Additives That Prevent Or Reverse Cathode Aging In A Helium-Based Gas

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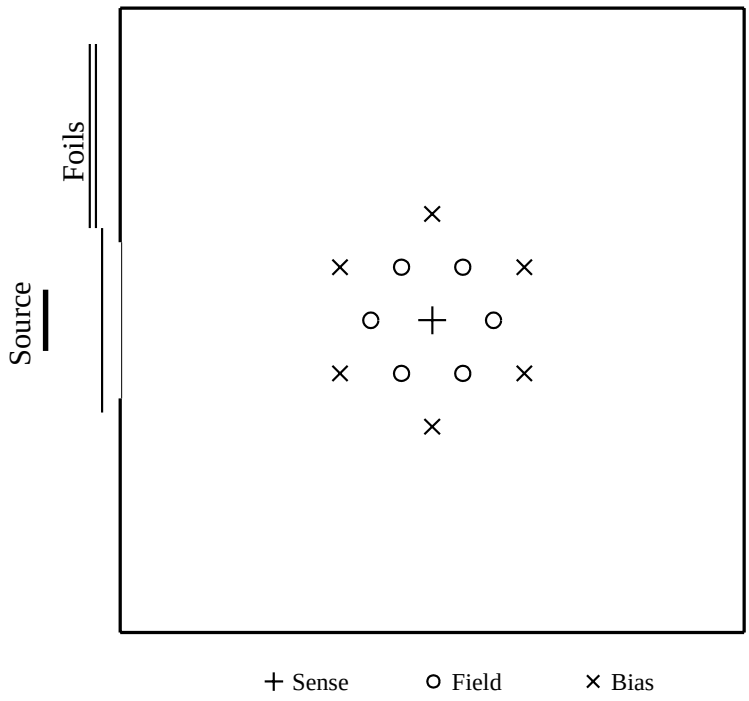
Introduction

- BaBar drift chamber observed current spikes:
  - He(80%)+Isobutane(20%) gas.
  - At ≈0.3 nA/cm on anode wires.
  - Prior over-voltage accident between cathode and guard wires may have scarred some of these wires.
- Adding 3500 ppm H_2O stopped the current spikes.
- But will this work at:
  - Higher upgraded chamber currents
  - A 5-10 year operating lifetime.
- Built a small BaBar-like test chamber to study cathode aging at high chamber currents.

Test Chamber

– Hexagonal cell, in 4"x4"x12" box:

- Al walls, Vitone seal, mylar window
- 1 anode wire, 20 um gold coated tungsten, 2050 volts, 239 KV/cm.
- 6 field wires, 120 um gold coated aluminum, 0 volts, 20 KV/cm.
- 6 outer bias wires, 120 um gold coated aluminum, 1300 volts.
- 1 cm wire spacing.



Source

- 100 mCi Fe^{55} source, with .001" aluminized mylar window.
  - Full coverage in transverse plane.
  - Covers ±11 cm along SW length.
    - Effective wire length at the max current density (i_{max}) is 13 cm.
    - Wire current I and i_{max} related by
    - $i_{max} = I / 13$ (nA/cm)
- Foils could be inserted to attenuate the source strength.
- Full source gives I ≈ 30 nA/cm.

Gas System

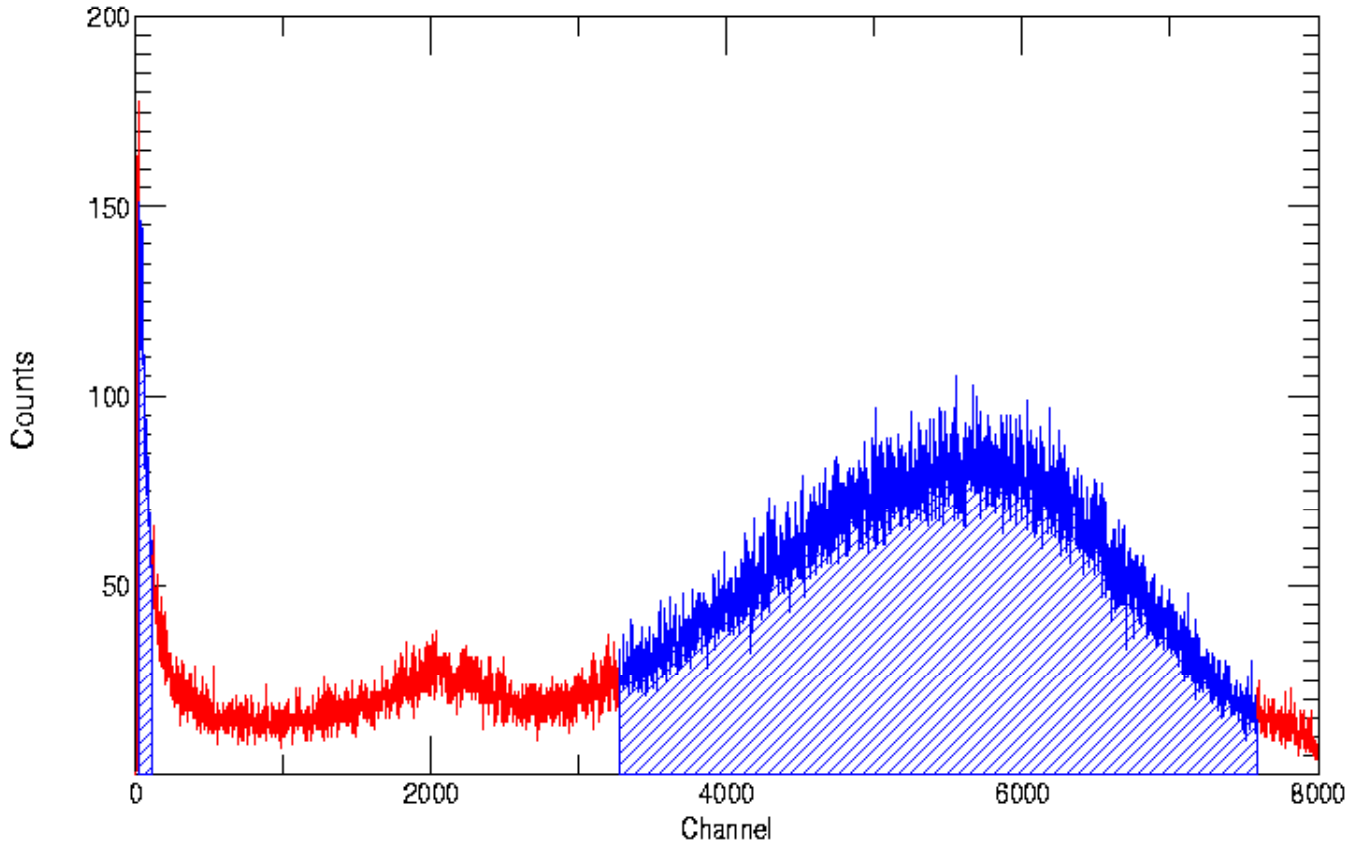
- At 1 atmosphere pressure
- 3 mass flow controllers (Sierra) for the helium, isobutane, and additive gases.
- For liquid additives, a fraction of the helium was diverted and bubbled through the additive at room temperature.
- Flow meters also used
  - For 4'th controller, when needed.
  - For redundant flow checks.
- Total flow at 125 cc/min, giving a volume change every 24 min.
- Vented through a bubbler to the atmosphere.

Instrumentation

- A picoammeter (Keithly 487) measured the currents from the six cathodes to ground.
  - A switchbox allowed measurement of either individual cathode currents or all cathodes together.
- An ORTEC MCA system (142PC preamp, 570 amplifier, TRUMP-PCI-8K analyzer), measured pulse spectra.
  - Programmed to record and analyze spectra every few seconds, repeatedly.
  - From each spectrum, save the small counts to peak counts ratio, together with the time, to a file suitable for plotting.

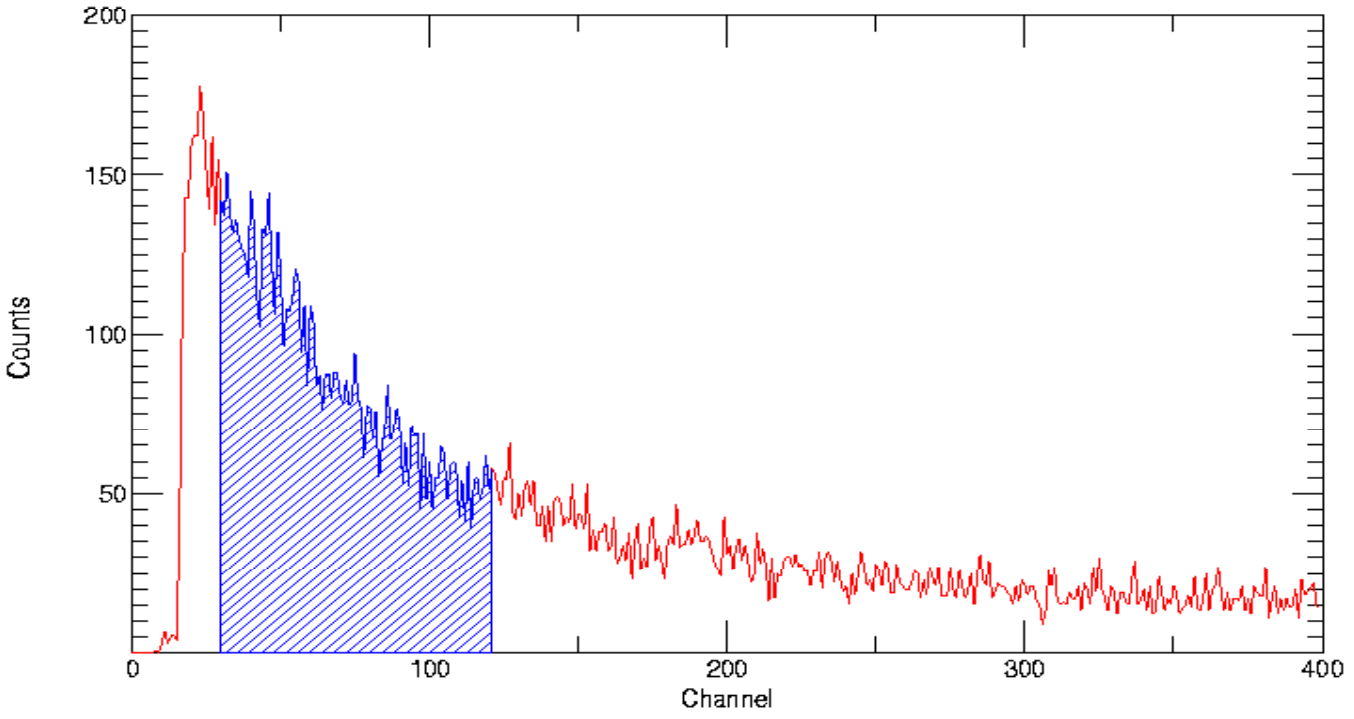
Fe^{55} Spectrum in Helium + Isobutane (80:20) Gas Mixture.

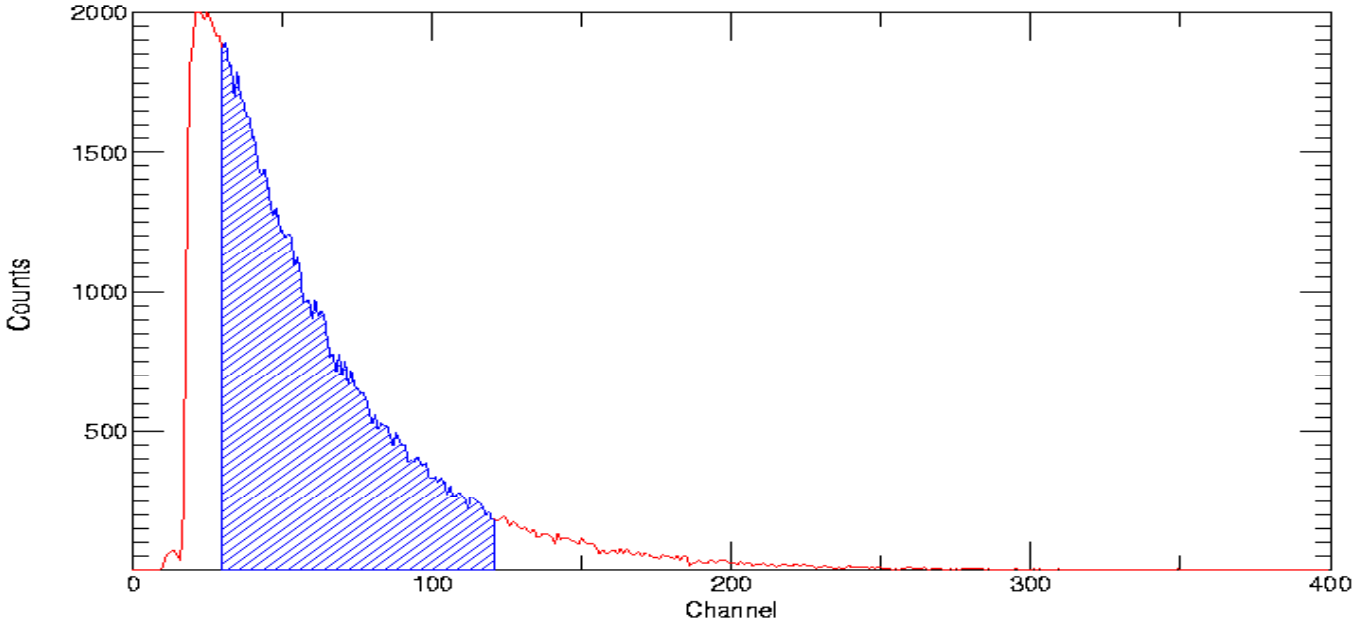
The 5.9 KeV peak is at channel 5500. The shaded regions show the channels used for counting the Fe^{55} peak pulses (ch 3280-7590) and the small pulses (ch 30-120) from single electron avalanches.



Small Pulse Height Spectra.

Top: Fe^{55}. Bottom: Single photoelectrons from room light. Establishes channels for 1 electron avalanche.



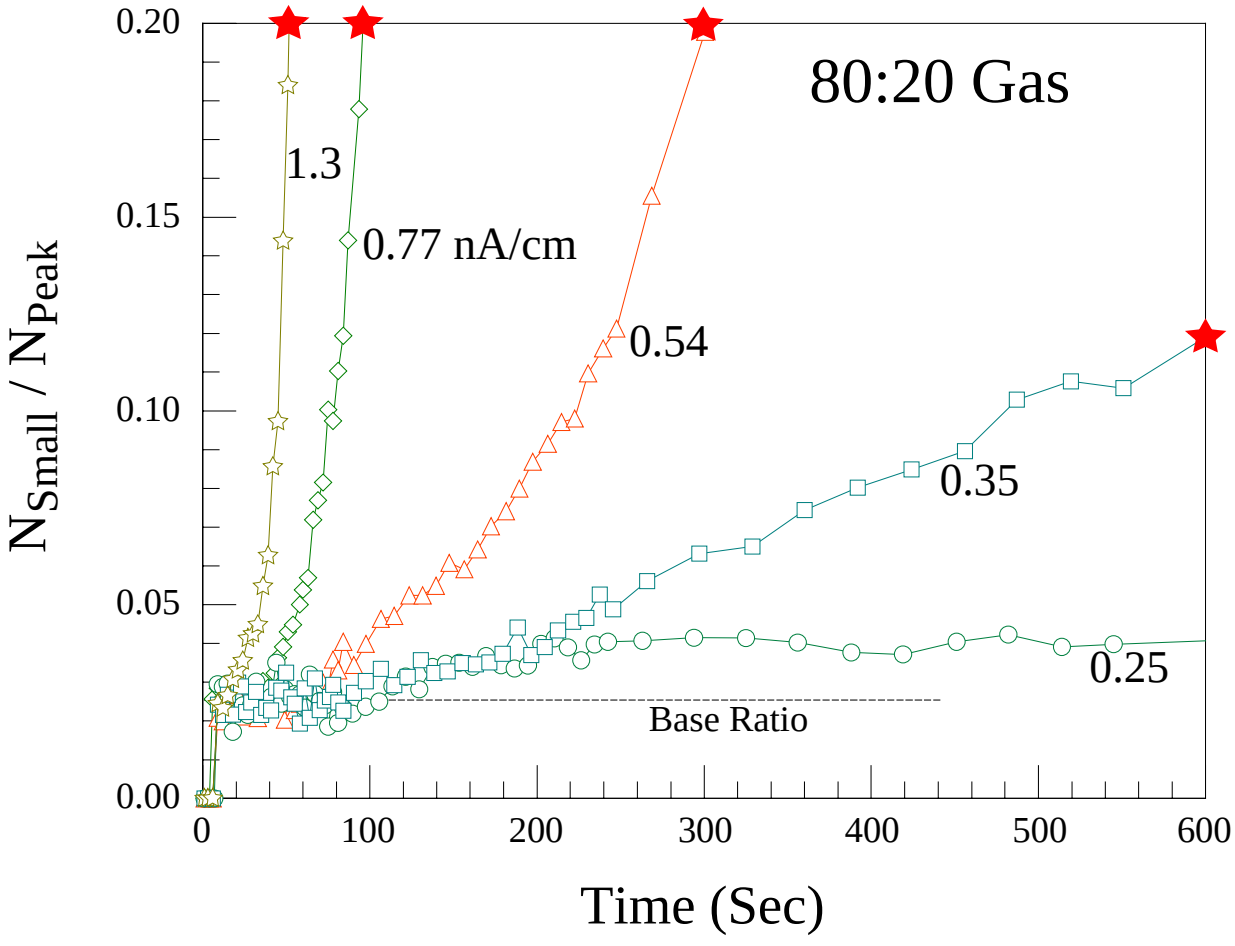


Measurements- For Each Additive

- Pre-age the chamber:
  - Use 80:20 gas,
  - Raise HV to 2500 volts,
  - Maximum source (≈900 nA/cm),
  - Run for 2-5 hours.
- At normal HV, max current I_{max} before breakdown is ≈0.4 nA/cm.
- Add additive, adjust HV for same chamber gain (i.e. peak at 5500).
- Measure small pulse response to a step in ionization
  - Close Fe^{55} source for > 10 min.
  - Open source, record small and peak pulse counts as function of time.
  - Plot ratio N_{Small} / N_{Peak} vs time.
  - Repeat for several source strengths.
- Remove additive, re-measure I_{max}.

Additive: None.

The small pulse response to a step current in an aged chamber is shown for several anode currents. The ratio starts at a .025 base level, and then increases rapidly at higher anode currents to Malter breakdown, as indicated by the star symbol on boundary. An anode current of ≤0.3 nA/cm is stable.

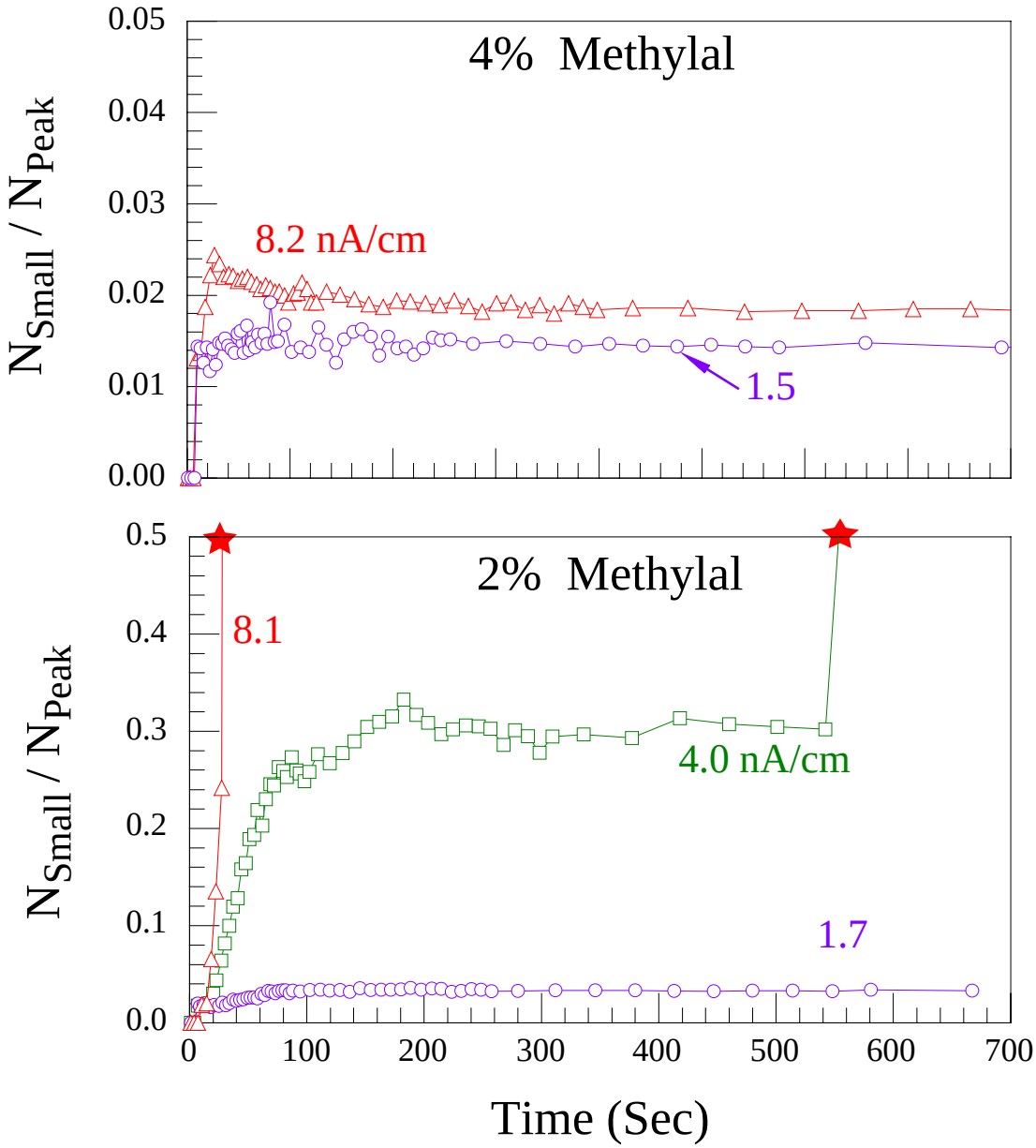


Which Additives to Try?

- Methylal and 2-Propanol.
  - Charpak, Sauli et al. found noise improvement with these additives in argon based gas.
- Water.
  - Many detectors using it.
- CO_2
  - HRS, MARKII, MARKIII detectors saw improved longevity.
  - Probably from O in the dissociation $CO_2 \Rightarrow CO+O$
- O_2
  - If CO_2 is good, O_2 should be better. O_2 and polymer deposits could burn, if heated by ion bombardment.
  - Va'Vra (1986) points out that oxygen is a good additive in plasma chemistry.

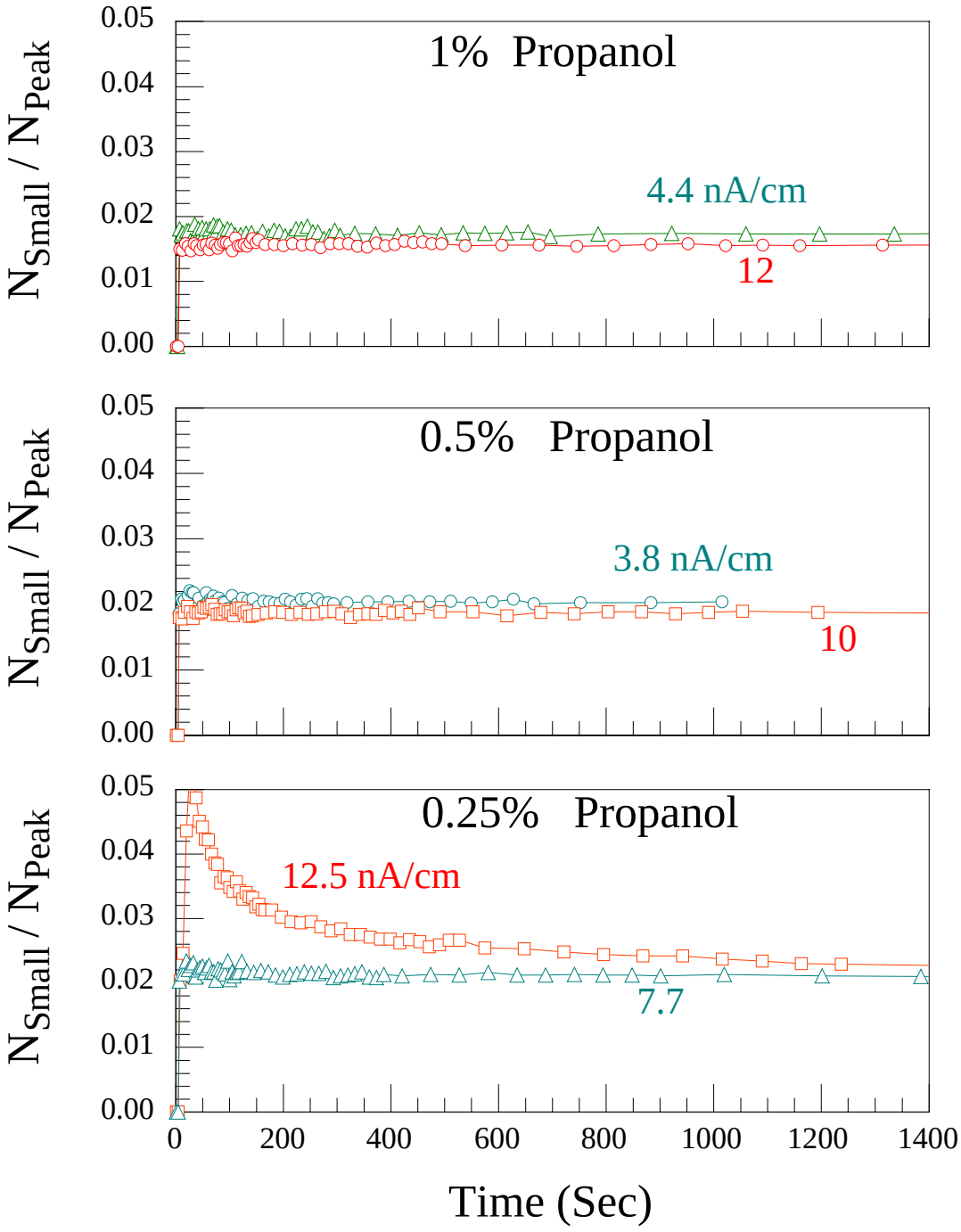
Additive: Methylal

Small Pulse Response to Step Current
80:20 Gas + Methylal



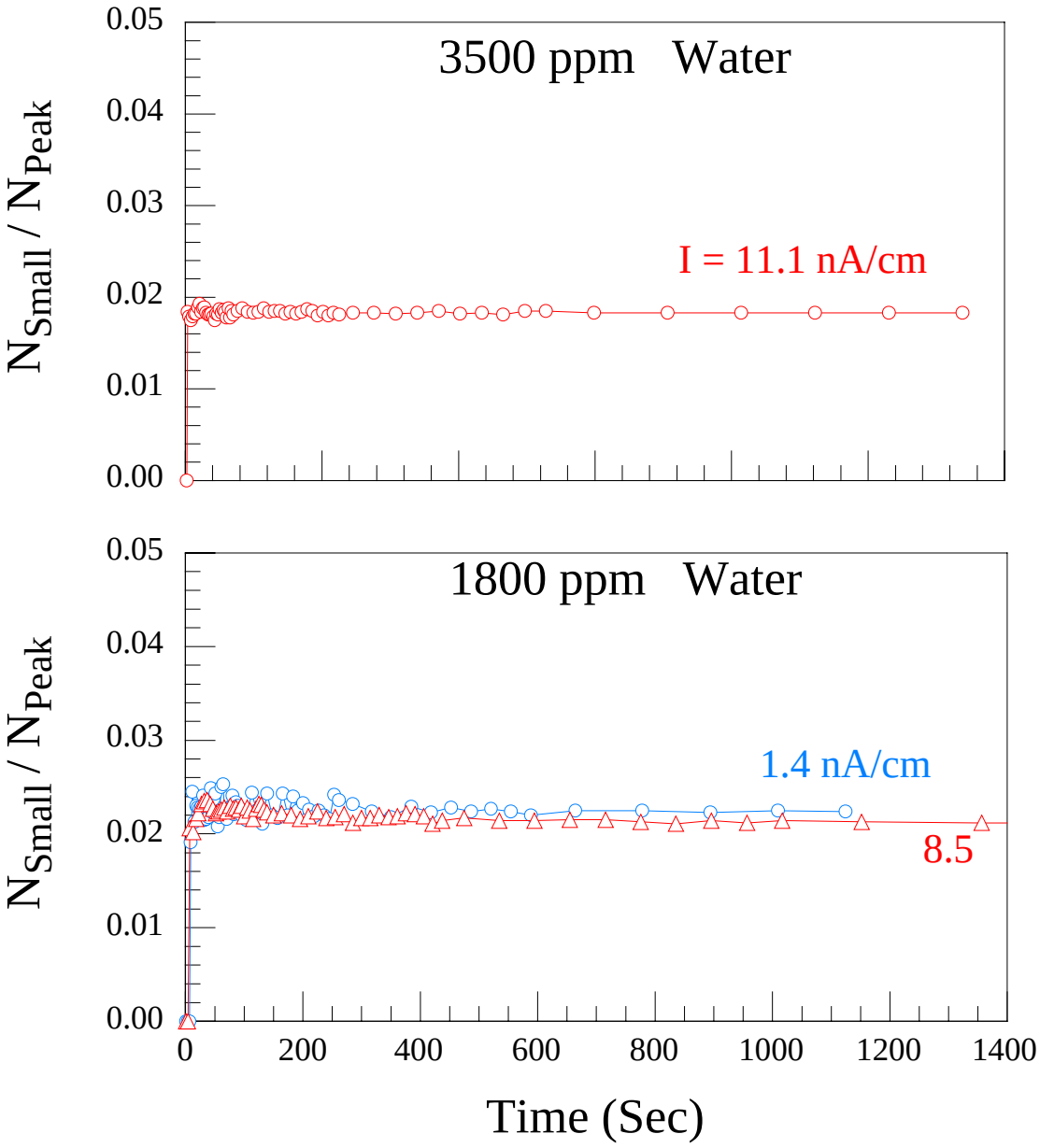
Additive: 2-Propanol

Small Pulse Response to Step Current
80:20 Gas + 2-Propanol



Additive: H_2O

Small Pulse Response to Step Current
80:20 Gas + Water



- Methylal, 2-Propanol, and H_2O provide immediate relief from Malter breakdown.
  - H_2O is best.
  - Chamber currents over 10 nA/cm are possible. (Ran at 40 nA/cm in some cases).
- When the additives are removed, the chamber reverts to the initial damaged state.
  - No curing capability.

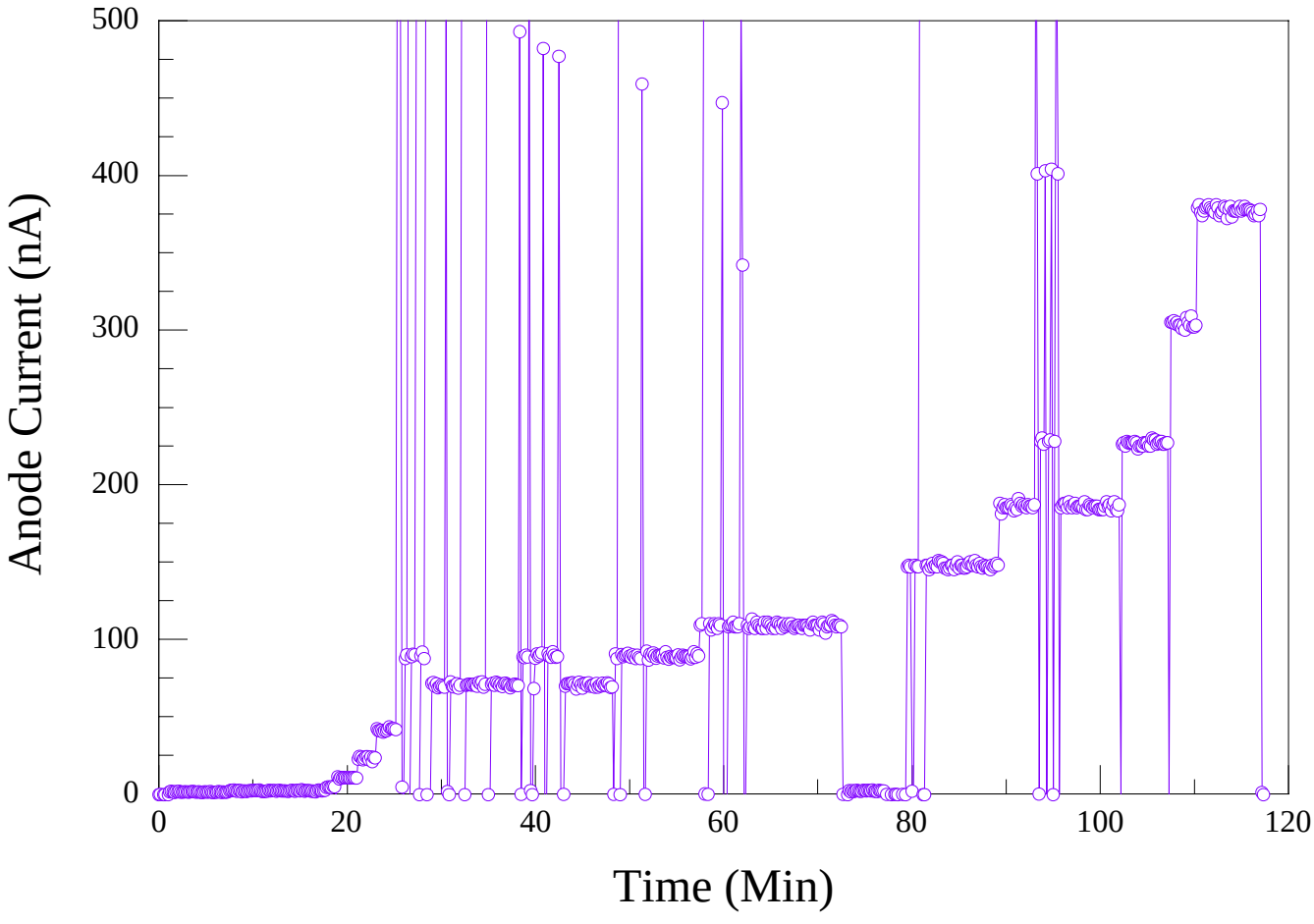
Additives: O_2 And CO_2

- These additives behave differently:
  - No immediate improvement,
  - As the chamber runs at low current, the max operating current is found to slowly increase,
  - The Fe^{55} source strength can slowly be increased to its maximum, to a steady I= 29 nA/cm for the O_2 case.
  - When the additive is removed, the chamber is still able to operate at the high current level.
- The following slide shows the maximum chamber current versus curing time for an O_2 case.

Additive: O_2

Shows the anode current versus curing time. When the Fe^{55} source is increased too quickly, Malter breakdown occurs. But after repeated attempts the higher current becomes steady, reaching 375 nA (29 nA/cm) at the maximum source strength.

Chamber Curing With 500 ppm Oxygen



- O_2 and CO_2, in the presence of high ionization, can revert or cure a chamber from Malter breakdown.
- 200-500 ppm O_2 worked best.
- Curing times:
  - 2 hrs with 500ppm O_2
  - 10 hrs with 200ppm O_2.
  - 35 hrs with 5% CO_2.
- Cured to >30 nA/cm in all cases.

Additive: H_2O and O_2.

- Does curing with O_2 work in the presence of H_2O?
  - Only partly.
  - After 40 hrs of curing, 13 nA/cm reached, but the chamber current was limited at 2.8 nA/cm when the additives were removed.
- Water slows down the curing process.

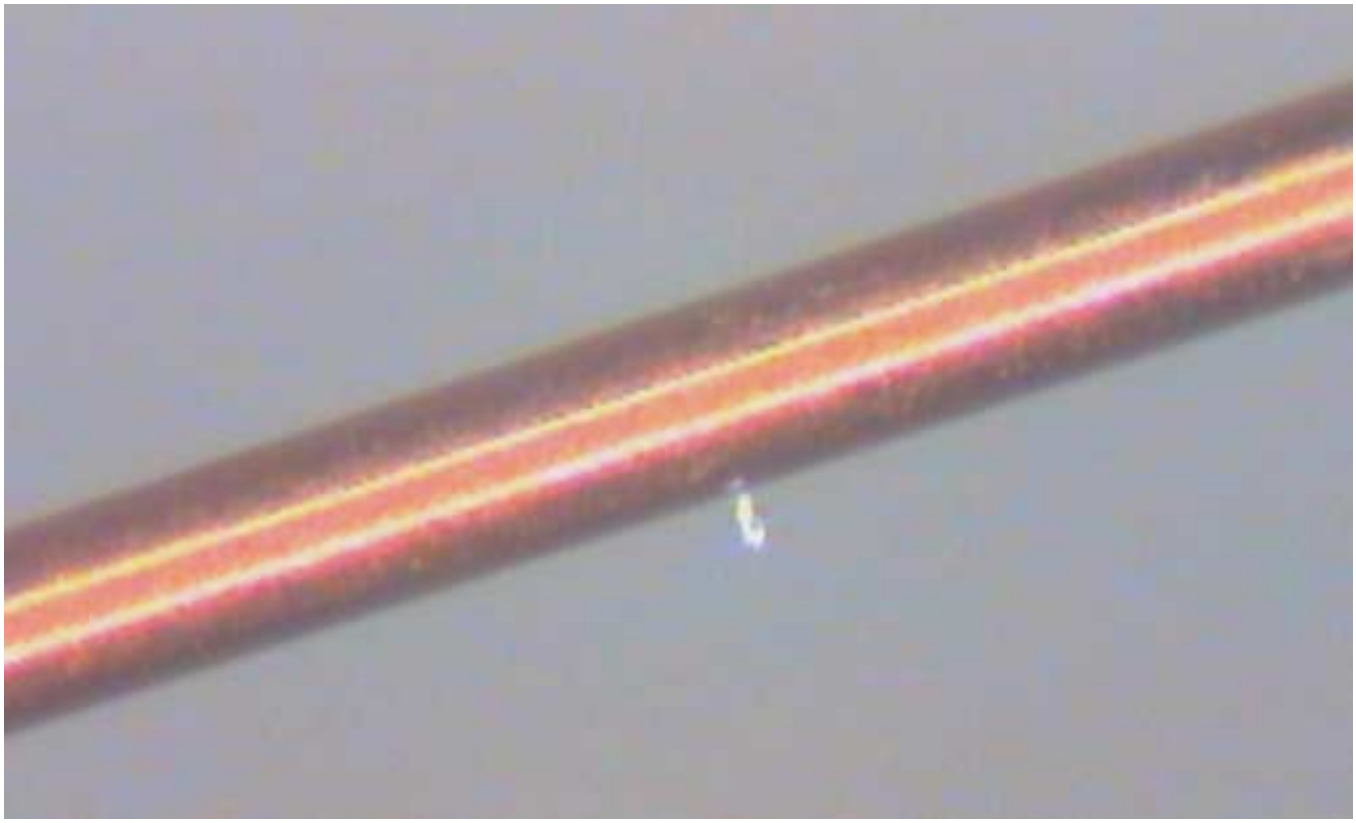
Summary of Measurements

Table 1: Maximum Chamber Current With Various Additives.
For the additives shown, the table gives the maximum chamber currents I_{max} in nA/cm for a chamber running initially with He:Isobutane (80:20) gas, then with the additive, and then after the additive is removed. Cases where the highest attempted current was below the maximum are marked with a " > " sign. The "Time" column gives the curing time necessary in some cases to achieve the highest current. It is seen that all these additives improve the operating current, but O2 and CO2 also cure a damaged chamber, as indicated in the last column.

		Before	With Additive		After	
Additive	(%)	I_{max}	Time (hr)	I_{max}	I_{max}	Cured?
Methylal	4	0.3	≈0	>8		No
	2			3	0.4	No
2-Propanol	1.0	≈0.5	≈0	>12		No
	0.5			>10		No
	0.25			>13	0.2	No
H_2O	0.35	0.4	≈0	>27		No
	0.18			>9	0.5	No
O_2	0.10	0.5	1.5	>32	>40	Yes
	0.05	0.4	2	>29	>16	Yes
	0.02	0.9	10	>35	>14	Yes
CO_2	5	0.4	35	>40	>27	Yes
O_2+H_2O (0.05 +0.35)		0.4	40	10	3	Partly

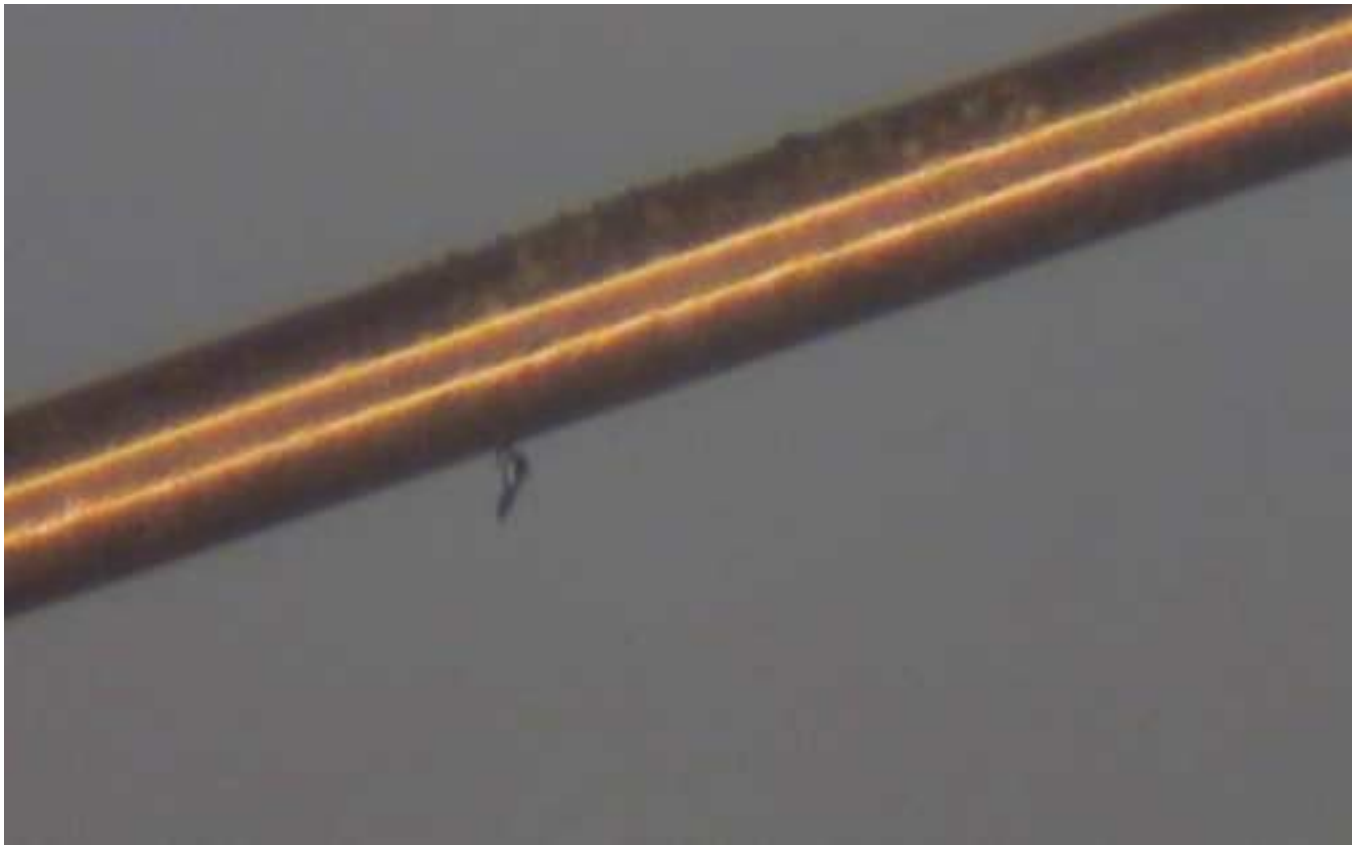
Picture of Whisker #1.

A picture of a whisker on a 120 um diameter field wire taken after the chamber was maximally aged.



Picture of Whisker #2.

A picture of another whisker on another field wire. This whisker is similar in size but darker in color than whisker #1.



Whiskers In A Cured Chamber

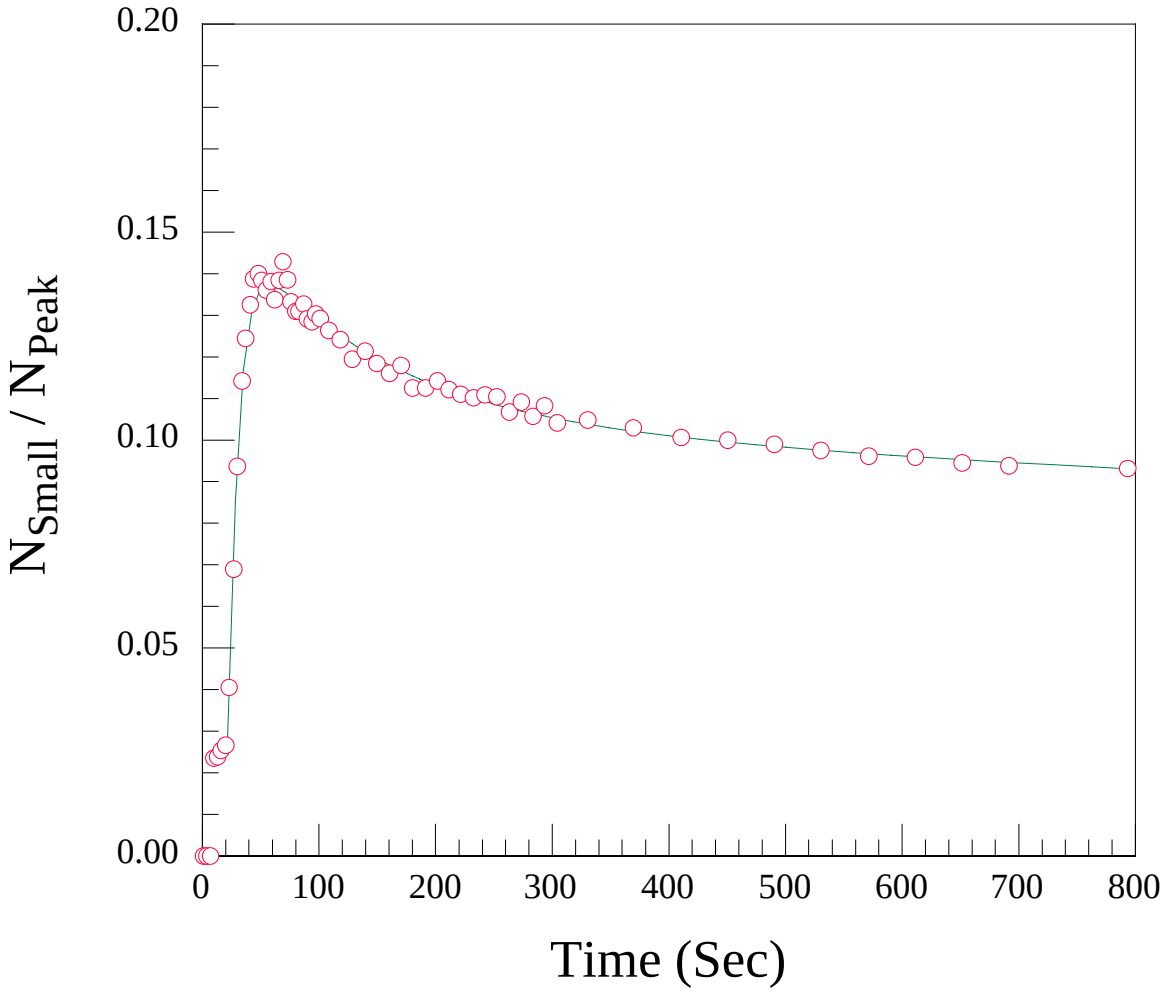
- After curing the chamber with 500 ppm O_2 to >30 nA/cm, the wires were examined again for whiskers.
  - The white whisker (#1) was gone.
    - Could have broken off in transit to optical lab, but unlikely.
  - The dark whisker (#2) was still there, intact.
- It would appear that not all whiskers are alike, some cause breakdown while others do not.
  - The white-colored whisker was more active, causing Malter breakdown and reacting chemically with O_2.
  - The dark-colored whisker was inert.
- More study needed.

So What's Happening?

- At high ionization levels – Malter.
  - Polymerization of isobutane builds up whiskers on cathodes.
  - The high resistance of polymer allows charge build up on whisker tip.
  - This high field pulls out electrons (somehow) from the tip, producing single electron avalanches at SW.
  - This creates feedback, and eventual Malter breakdown.
- At moderate ionization levels – a new effect.
  - Just below the Malter threshold, the small pulse rate from a step source first increases and then decreases at some point in time. Why? See next figure.

Small Pulses At Intermediate Currents

The Rise And Fall of Small Pulses
In Response to Step Current.
For 80:20 Gas at 3.7 nA/cm.



New Effect - Heat

- Work done by electric field on the arriving ions produces heat,
  - A positive ion passing through a mfp (~10^{-5} cm) of gas at a field of 20 KV/cm gains 0.2eV.
  - From 3/2KT=0.2eV, T=1550^{O}C.
- The hot ions heat up the polymer surface, suddenly changing to a phase that has a lower resistance.
- The surface charge then more readily discharges through the polymer and single electron emission is reduced.
  - But at high currents, the resistance is not low enough to prevent breakdown.

Scenario With O_2

- Two possibilities,
  - If the polymer whisker tip gets hot enough, combustion occurs between the O_2 in the gas and the carbon based polymer.
  - Oxygen gets ionized by collisions in the high field region near whisker tip, and the bombarding hot O^+ ions react with the carbon based polymer.
- In either case, the by-products (CO, CO_2, H_2O, etc.) are flushed out with the gas flow, and the polymer is removed.

Conclusion

- Methylal, 2-propanol, or H_2O provide remedies for cathode aging:
  - Water is best.
  - Can run above 10 nA/cm.
- O_2 and CO_2 are curing agents.
  - Curing requires the same high ionization environment that causes cathode damage in the first place (when no additive is used)!
- Heat from ionic bombardment plays a role in wire aging.