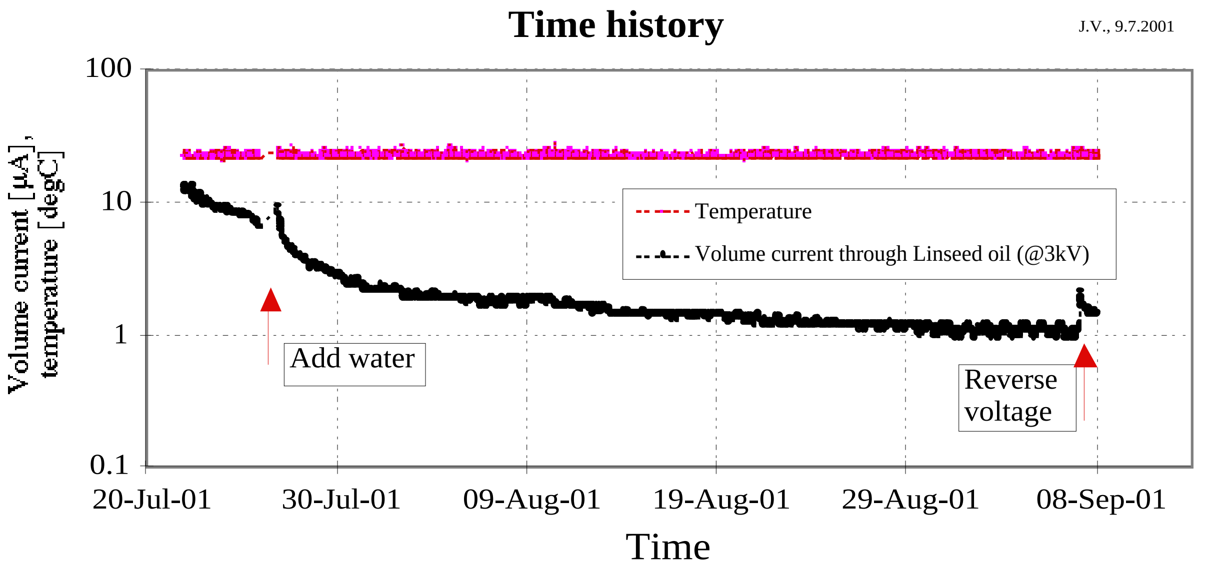
1) We should add a small silica gel cartridge into every entry of each chamber or at least close to it. Wherever possible, switch to copper tubing. In other words try to make the gas as dry as possible. While keeping voltage, the currents should slowly diminish, as shown in my electrolytic tests.
2) We should blow dry air into the detector.
3) We should keep adding a small amount of oxygen, say 5%, to help the polymerization of the Linseed oil.

Is the current going to a zero ?

8.9.2001

I was curious how low the current will go, if I leave the linseed oil as it is. The initial current in the electrolytic experiment was about 16µA. After ~2 months it came to less than ~1µA. As is shown on next graph, the current did not change much when the voltage was reversed. However, it shot up when water was added. This supports a theory that the Linseed oil current is of ionic origin, and will decay away unless we provide a new water supply.





What about if it is all other way around ?

Marcello and Rinaldo wrote recently a note[1] indicating that several BaBar RPCs, which have zero efficiency, had interesting behavior towards their life end. Both the current and the efficiency started to drop rapidly to zero together. All this happened in a few weeks. My initial comment was negative because I was always assuming that the BaBar RPCs suffer from too much moisture, which is distributed non-evenly, which in turn causes the voltage divider effects around the edges and buttons, making the efficiency holes. All this would be consistent with my lab observations indicating that the Linseed oil carries a current up to a certain charge, and then it becomes an insulator unless we add some new water.

Marcello came to my office and suggested that their observation could be still consistent with my lab observations if we assume that these particular RPCs are extremely dry, and after a certain charge the Linseed oil does not conduct the charge, and the RPC starts charging up. This would create rate dependent gap voltages, undoubtedly resulting in the efficiency loss.

So, I went to my numbers and tried to estimate if this idea is possible. The estimate is an approximation to get a feel for the problem. The calculation has three parts:

a) Estimate of the total charge needed to reduce the current by a factor of 10.
b) Estimate a fraction of the fatty acids "R-COOH" in the

---

[1] http://www.slac.stanford.edu/~mxp/slac_aug_2001.pdf

Linseed oil.

c) Estimate how long it would take to run at BaBar to deplete the Linseed oil charge and make it an insulator, assuming that there is no water coming in.

To work out the problem (a), I have numerically integrated the "current = f(time)" curves shown on pages 66 and 68 in my EXCEL spreadsheet. The result is ~9.4 Coulombs. Assuming that this current will still continue for several more weeks, I will use ~20 Coulombs in my calculation. This amount of charge is needed to completely deplete the fatty acid "R-COOH" from my Linseed oil sample in the test (if I do not add any water).

To work out the problem (b), I have to know what is the molecular weight of a molecular piece "R" in the fatty acid "R-COOH". I do not know this, however, I am told by my friend chemist, who judged it based on the fact that it is still a liquid, that it might be of the order of ~100. I know how to estimate the "COOH" fraction (45). Therefore, I will assume that 1 mole of R-COOH is about ~150 grams. Knowing the volume of the sample in my test, and knowing the density of the Linseed oil, I can now estimate the fraction of "R-COOH" in the Linseed oil sample using the following calculation:

$$100*((20\ C/96500\ C)*150g)/(3.14*(3.8cm\ /2)^2\ *1cm\ *\ 0.938g/cm^3) \sim 0.29\%$$

To work out the problem (c), I assume that I am dealing with a BaBar RPC with these parameters (needless to say that these are hypothetical assumptions):

- The RPC is 100 cm x 100 cm in size,

- It draws a current of ~50μA,
- The Linseed oil thickness is ~10mils thick,
- The current is drawn uniformly
- Use results of the calculation in problems (a)&(b).

My estimate indicates that after 3-4 months of operation under such condition will completely deplete the fatty acid “R-COOH” from the Linseed oil, if there is no new water coming. The Linseed oil would become non-conducting, resulting in complicated response to a rate loading, i.e., charging. The calculation goes as follows:

100%~
100*{[3.5months*30days*24hrs*60min*60sec*(50μA*10^{-6})C]/96500C}
150g /[(0.29/100)(100cm*100cm)*(10mils*10^{-3}*2.54)*0.938g/cm^3]

Conclusion:

It is a certainly useful to test this hypothesis by adding a small amount of water in the gas stream of these particular “so called dry” RPCs, which Marcello and Rinaldo discovered.

I still think that many other RPCs suffer from too much water, and therefore the complementary part of the theory is also right. For these “so called wet” RPCs, we would have to remove water.

Isn’t life interesting….

Decomposition of the Bakelite ?

What is the Bakelite?

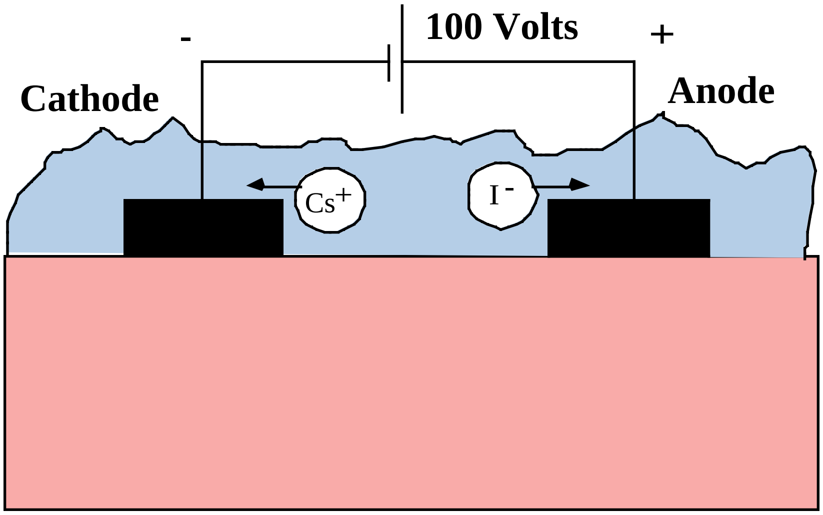
Looking into my chemistry book I read that it is the phenol-formaldehyde polymer, one of the oldest known (discovered by Bayer at 1872). The theory of this particular polymer formation is rather complicated, and I will not attempt to reproduce it here. Instead, I called again my friend J. Maly, a retired chemist, to help me to judge it electrically. He told me that this polymer is highly cross-linked and rather stable and should be almost non-conducting. Its conductivity results from some phenol impurities left in the structure. Current through the Bakelite is made by a motion of H^+ and negative ions, which is similar to the Linseed oil. There is not a current in a form of electrons, as is normal in metals !! However, contrary to the Linseed oil, the Bakelite polymer’s resistance should be stable even at large currents, i.e., there is not going to be a relative buildup of the phenol molecules as the charge is accumulated. This actually agrees with my observation that the Bakelite resistance is stable by performing long term temperature cycling tests while running a current through its volume (see pages 14-27).

Electrolytic processes in insulators

- Current in Glass, Alkali Halides (CsI), Bakelite and the Linseed oil is of an ionic origin.

- Electrolytic process in CsI

(J. Va'vra et al., NIM, A387(1997)154; and my talk at DESY Aging Workshop, 2001)



- The current in alkali halides is of an ionic origin, i.e., for example in the CsI, it is carried by the Cs^+ and I^- ions.

- This may be a mechanism to alter the resistance of CsI photocathode, and thus cause the Malter effect.
  - Iodine is very resistive $\rho \sim 1.3\times10^{9}\ \Omega.cm$
  - Cesium is very conductive $\rho \sim 2\times10^{-5}\ \Omega.cm$

- If the current flows in one direction, one ends up with a non-uniform resistance distribution on the surface.

- If we reverse the current direction and run for similar total charge, we will make the resistance distribution more uniform.

- Electrolytic process in glass

(G. Cicognani, P. Convert, A. Oed and J. Pannetier, ILL, Grenoble, France)

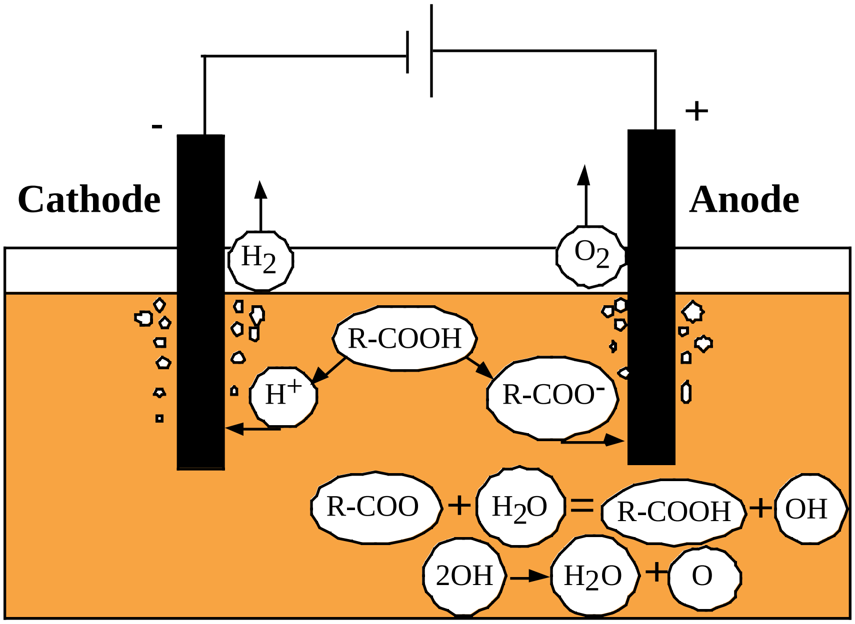
- Long-term instability of the ionic glasses:
  The conductivity in standard glasses is ensured by the movement of the alkaline ions, and for that reason they are called ionic conducting glasses. Typical resistance of these materials is 10^{12}-10^{16} Ωcm. However, during the long-term operation, the alkali ions migrate towards the cathode by the electric field and leave a depleted layer close to anode. This leads to a permanent increase of the surface resistance. The ionic glasses therefore suffer from long-term instabilIty.

Note:
From BaBar DIRC experience we know that alkali ions can leave the glass by "vacuum effect" of ultra pure water (Na leaching).

- Electrolytic process in Linseed oil

Linseed oil: "It is a mixture of the glycerides of linolenic, linoleic, oleic, stearic, and palmitic acids with high degree of unsaturation of its fatty acid radicals." It is pressed from seeds.

Potential trouble with the Linseed oil:
A current in "Fatty acids" is modulated by a presence of water.
(Organic Fatty acids have a form: R-COOH)

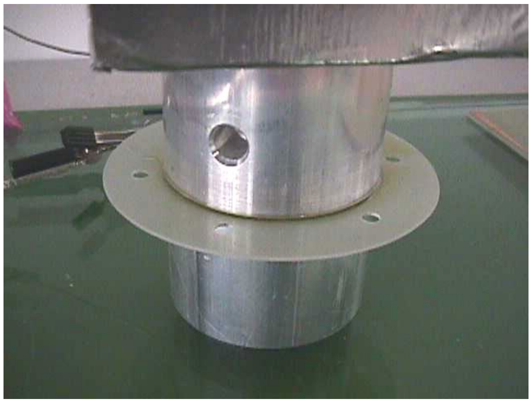


1) If there is no water then $R\text{-}COO^-$ just shares a charge:
=> The current slowly decays as R-COOH is consumed.

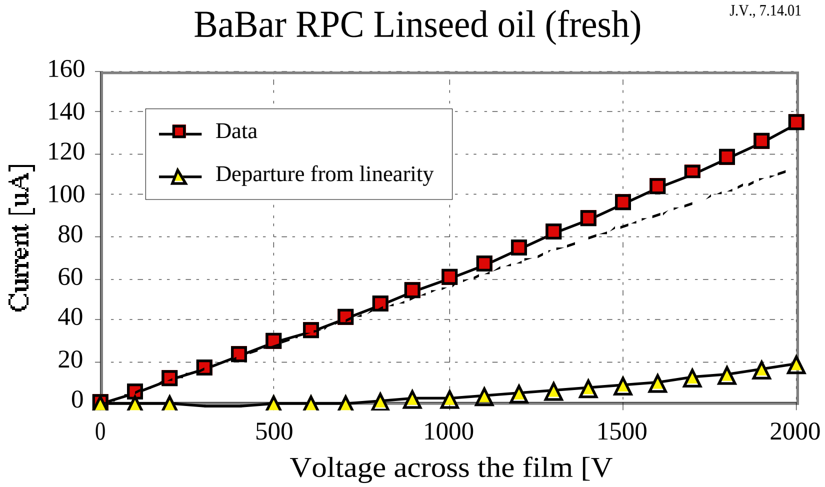
2) If there is water then $R\text{-}COO^-$ will share a charge and convert back to the fatty acid R-COOH.
=> The current will continue.

- Source of water: Bakelite, gas tubing, etc.

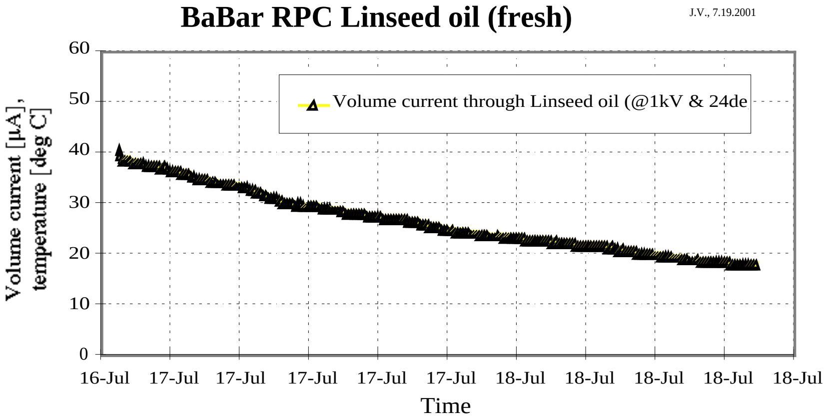
- Test #1: The Linseed oil current is non-linear:



The short-term test proves a non-linear dependency of I = f(V):

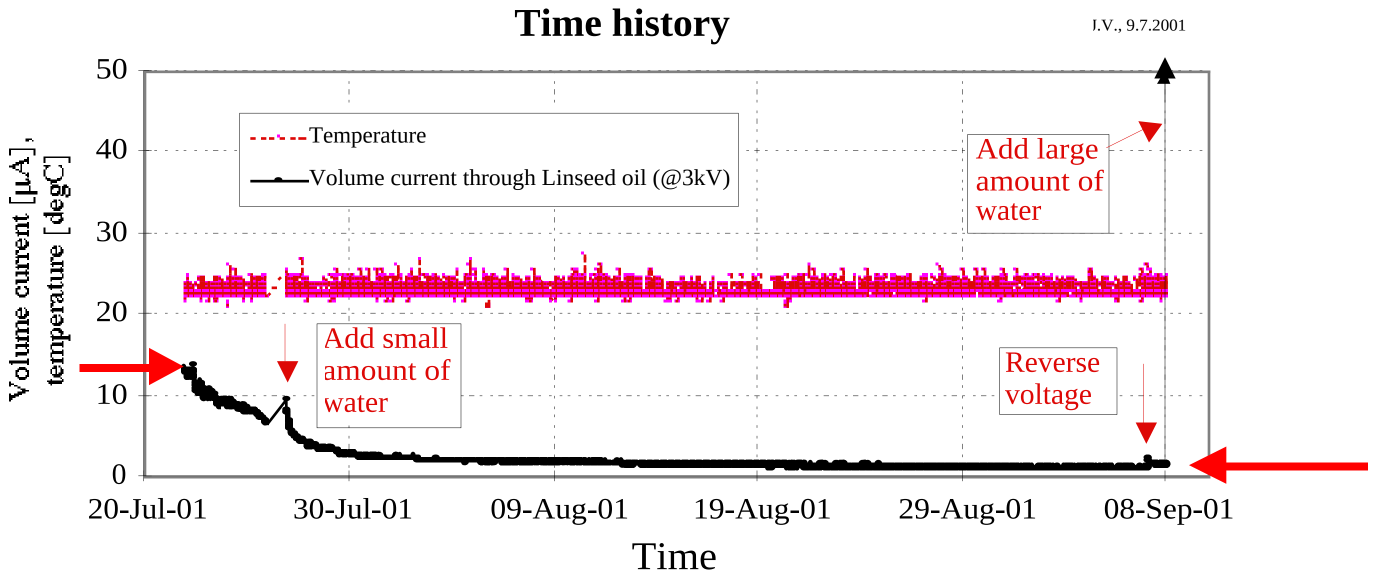


However, the long-term test shows that the current decays away:



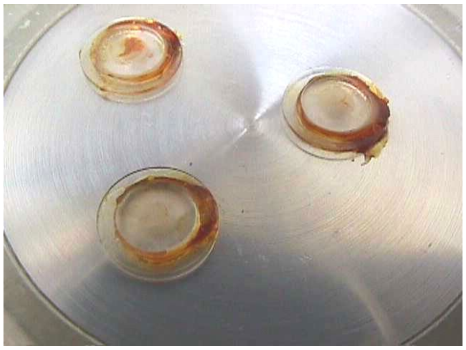
- The first indication that oil does not behave like a simple resistor

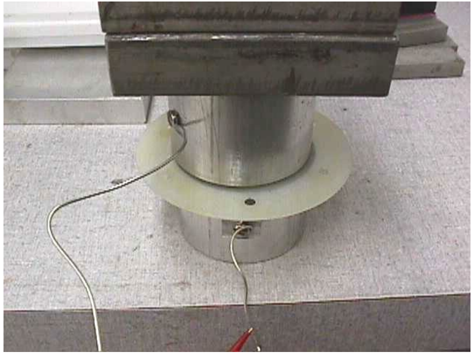
- Test #2: The Linseed oil current decays if we do not add water:



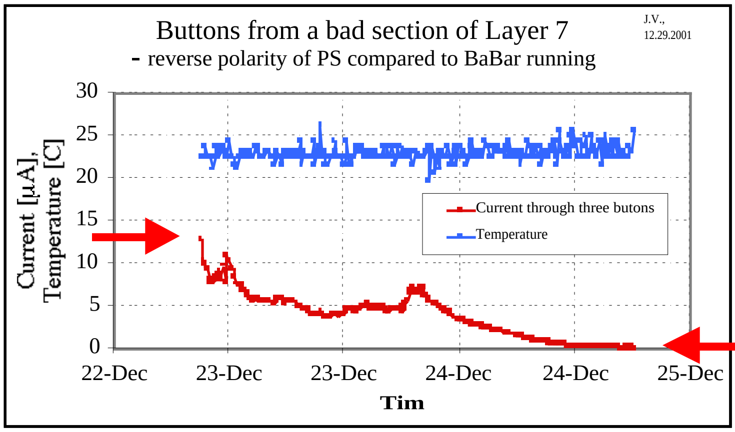
- Total charge in this experiment: ~11.4 Coulombs.
- Adding water sharply increases the current.
- Reversal of the voltage does not return the current to the original high value !!
- There is an evidence of an accumulation of some substance on the surface of the Linseed oil (probably related to R-COO). This substance hardens after a few months. A fresh Linseed oil does not do this.

- Test #3: Curing of the gui brown Linseed oil on the buttons from a bad region of Layer 7:





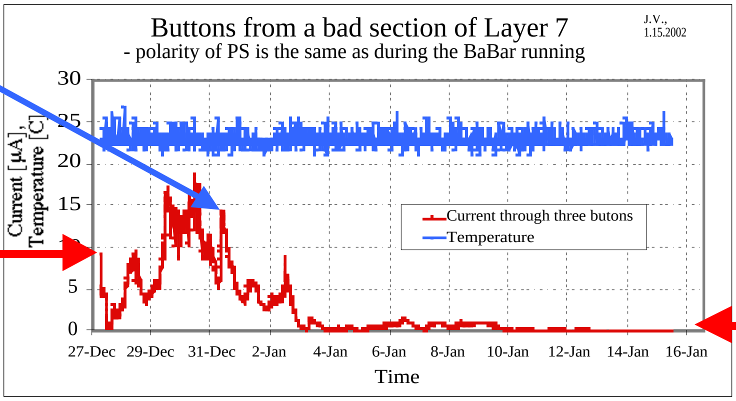
1) Reverse polarity during curing (the 1-st three buttons):



Total charge:
~0.2 C/button

2) Do not reverse polarity during curing (the 2-nd three buttons):

Peaks due to daily peaks/dips in humidity (61-74%) because of very raining period



Total charge:
~1.5 C/button

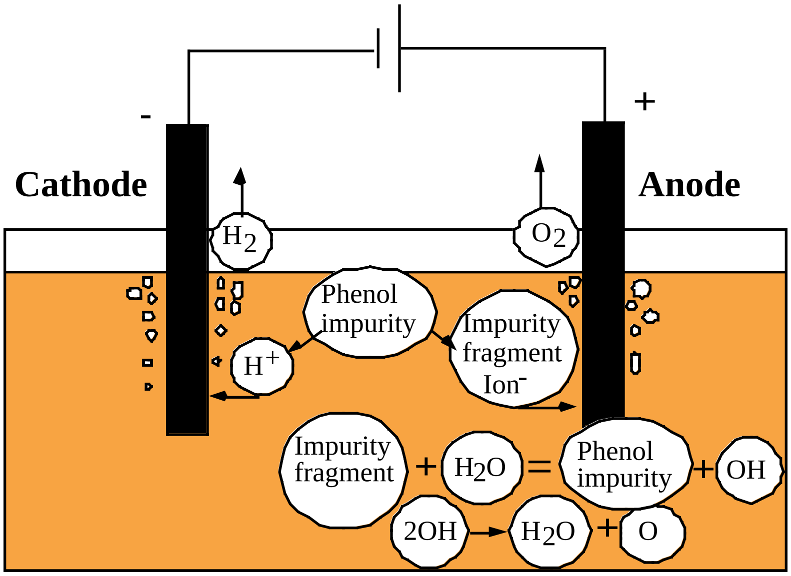
- Is this real ? If yes, it would support the electrolytic model.
- Results are affected by the humidity due to poor wet weather conditions during the test. Current decreased by a factor of >400.
- Develop a hard film on the electrode difficult to scratch away.

- Electrolytic process in Bakelite

Bakelite: "It is the phenol-formaldehyde polymer, almost non-conducting. Its conductivity comes from the phenol impurities"

Potential trouble with the Bakelite:

A current in Bakelite is modulated by a presence of water, and a level of Phenol impurities. Its volume resistance may not be uniform !!!

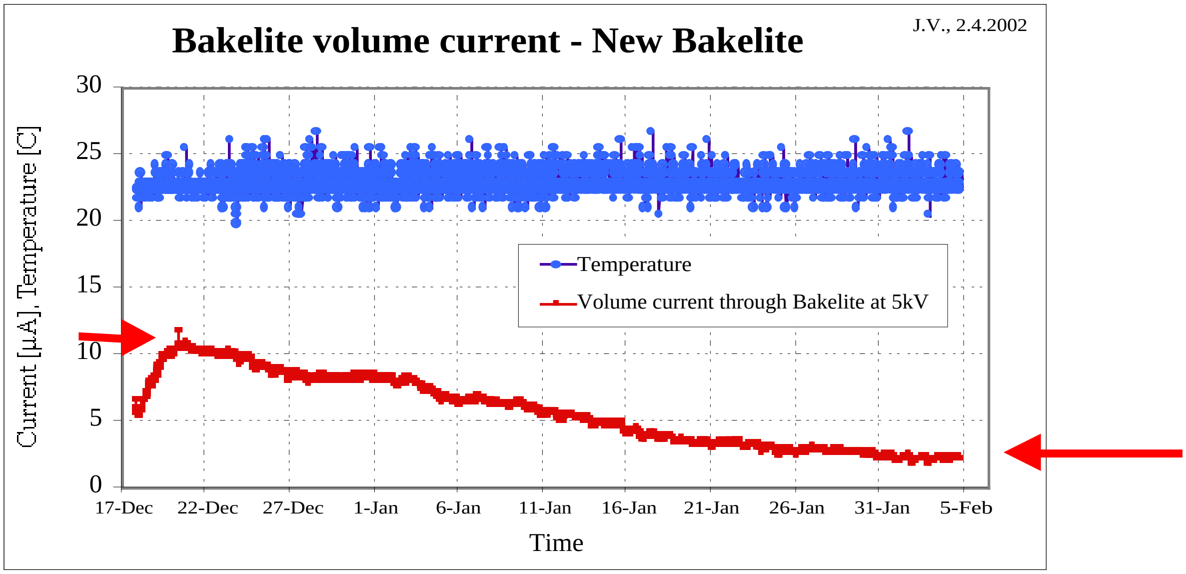


- Presently, I do not know the molecular structure of the "phenol impurity."

- If this model is right, the volume current through Bakelite should diminish if we do not add water.

If the electrolytic model applies to the Bakelite, its long-term current capability must stop as we consume ions.

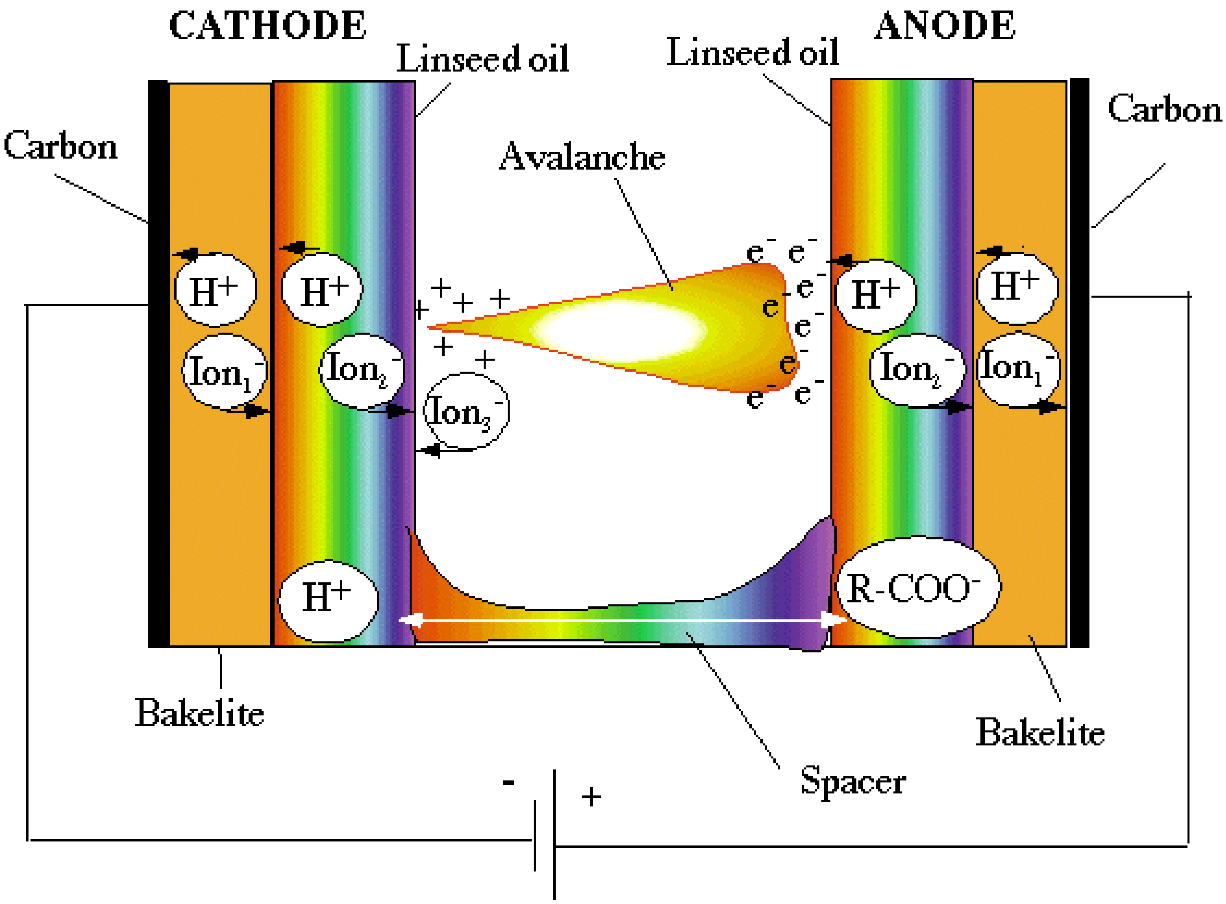
- Bakelite from the new BaBar RPC chamber (LHC equivalent).



- Total charge in this experiment: ~20.7 Coulombs (at 5kV).
- Total charge density is: ~0.63 Coulombs/cm^2 (test continues).

- I predict that it will take ~1 Coulombs/cm^2 to increase the Bakelite resistance by a factor of 10 (this is in air !!!).

- Ionic model of BaBar RPC & remediation:

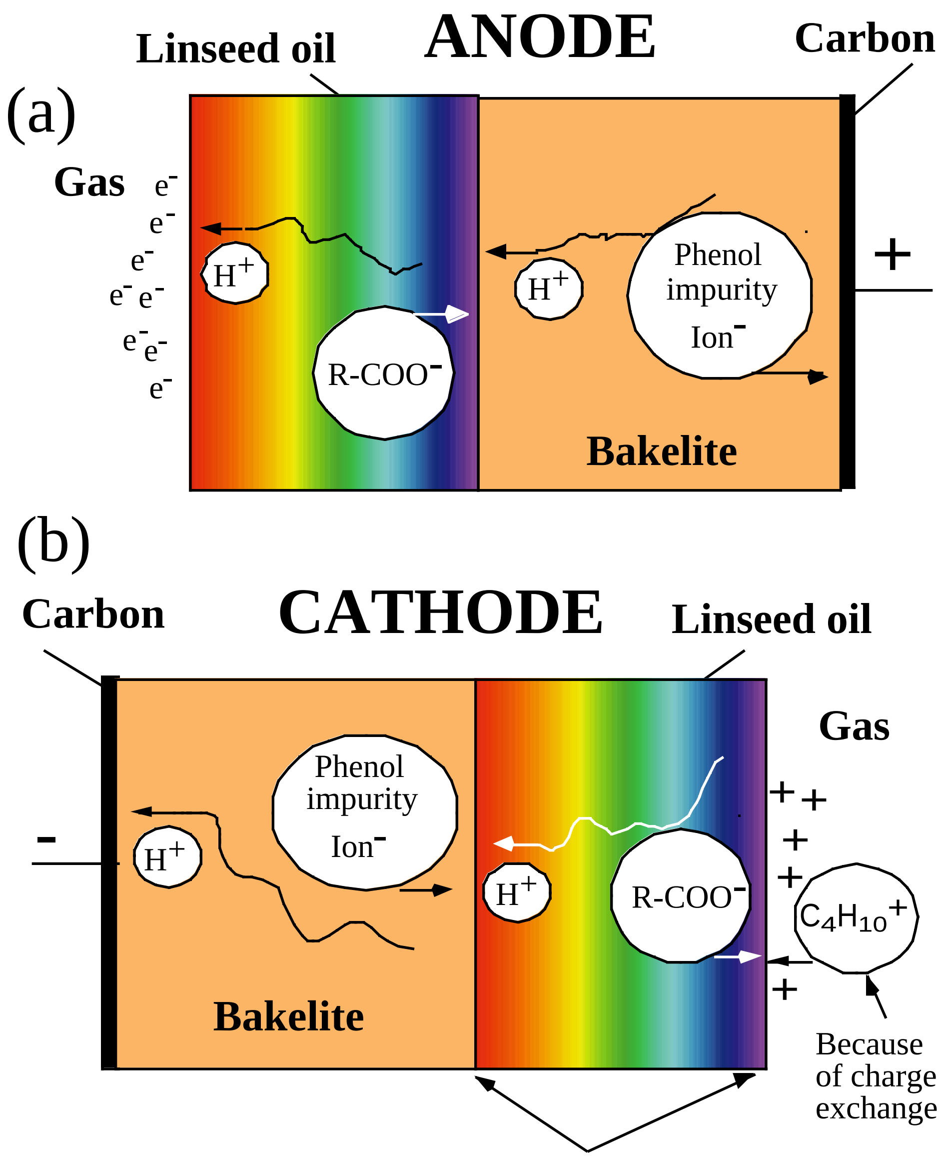


- There are several ions involved in the current flow. The charge exchange has to work to prevent the charging at various boundaries. If a resistivity buildup occurs at some boundary, there may be a charging effect.

- Within the context of the electrolytic model, water modulates the conductivity of both Linseed oil and the Bakelite.

- During the Marcelo's remediation procedure by running RPCs in pure argon, apparently some portion of the current goes through the buttons. This is what fixes the RPC, according to this presentation.

1. BaBar RPC – normal operation



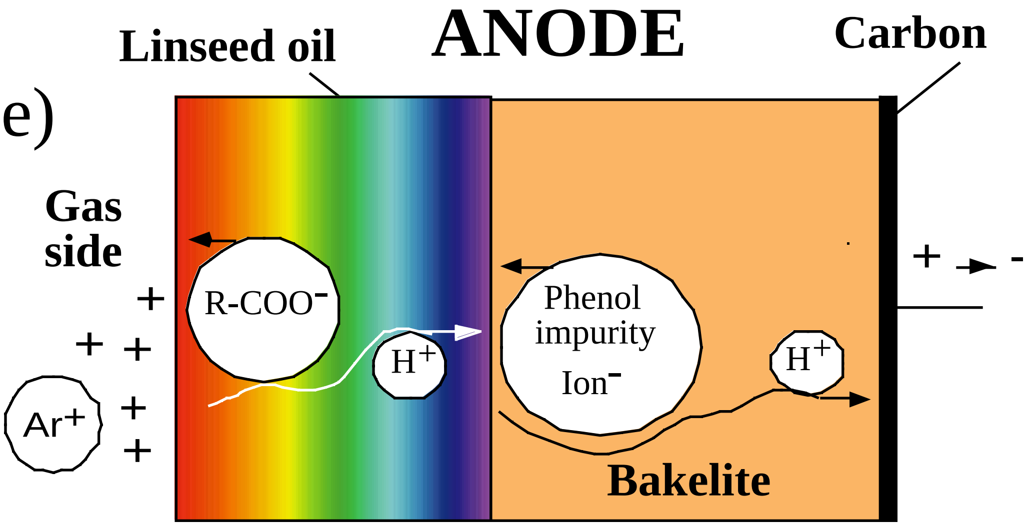
EXPECT BUILD UP OF "R-COO" AND "PHENOL IMPURITY" FILMS AT VARIOUS BOUNDARIES

- There is a build up of molecular layers at various boundaries; <u>this applies to the Linseed oil-covered buttons and side spacers !!!</u>

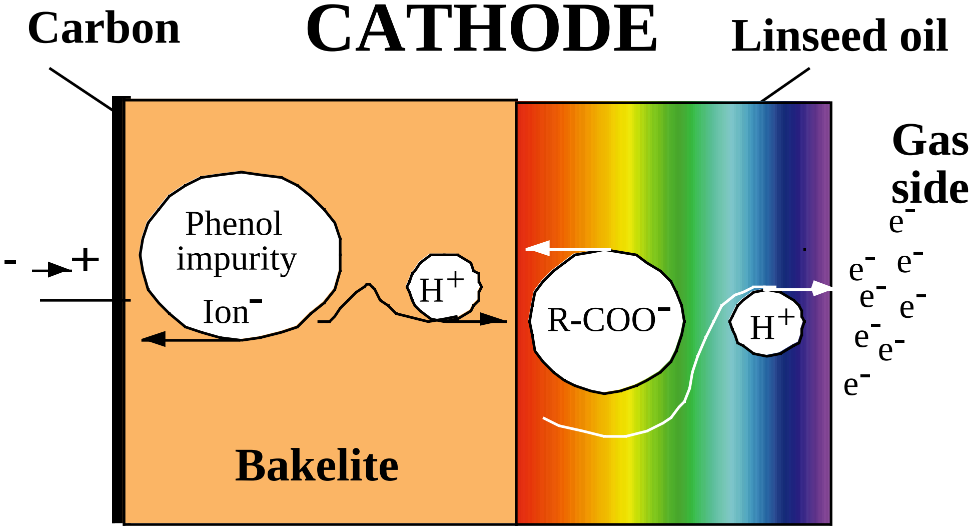
- This process may cause a highly non-uniform distribution of resistance throughout the electrodes depending where the currents wants to go.

2. Ar-treatment at reversed voltage

(e)



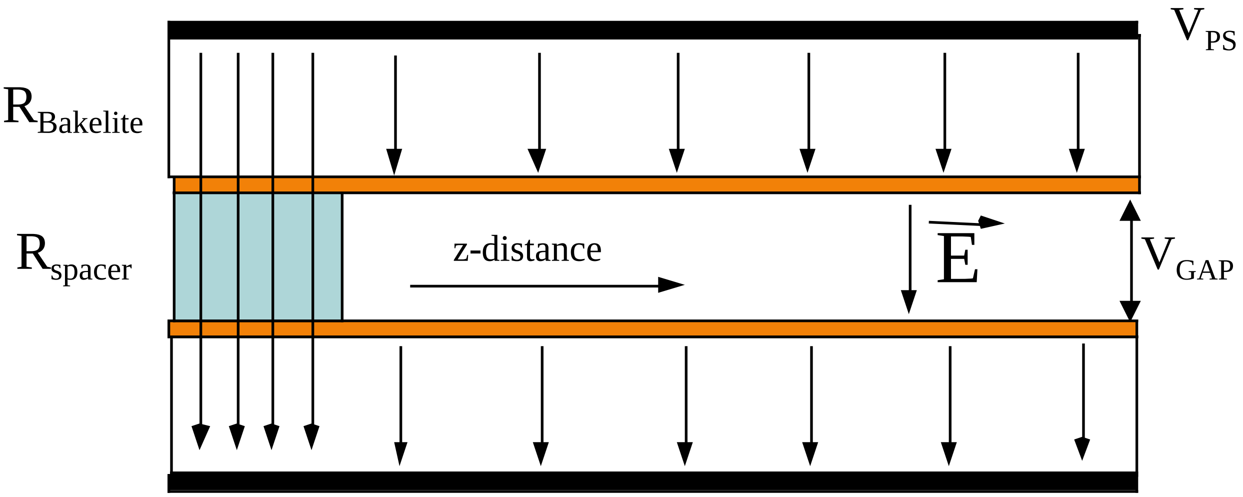
(f)



- Large currents follow the path of the lowest resistance.

- The "R-COO" and "Phenol impurity" films are produced in areas where they were missing up to this point; a kind of "uniformity" producing effect. Including the Linseed oil-covered buttons and side spacers !!!

1) Good region of Layer 7:



$$\mathbf{V_{GAP} = V_{PS} / (1+ 2\, R_{Bakelite}/R_{Lexan\ spacer}) \sim V_{PS}}$$

$$\mathbf{if\ \ R_{Lexan\ spacer} >> R_{Bakelite}}$$

In this case, the chamber will work OK:

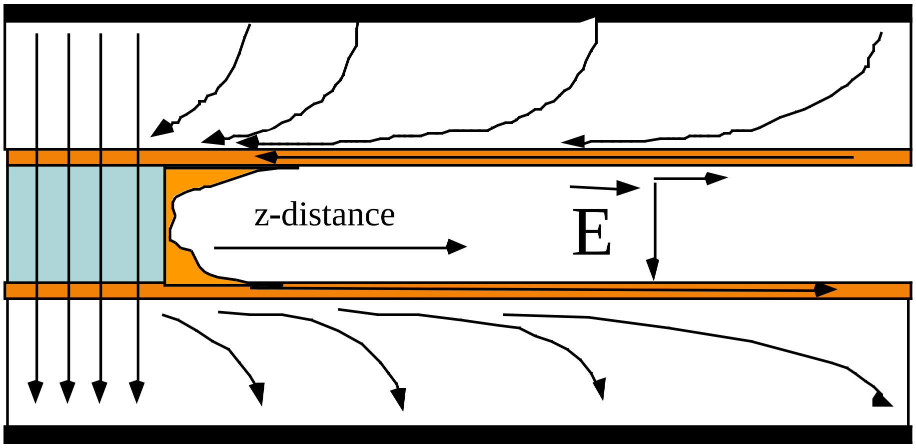
$R_{Bakelite} = \rho_V\, (t_{gap} / Area) \sim 2.5 \times 10^{11}\ \Omega.cm \times (0.2cm/100cm^2) \sim 5\times10^8\ \Omega$

$R_{Lexan\ button} = \rho_V\, (t_{gap} / Area) \sim \mathbf{1.7\times10^{11}\ \Omega.cm} \times (0.2cm/0.1cm^2) \sim 3.4 \times 10^{11}\ \Omega$

$$\Rightarrow \mathbf{V_{GAP} = V_{PS} / (1+2*5*10^8 / 3.4\times10^{11}) \sim V_{PS} * 0.99}$$

2) Bad region of Layer 7:

Buttons are shorted by a "gui" Linseed oil:



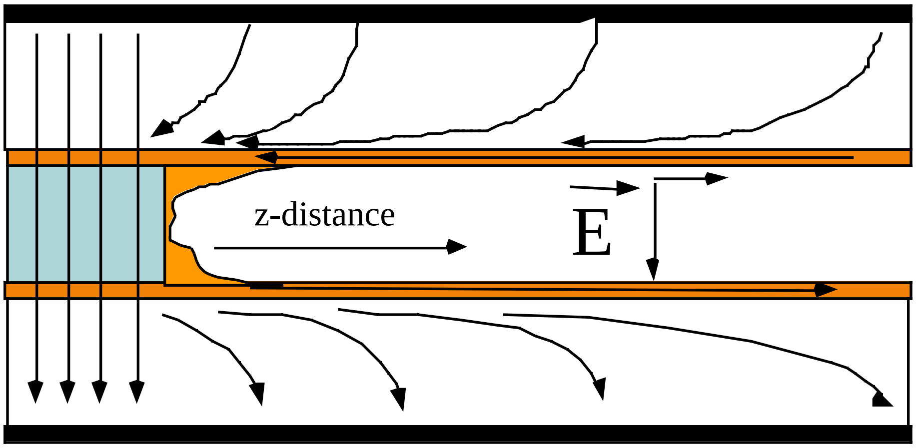
A button is shorted by the "brown gui Linseed oil blob":

$R_{Bakelite} = \rho_V\ (t_{gap}\ /\ Area) \sim 2.5 \times 10^{11}\ \Omega.cm \times (0.2cm/100cm^2) \sim 5 \times 10^8\ \Omega$
$R_{Linseed\ oil\ blob} = \rho_V\ (t_{gap}\ /\ Area) \sim \mathbf{2.5*10^8\ \Omega.cm} \times (0.2cm/0.1cm^2) \sim 5 \times 10^8\ \Omega$

$$=> \mathbf{V_{GAP} = V_{PS} / (1+2*5*10^8 / 5x10^8) \sim V_{PS} * 0.33}\quad \mathbf{!!!!!!!!}$$

=> The chamber may not work with such buttons.

3) Once we get to such low button resistance range, a factor of 2-3 change of Bakelite resistance does indeed matter:



A button is shorted by the "brown gui Linseed oil blob" and the Bakelite resistance changed by a factor of 3x:

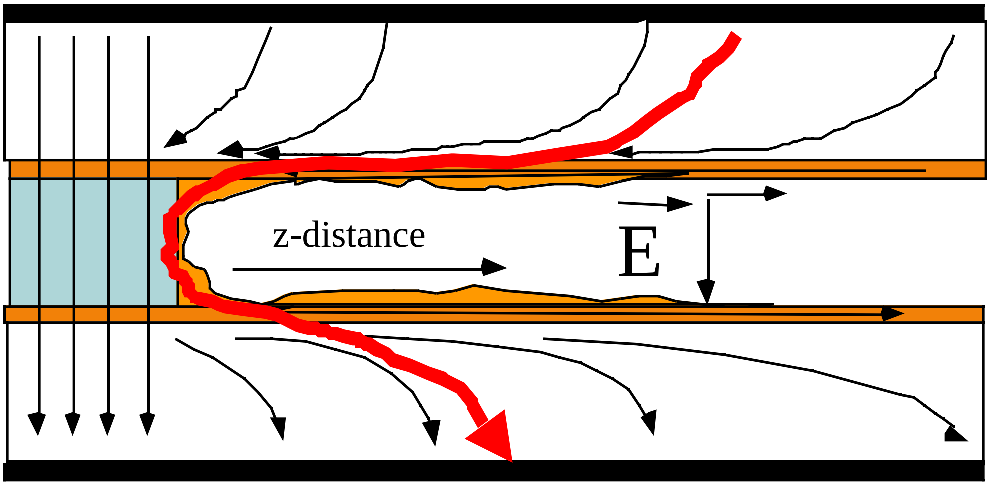
$R_{Bakelite} = \rho_V\,(t_{gap}\,/\,Area) \sim \mathbf{3\ x}\ 2.5\ x\ 10^{11}\ \Omega.cm\ x\ (0.2cm/100cm^2) \sim 1.5x10^9\ \Omega$

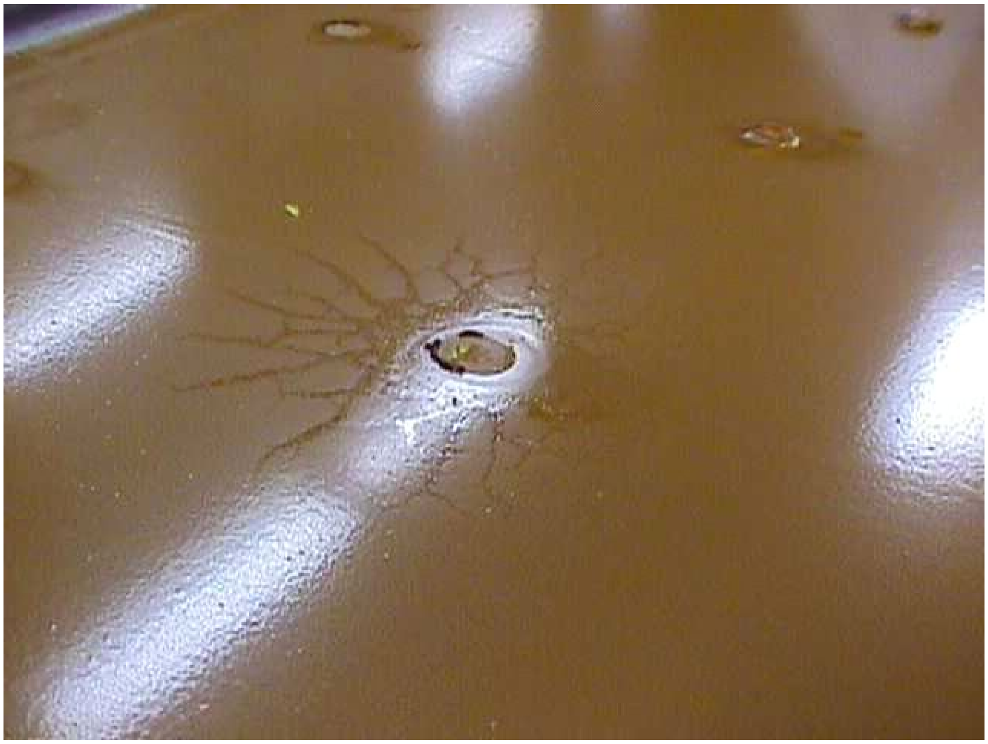
$R_{Linseed\ oil\ blob} = \rho_V\,(t_{gap}\,/\,Area) \sim \mathbf{2.5{*}10^8\ \Omega.cm}\ x\ (0.2cm/0.1cm^2) \sim 5\ x\ 10^8\ \Omega$

$\Rightarrow \mathbf{V_{GAP} = V_{PS}\,/\,(1+3{*}2{*}5{*}10^8\,/\,5x10^8) \sim V_{PS}{*}\ 0.14}$ **!!!!!!!!**

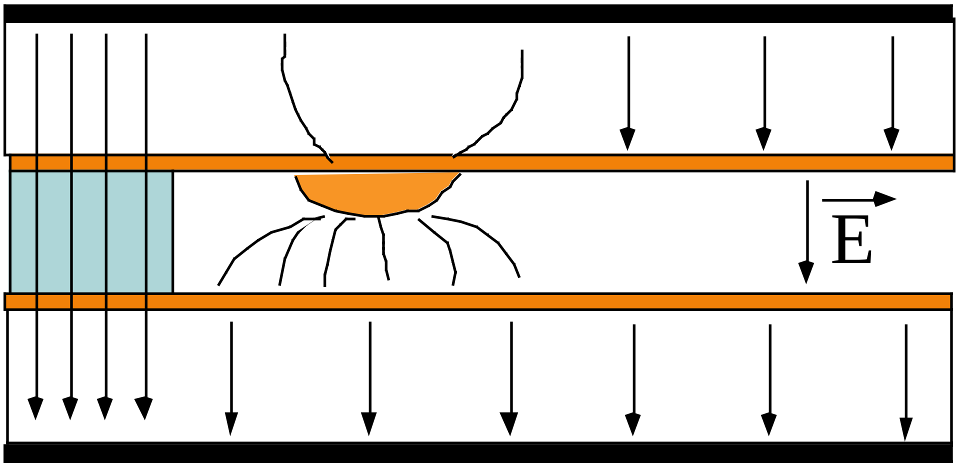
It would appear that if one wants to cure a good fraction of the BaBar RPC problems, one should increase the resistance of the Linseed oil-covered buttons.

4) However, things are more complicated because it is a 3-D problem, involving the surface resistance of the Linseed oil and volume resistance of the Bakelite:

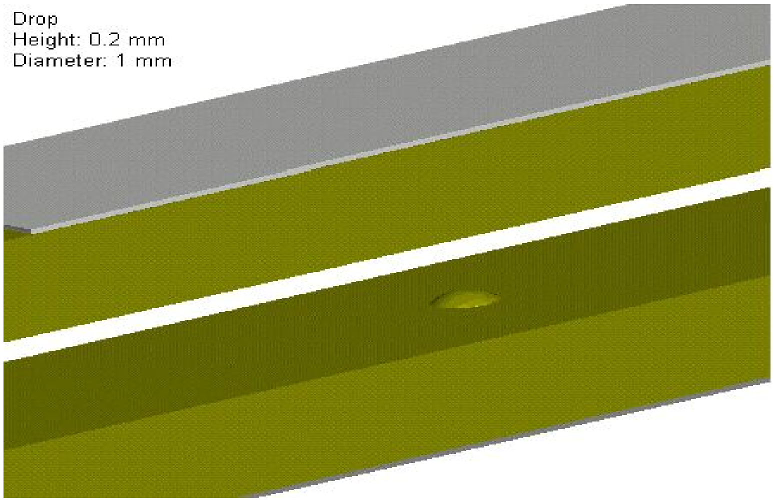


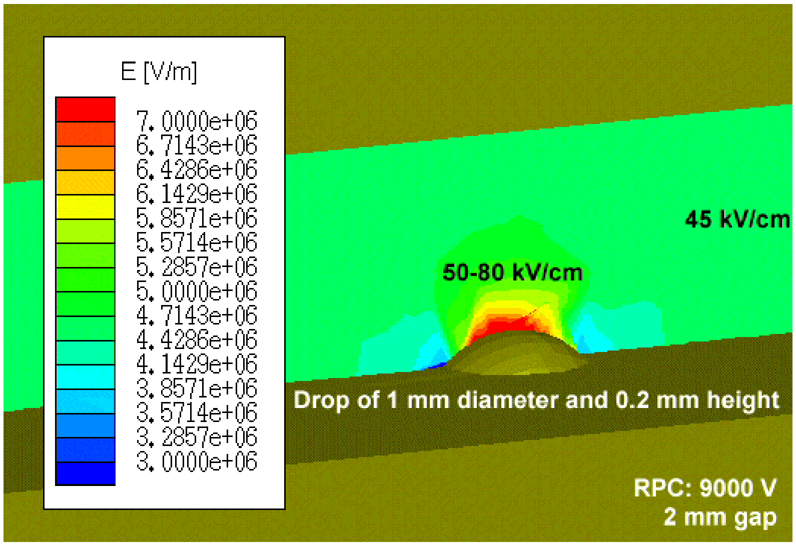


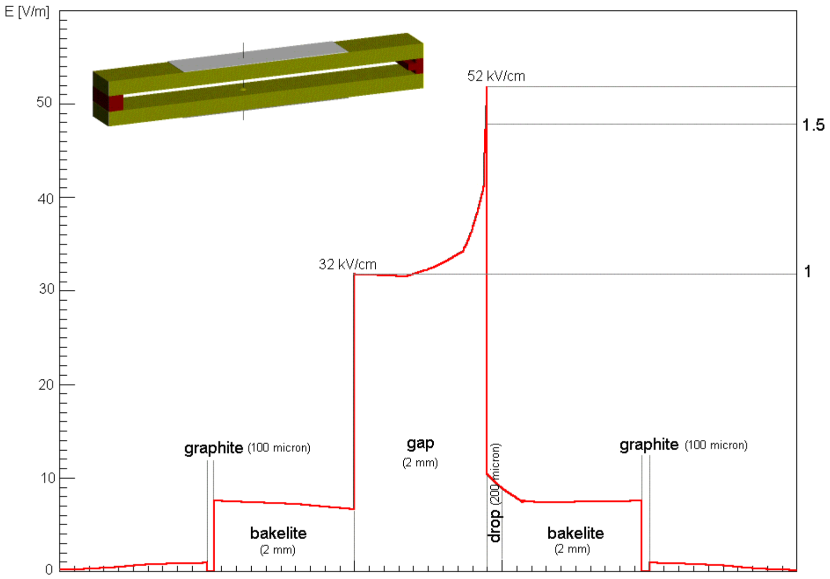
5) For example, an oil droplet creates a large distortion of the electric field, which can cause a permanent breakdown and local currents:



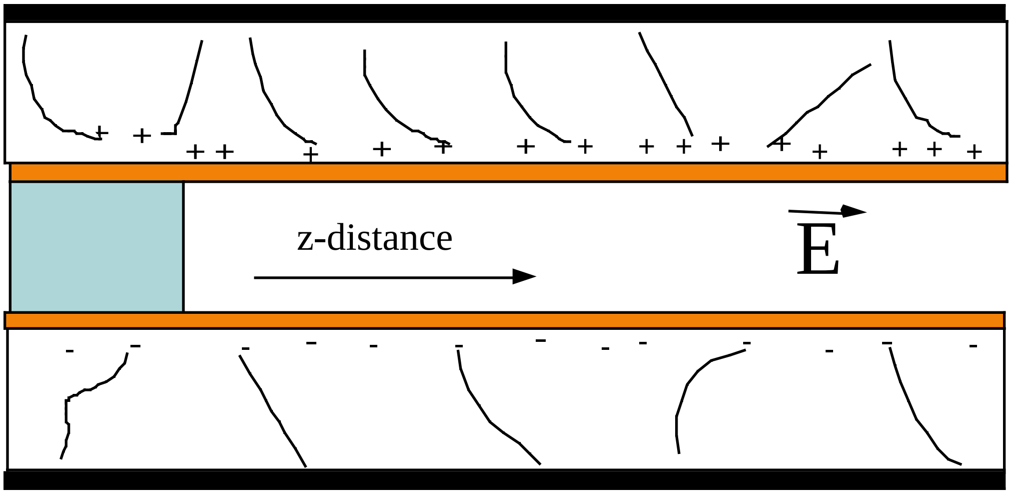
Calculation by A. Sharma:



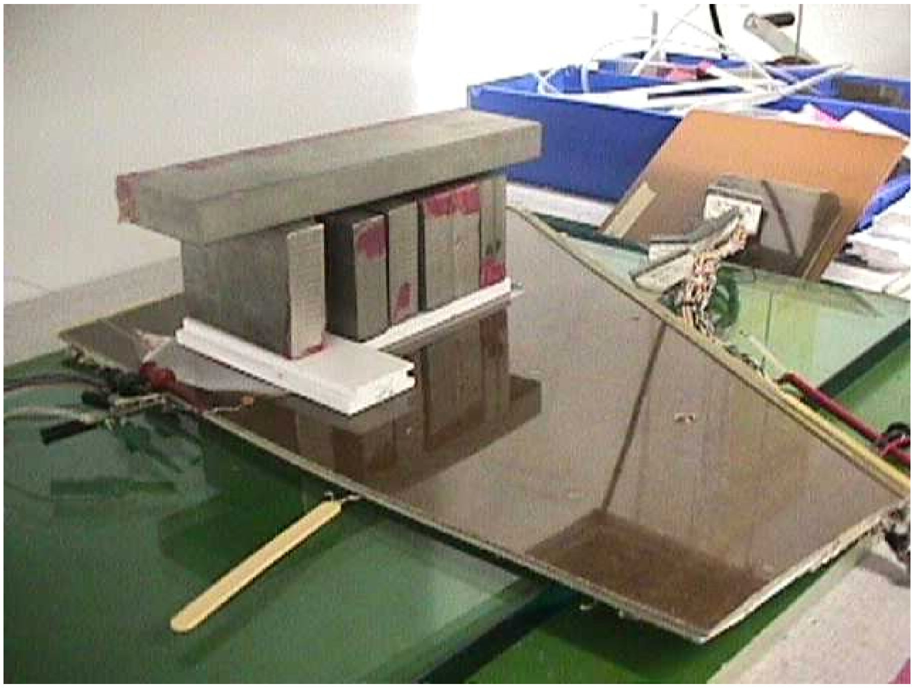




6) Can spacers or Bakelite electrodes become perfect insulators after a certain charge dose ?

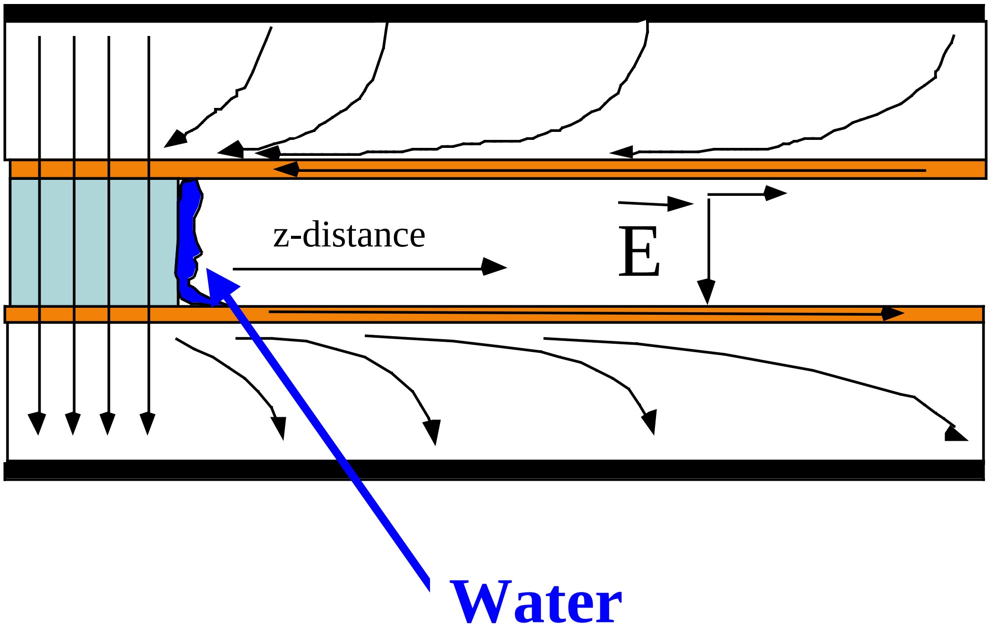


Electrodes from the brand new BaBar RPC chamber:



- If the answer is yes, how do we make it conducting again ?
  For example, by adding a small amount of water ?

7) However, water can cause problems also:



- We must not forget about the simple surface breakdowns:

  Example:
  F. Sauli – GEM cannot take too much water because of the surface breakdown problems (~a few hundred ppm). The GEM gradients are typically >80kV/cm, the RPC gradients are typically <40kV/cm

- We also must not forget that water may affect the resistance of the Linseed oil blob around a button or side spacer. This is another reason why one has to be careful adding too much water.

Conclusions:

- Primary events, which caused difficulties of the BaBar RPCs:
  a) Improper draining of oil, which got trapped by the buttons,
  b) High temperature allowed the oil to leak out,
  c) High voltage operation while the oil was still wet,
  c) Allowing operation at high current in a freon gas.

- The electrolytic model of the ionic current conductivity in the Linseed oil and the Bakelite were proposed. In this model, the electrical conductivity of the Linseed oil and Bakelite is modulated by amount of water. The primary source of water is Bakelite, which is very hydroscopic. Within the context of the electrolytic model, if no water is present, a buildup of R-COO molecules will create non-conducting films impeding the charge flow.

- Inefficiency regions in the Layer 7 are primarily caused by the dark brown "gui" Linseed oil blobs around the buttons, which are "shorting" the gap, together with the excess of oil in the active region (assumption only at this point). These blobs have very small volume resistance, much lower than the "fresh" Italian Linseed oil. This resistence is consistent with the resistance of the brown stuff taken from the very bottom of the Layer 7. It is not understood why the dark brown "gui" Linseed oil has such a low resistance at present ($\rho_V \sim 2.5 \times 10^8\ \Omega$.cm). It is possibly either due to some chemical reaction with a Freon molecule or due to porosity of the stuff due to a release of the gases during the electrolysis.

- In a chamber where the buttons are either shorted or near-shorted, changes in the Bakelite volume resistance by a factor of 2-3 do matter. Such change can occur either by drying the Bakelite surfaces or by a huge charge of about ~0.5 C/cm^2.

- The curing of the shorts was attempted by sending a large current through the buttons. The current diminishes (a factor of >400) after a certain charge (0.2-1.5C/button), independently of the polarity of the current. This would be consistent with the electrolytic model. There is evidence that a hard film developed on the aluminum electrode during the test, which is difficult to scratch away. Almost like cooking without a Teflon surface.

- The "curing current" seems to be very sensitive to air humidity. Again, this would be consistent with the electrolytic model.

- No stalagmites were observed in the active region of the "bad" section of the BaBar RPC Layer 7. By stalagmites I mean shorts created by a force of the electric field acting on liquidy Linseed oil (according to Lu's tests).

- If the Lexan buttons or Bakelite would become a perfect insulators, the chamber could charge up and stop working. A solution to add water has to be done very carefully to avoid the problems mentioned above.

- The Marcello's "Argon curing treatment" is a convenient way to introduce the uniform current throughout the chamber. Some portion of this current goes through the buttons, and this portion does the fixing of the bad RPCs. Its effect is to increase the chamber overall button resistance, and also the uniformity of the Bakelite resistance. It seems to me that the polarity does not matter.

- To explain the problems of the BaBar Layer 18, one clearly needs more studies. However, a possible explanation is related to the changes of the Bakelite/Linseed oil resistance under the influence of very large charge doses, and influence dry gas creating a very thin water-free layer. We should remove this chamber very carefully from BaBar this summer to allow this test, meaning not to allow too much exposure to water.
- More work is needed.

BaBar collaboration meeting – February 2002:

Content

1. **Update on the "curing" of the buttons from the SLAC Test Chamber and comparing it with the same measurement from the Layer 7.**

   Note:

   a) SLAC test chamber was heated and then subject to the Marcello's Argon remediation procedure. The efficiency increased from ~5% to ~30%. Therefore it was not surprising to find out that the resistance of these buttons was much higher than what was found in bad section of Layer 7.

   b) Compare it with to the Layer 7, which was never remediated. In this case the buttons, taken from a "bad" section of Layer 7, had a thick coat of the brown Linseed oil and had very low "starting" resistance. After passing ~0.5-1.5 C/button, the button resistance increased by at least a factor of >100. This is enough to remove a short in the chamber caused by the coated button. This supports a theory that during the Marcello's remediation procedure a portion of the current passes through the Linseed around the button and makes it more resistive (see pages 90-91).

2. Update on the Bakelite volume resistance = f(charge).

   - Observe what looks like a threshold effect of the resistance increase. (following the measurement shown on page 91).

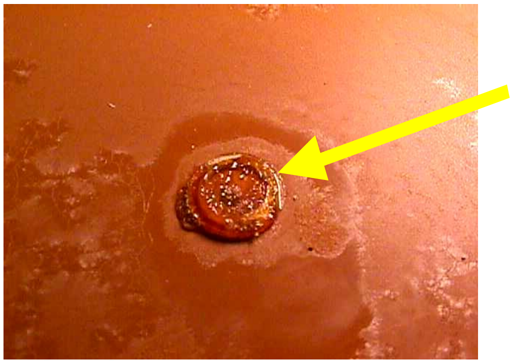
SLAC test chamber was subject to:

a) heat cycle during tests at SLAC, and then to

b) Marcello’s remediation procedure, during which: ε ~5% → ~30%.

Button #1:

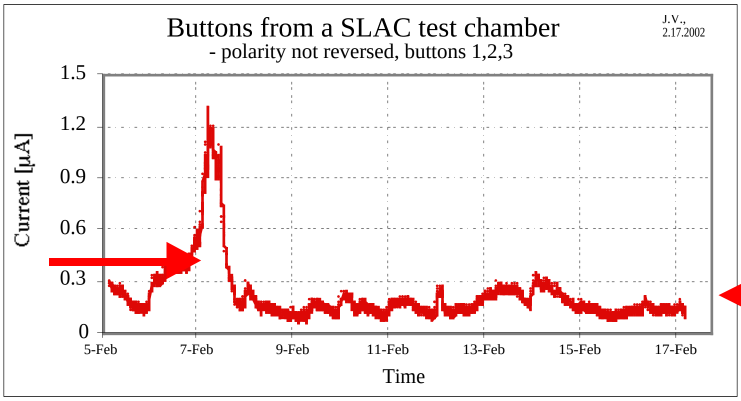
Button #2:



One sees buttons full of oil

Button #3:

A three-button test:



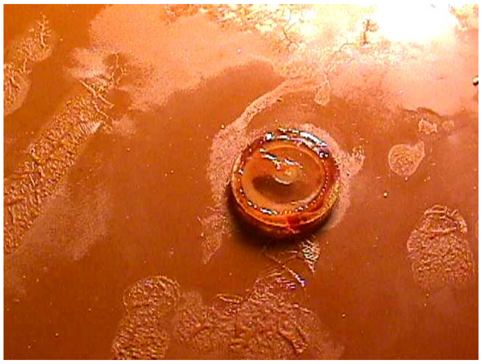
Total charge: ~0.08 C/button

- Typical starting current was <1µA, i.e., 5-20 smaller than when I did the Layer 7 buttons. After my addition of ~0.08C/button, the current is reduced to ~0.1µA.
- Extremely bad looking surface. This must degrade efficiency.

SLAC test chamber - continue:

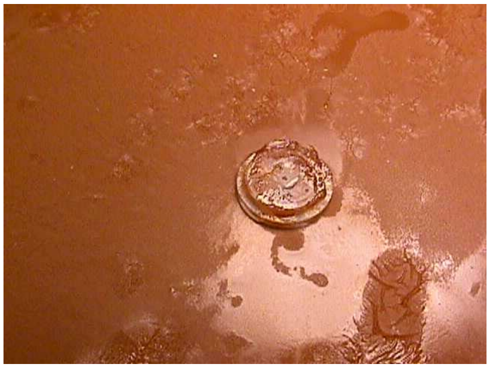
-Repeat with three different buttons

Button #4:

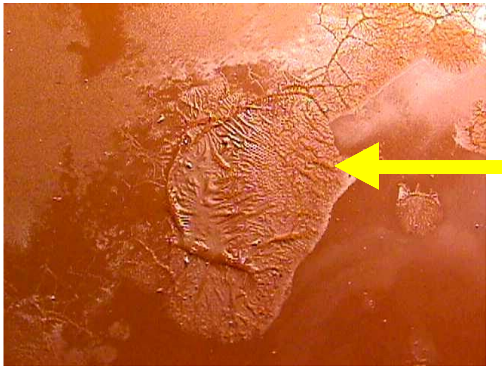


Button #5:

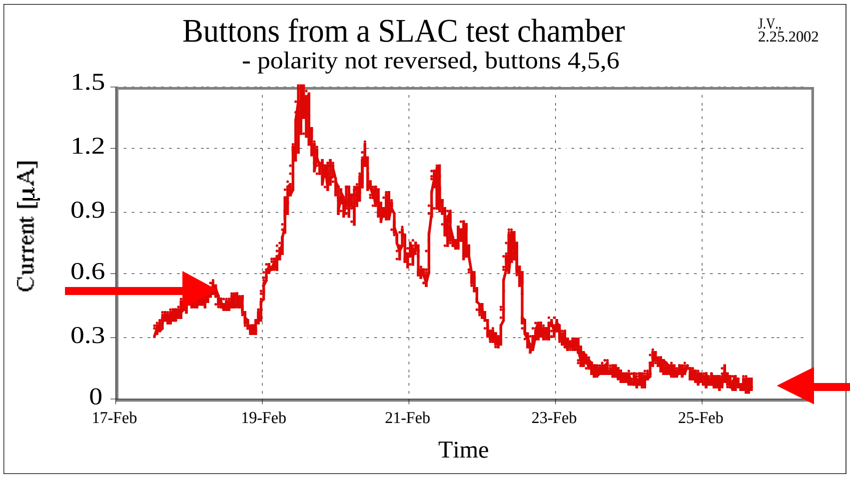
Button #6:



A very ugly surface:



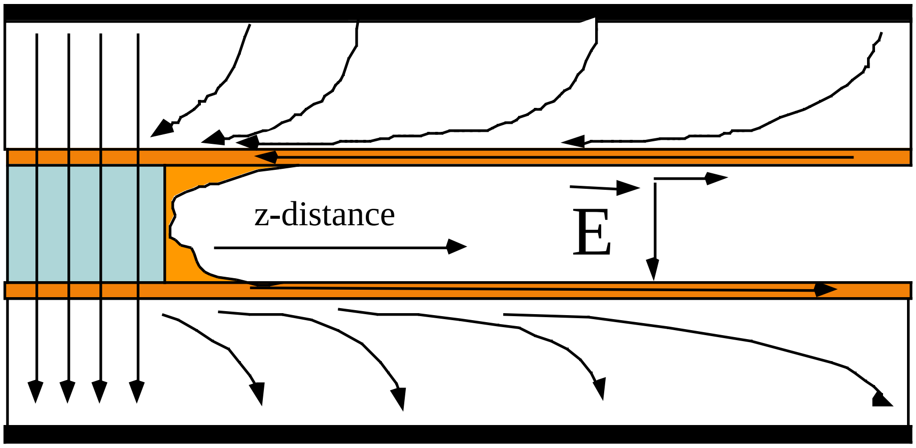
In addition, one sees very bad surface, which means that in this chamber portion the inefficiency comes from a bad surface



Total charge:
~0.11 C/button

- Typical starting current was <1.5µA, i.e., 5-10 smaller than when I did the Layer 7 buttons. After my addition of ~0.1C/button, the current is reduced to ~0.1µA.
- <u>Extremely bad looking surface. This must degrade efficiency.</u>

SLAC test chamber - continue:



A button is shorted by the "brown Linseed oil blob":

$R_{Bakelite} = \rho_V (t_{gap} / Area) \sim 2.5 \times 10^{11}\ \Omega.cm \times (0.2cm/100cm^2) \sim 5\times10^8\ \Omega$

$R_{Linseed\ oil\ blob} = \rho_V (t_{gap} / Area) \sim (\mathbf{5\text{-}10})*2.5*10^8\ \Omega.cm \times (0.2cm/0.1cm^2) \sim$
$\sim(2.5\text{-}5)\times10^9\ \Omega$

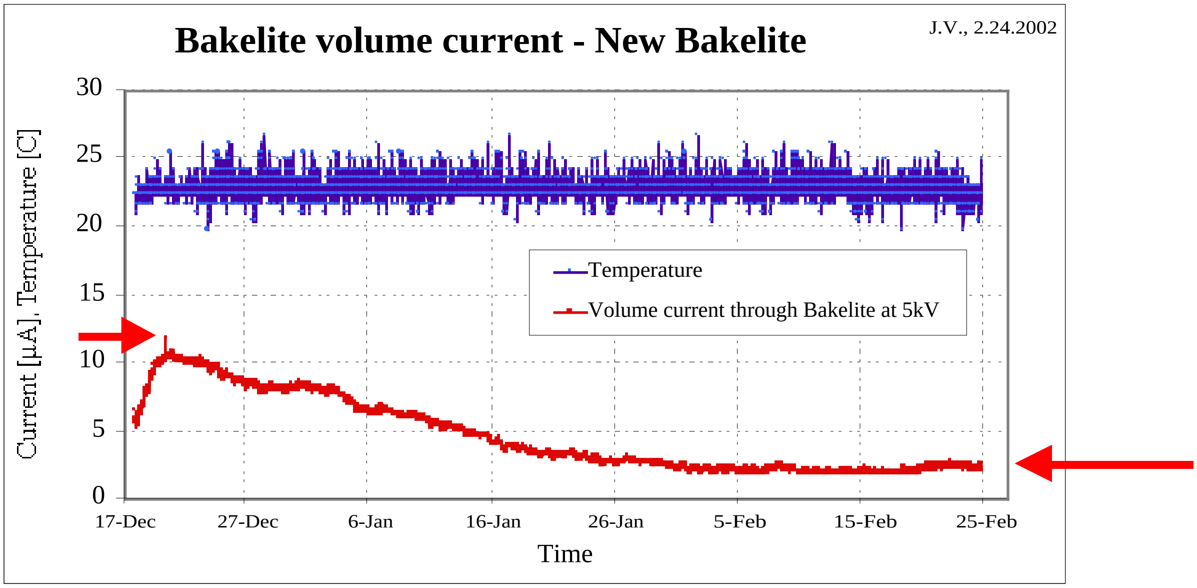
=> $\mathbf{V_{GAP} = V_{PS} / (1+2*5*10^8 / (2.5\text{-}5)\times10^9) \sim V_{PS} * (0.71\text{-}0.83)}$

=> The chamber efficiency is still degraded, but it is not as bad as the Layer 7 was.

=> So, perhaps, the Marcello's treatment helped. This is assuming that the button resistance increase is due to remediation.

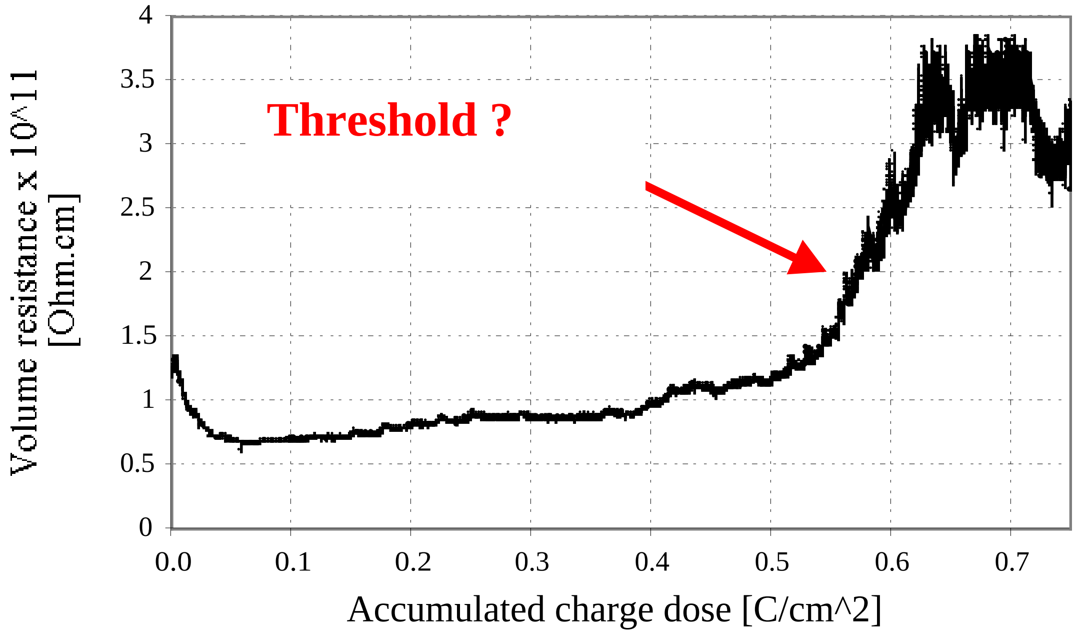
If the electrolytic model applies to the Bakelite, its long-term current capability must stop as we consume ions.

- Bakelite from the new BaBar RPC chamber with graphite layer, but without the Mylar sheet (LHC-like).

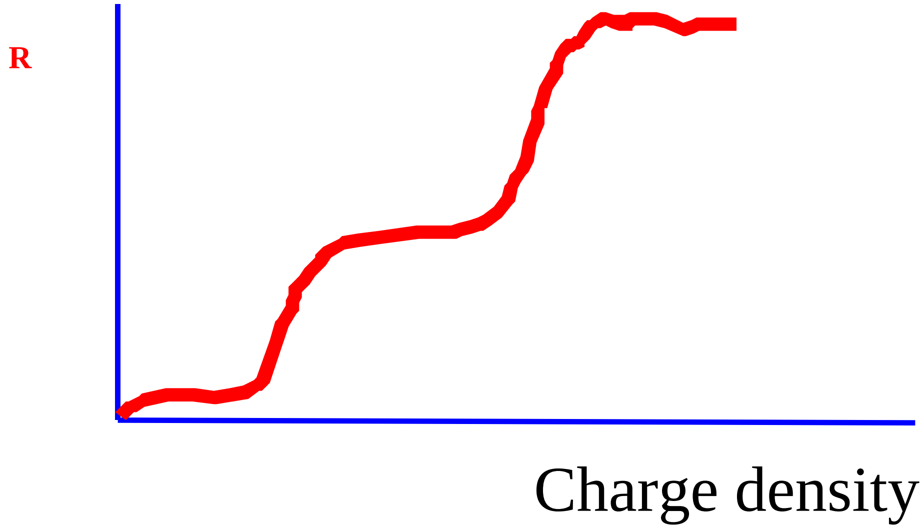


- Total charge in this experiment: ~24.5 Coulombs (at 5kV).
- Total charge density is: ~0.75 Coulombs/cm^2 (test continues).

Plot the same data from the previous page
as a function of charge density:



- A factor of ~5 increase in resistance after ~0.75C/cm^2 (in air).
- There seems to be a threshold effect near ~0.5C/cm^2. Is it related to the ions of certain species being depleted ?
- In principle, if several ions are involved, one could see a staircase dependency:



Concluding comments:

1) It appears that the brown buttons from SLAC test chamber, after the Marcello’s argon remediation, have higher resistance compared to the buttons from Layer 7 by a factor of 5-20.

2) A threshold of ~0.5C/cm^2 is a large charge density, of course. However, it is not so large if there is either localized sparking or excessive localized background. In that case, in these areas the chamber can deteriorate further by increasing the local resistance, which can lead to the Malter effect. This can lead to repetitive sparking, and to a total deterioration of chamber.

=> We must prevent large currents because we do not know if they are localized.

In this sense, the charge dose during the Marcello’s Argon remediation should be limited to less than ~0.5C/cm^2, and one should also worry if the charge deposition is localized.

3) <u>DESY workshop:</u>

G. Passaleva reported on tests with LHC-b RPC chambers, which were exposed to Co^{60} γ source. A large increase in the Bakelite resistance and noise increase was observed after ~0.5C/cm^2.

IFR 127 chamber (Barrel "spare") was subject to:

the Marcello's remediation procedure: ε ~5% → ~75%.

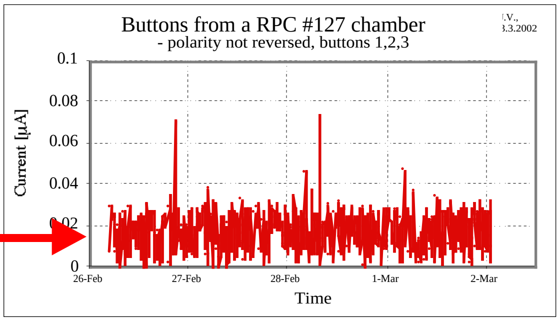
Button #1:

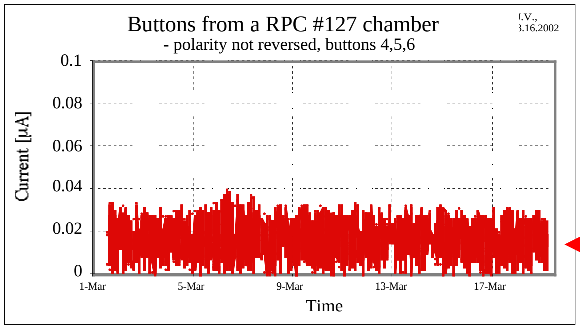
Button #2:

Button #3:

A three-button test:

Buttons
Have sor
oil, but it
Seems
be more
dry
looking;
surface
very rou
though





- Current stays small right from the beginning – buttons were already "cured" by Marcello's procedure.
- <u>In addition, bad looking surface - must degrade efficiency.</u>

Comments about the button “curing”:

1) Buttons from the RPC Layer 7 (EC West FWD Top), which was taken from the BaBar, and which was not the subject to the Marcello’s Argon curing treatment, needed additional charge of about 0.2-1.5 C/button to reach the “terminal” value of the resistance – see pages 89 & 96. The “oily buttons” were taken from a section of Layer 7 with low efficiency – see page 29.

2) Buttons from the SLAC RPC test chamber, which was not in the BaBar, which was a subject to a heat treatment, and which was the subject to the Marcello’s Argon curing treatment, during which the efficiency increased from 5% to 30%, needed additional charge of about ~0.1C/button to reach the “terminal” value of resistance – see pages 107-110. The 30% efficiency limit is probably caused by extremely rough surface quality due to running of the over-oiled chamber.

2) Buttons from the RPC 127 chamber (Barrel spare), which was not in the BaBar, and which was the subject to the Marcello’s Argon curing treatment, during which the efficiency increased from 5% to 75%, needed no additional charge to reach the “terminal” value of resistance – see pages 114, i.e., the buttons were already “cured.” The 75% efficiency limit is probably caused by extremely rough surface quality due to running of the over-oiled chamber.

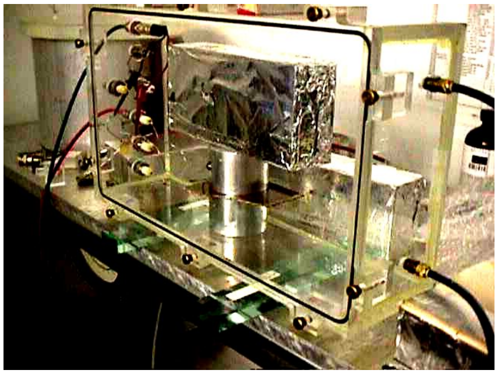
Effect of pumping on the Bakelite volume resistivity.

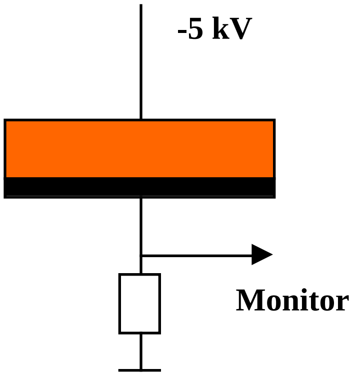
- "New Bakelite with newly treated Linseed oil" – place it in the vacuum vessel.
- Prior to the pumping, it holds ~5kV across the Bakelite sheet.

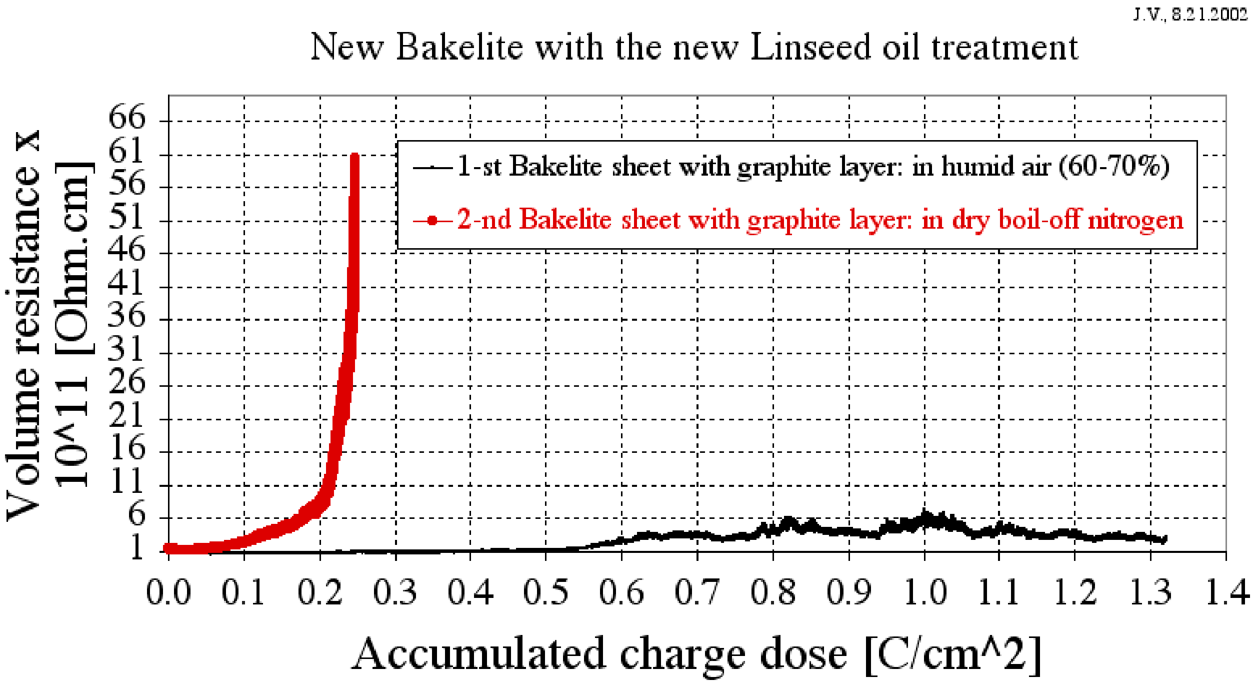
- Pumping caused a disaster:
  - a) The Bakelite would not hold even ~1kV while pumping.
  - b) After a few days of pumping, it would not hold ~1kV even if one returns to air at 1 bar. This means that the Bakelite sheet is permanently damaged, probably, the pumping created micro-voids.

Long-term behavior of the Bakelite volume resistance in a <u>dry nitrogen atmosphere</u>, and as a function of charge.

- Bakelite from the new BaBar RPC chamber with the graphite layer, but without the Mylar sheet (LHC equivalent).

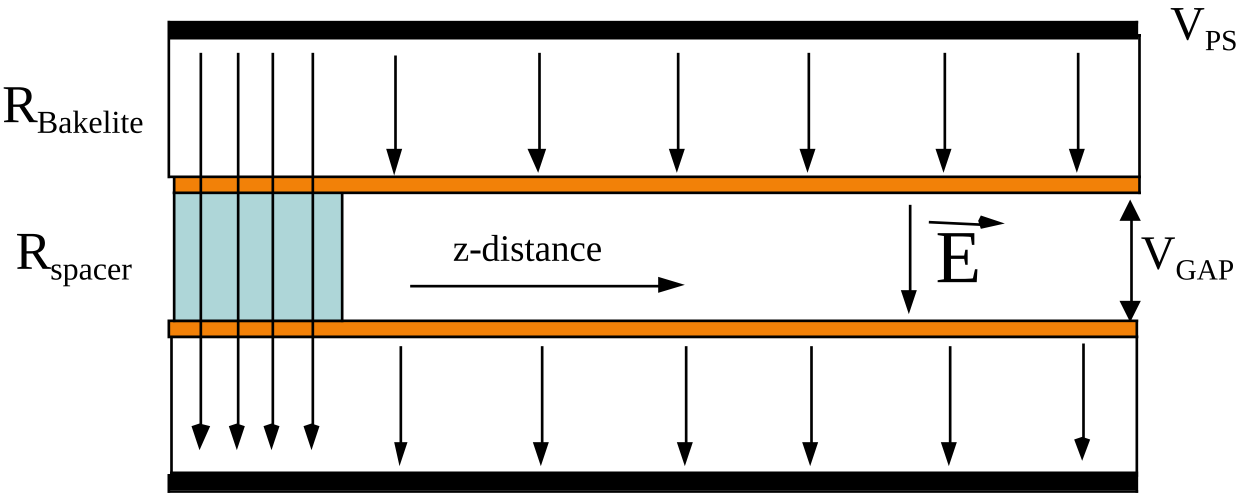






- The resistance increase of the Bakelite in the dry nitrogen is much larger than that of Bakelite in the humid atmosphere.

The effect of a huge bakelite resistance increase:



$$\mathbf{V_{GAP} = V_{PS} / (1 + 2\, R_{Bakelite} / R_{Lexan\ spacer}) \sim V_{PS}}$$

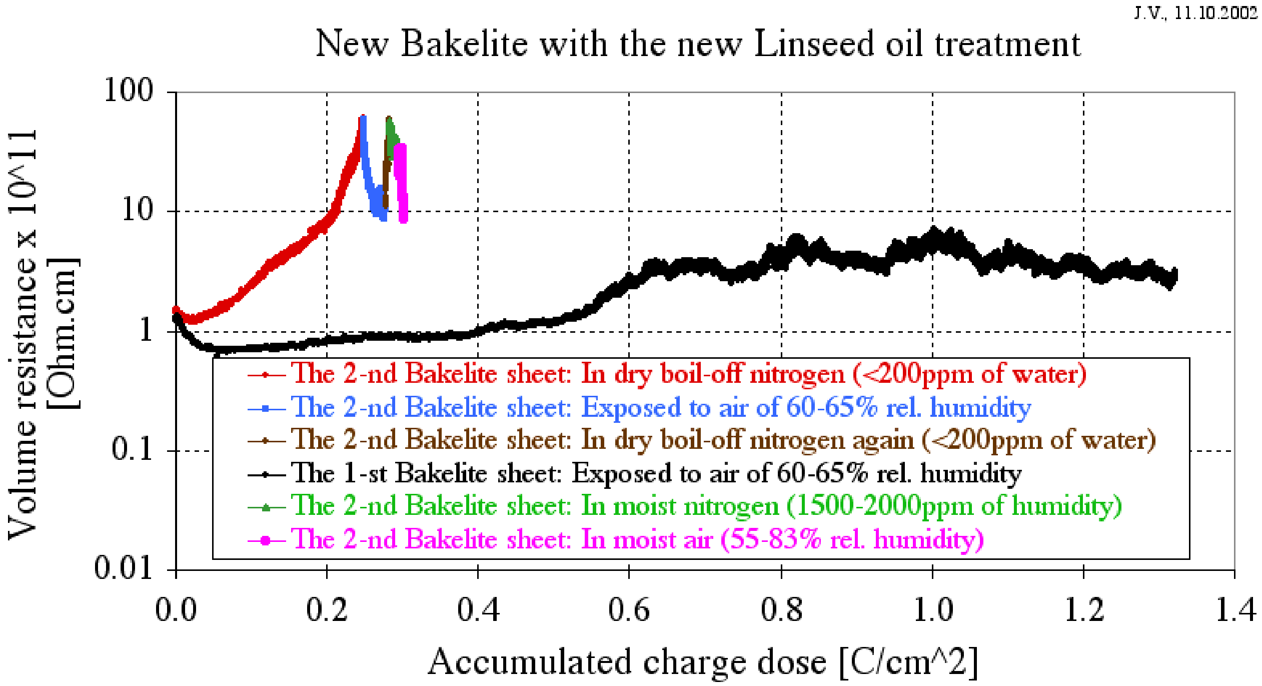
$$\mathbf{if\ \ R_{Lexan\ spacer} >> R_{Bakelite}}$$

A factor of ~60 increase in Bakelite volume resistance is bad !!!!

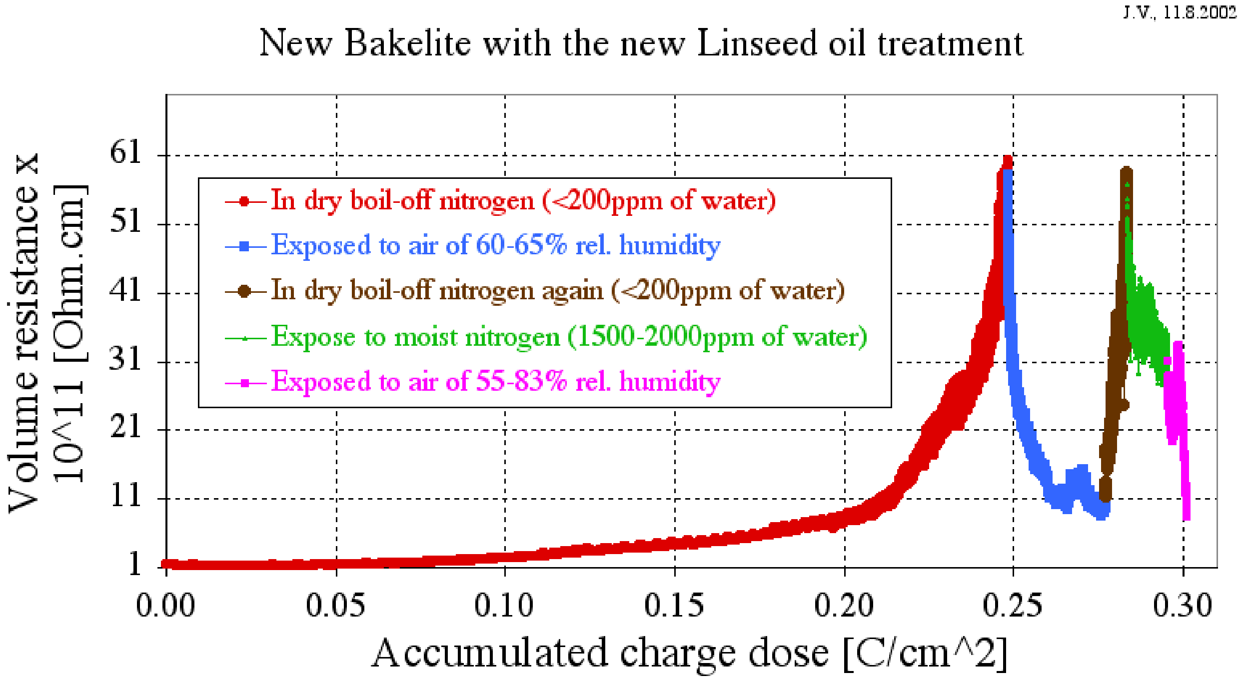
$R_{Bakelite} = \rho_V\,(t_{gap} / \mathrm{Area}) \sim \mathbf{60\ x}\ 2.5 \times 10^{11}\ \Omega.\mathrm{cm} \times (0.2\mathrm{cm}/100\mathrm{cm}^2) \sim 2\mathrm{x}10^{10}\ \Omega$

$R_{Lexan\ button} = \rho_V\,(t_{gap} / \mathrm{Area}) \sim 1.7\mathrm{x}10^{11}\ \Omega.\mathrm{cm} \times (0.2\mathrm{cm}/0.1\mathrm{cm}^2) \sim 3.4 \times 10^{11}\ \Omega$

$$\mathbf{\Rightarrow V_{GAP} = V_{PS} / (1 + 60 \times 2*5*10^{8} / 3.4\mathrm{x}10^{11}) \sim V_{PS} * 0.85}$$

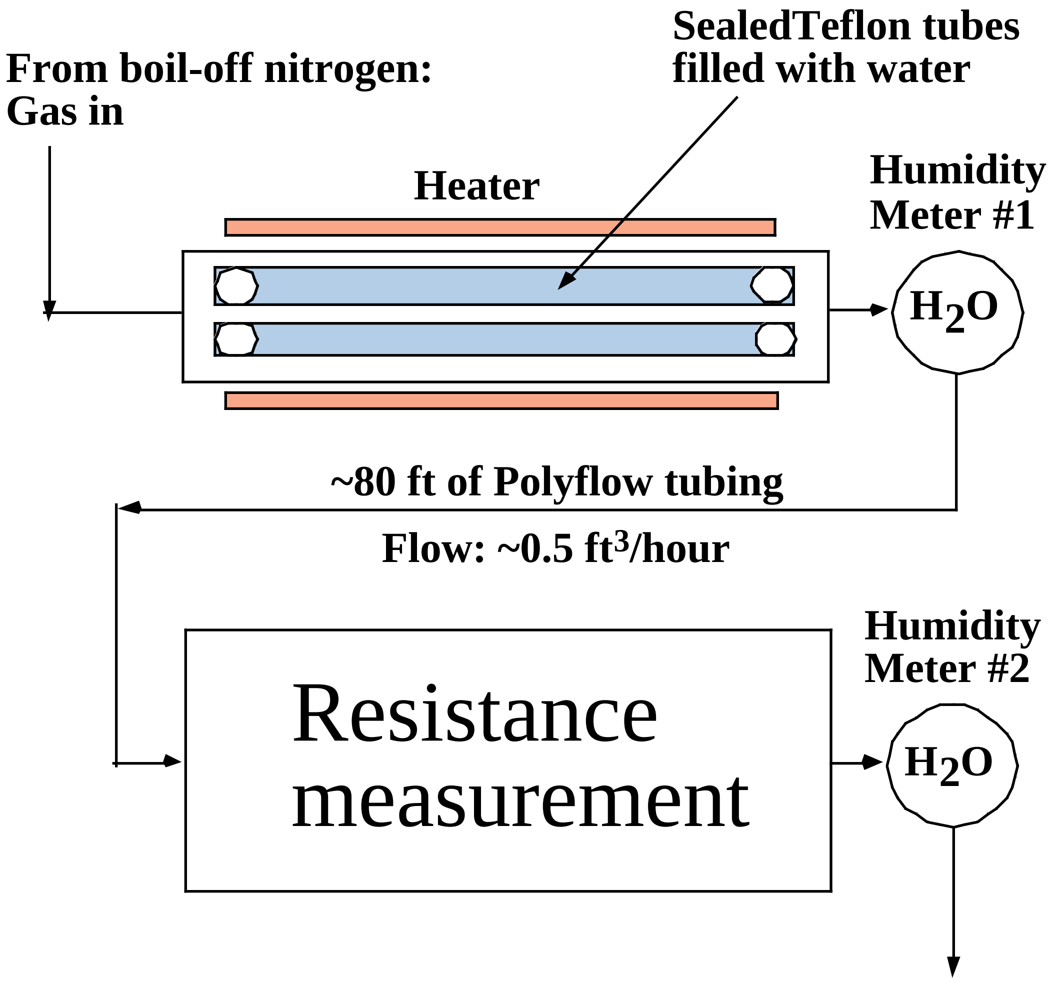


On linear scale:



- Opening the Bakelite to humid air lowers the volume resistance to a point that the RPC chamber would start working again. It is not, however, the original starting volume resistance.

Gas setup to measure the Bakelite volume resistance as a function of humidity:



- It was necessary to make this setup to be confident what is the humidity. Water permeating through the Teflon wall tubing produces the gas humidity. Control the level of humidity by a temperature and gas flow (in principle, a nice way to do it).

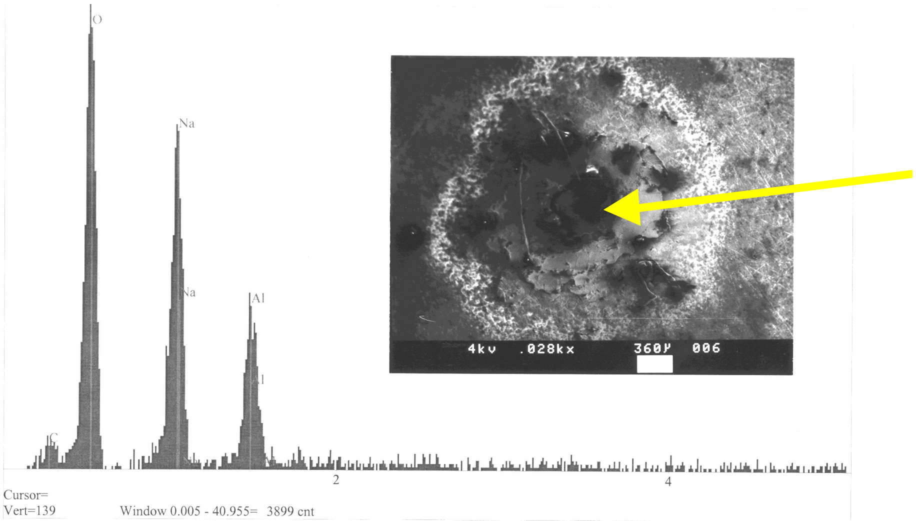
- Conclusions:
  a) Humidity of the “boil-off” nitrogen was <200ppm.
  b) To start reducing the volume resistance, after a peak is reached, one needs at least 1500-2000ppm.

8.7.2002

Terminate the “wet” Bakelite study (p.117):

- Cathode’s side of the Bakelite is full of blisters. They appear similar to what we usually identify as sparking spots. On the mating aluminum surface we see bumps, each corresponding to the Bakelite spot. The bumps seem to be clear sign of a chemical reaction with aluminum.
- Anode looks fine to me - just compressed graphite (no picture).

Cathode’s side – Spots on the Bakelite surface and on the mating Aluminum electrode:

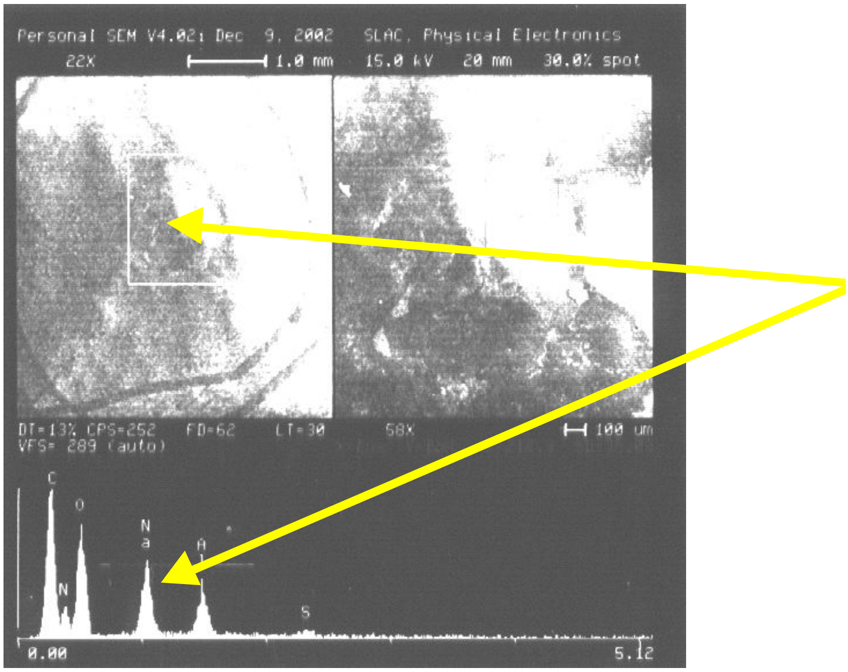


Study of a core of one blister

- Observe C (small amount), O, Na and Al.
- Oxygen is probably from Alumina Oxide. Sodium is known to migrate under electric field very easily.

Terminate the "dry" Bakelite study (p.119):

- Cathode's side of the Bakelite has also blisters. Again, they appear similar to what we usually identify as sparking spots.
- Anode looks fine to me - just compressed graphite (no picture).



Study of a core of one blister

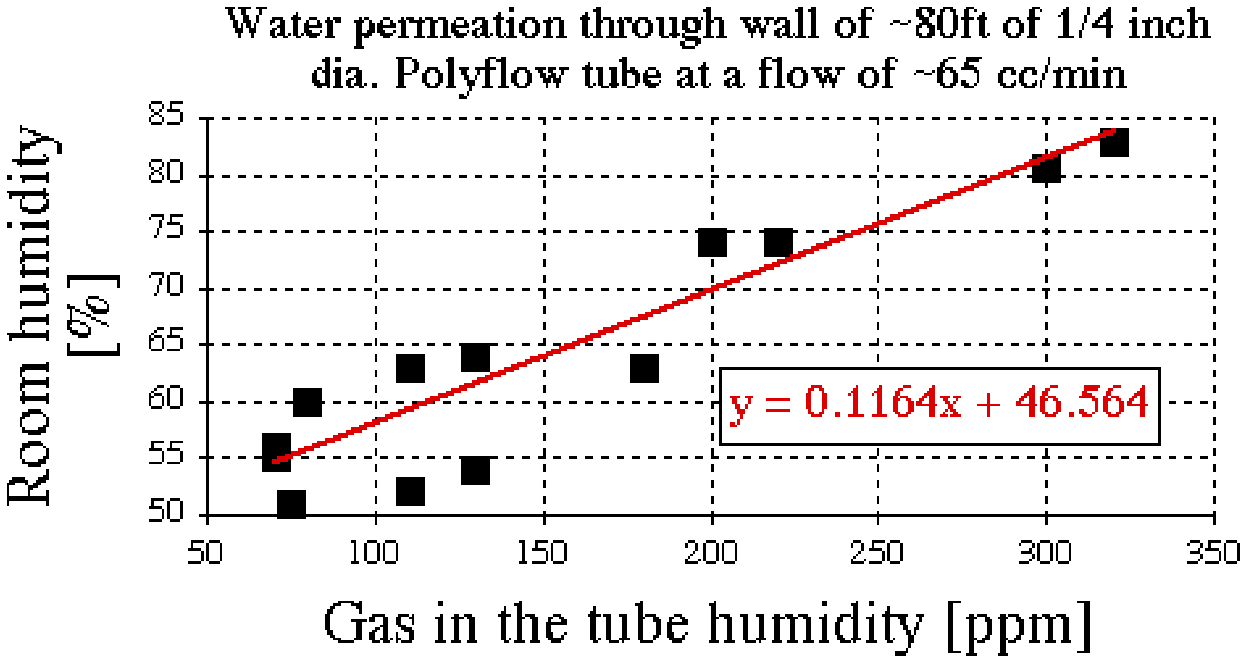
- Analyze three spots in the region where there was current. They all show excess of sodium. Compare this with two regions where I did not have a current. No sodium observed there. Sodium is known to migrate under electric field very easily.

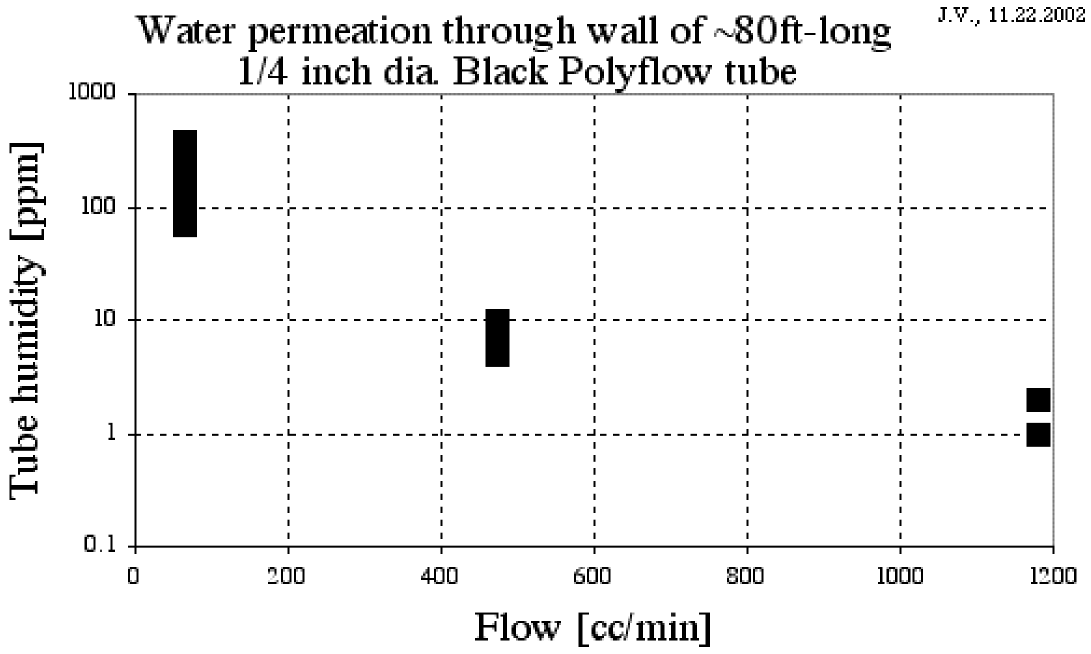
Why is the sodium in the Bakelite ? Not clear to me. In any case, such migration, similarly to what is known to happen to the Micro-strip chambers made of an ordinary glass, will cause (a) a resistance increase, (b) possibly affect the carbon adhesion to the Bakelite. It is not clear to me how to prevent the sodium migration. Incidentally, I believe that this will cause a death of the Belle RPCs.

11.10.2002

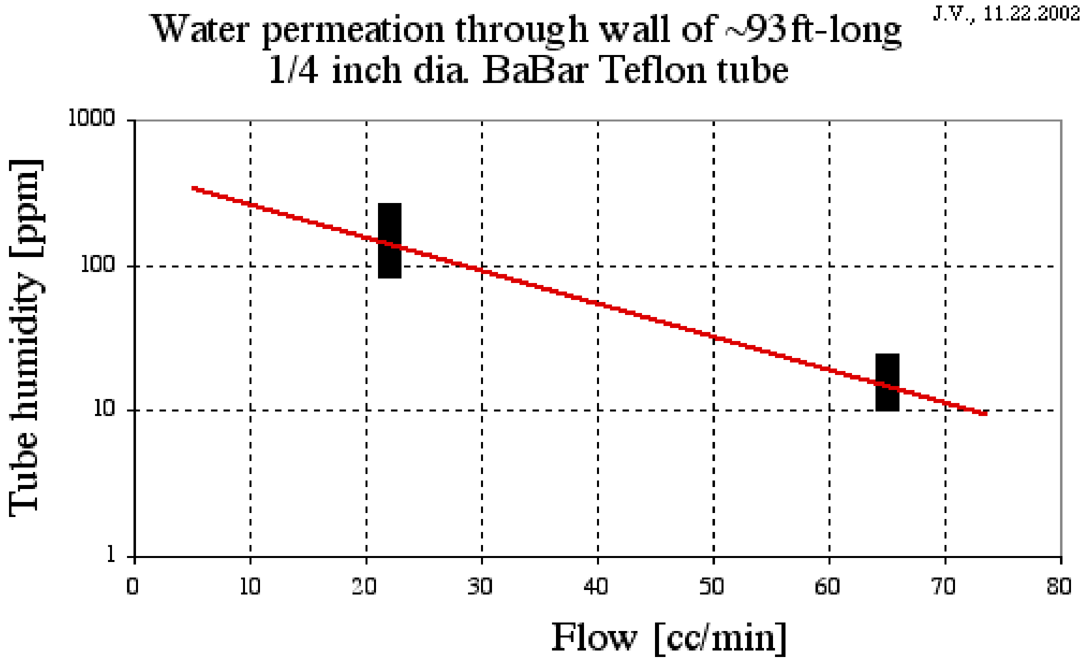
How much water permeates through a wall of the 80ft long 1/4 inch dia. Polyflow tubing ?

- Gas flow ~65cc/min (flow controller calibrated with the HP Soap Film Flowmeter and stopwatch).





- BaBar is using a Teflon tubing which is even better.



- This shows that only small amount of water permeates.

Do we know what is down there ?