Switching Notes

Note 24

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High Speed Breakdown of Small Air Gaps in Both Uniform Field and Surface Tracking Geometries

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1 INTRODUCTION

This note briefly summarises some data obtained on the high speed breakdown of air for small gaps in various geometries. The data in all cases was obtained incidentally during other work and while reasonable care was taken to calibrate the voltage monitors and to allow for 'scope response, etc., the accuracy of the data is not outstanding, being no better than ±3%.

2 8 mm UNIFORM FIELD UNIRRADIATED GAP

This 'gap' was actually part of a possible laser pumping cell and had electrodes 50 cm long and was connected to a 1.5 nF capacitor by inductance of about 0.7 nH when uniform current filled the length of the electrodes. The 1.5 nF capacitor was charged with a $\sqrt{LC}$ time of about 3.5 ns from a larger pulse charged capacitor via a pair of multichannel edge plane gaps of total length about 120 cm. The gap operated in pressurised nitrogen and gave a total of 10 to 15 channels and operated closely in accord with the data given in "Results from Two Pressurised Edge Plane Gaps," (J. C. Martin, F. Grimson; Switching Note 20, September 1972) without any significant signs of fizzle at voltages up to 190 kV.

In the air breakdown experiments the effective time the voltage was applied to the gap (full pulse width at 89% of peak volts) varied from 2 to 13 ns, with most of the times between 2 and 5 ns. These times were corrected to a time of 2.5 ns, assuming $Ft^{1/6}$ was constant. Such a correction brought the data into good agreement. The air pressure was varied between 0 to 67 psig and the 'scope response corrected breakdown voltage varied between 71 and 180 kV.

The air results from "High Speed Breakdown of Pressurised Sulphur Hexafluoride and Air in Nearly Uniform Gaps" (J. C. Martin, Switching Note 21, February 1973) suggest that for the very limited range of data studied, $Ft^{1/6} d^{-1/6}$ is constant. The data from the last graph in that note, when scaled to a gap of 8 mm and a time of 2.5 ns, gave the solid line in Figure 1. Some other data obtained with a fast charged fairly uniform weakly irradiated pressurisable gap operating at up to 600 kV agreed well with the data of Switching Note 21, except near one atmosphere, where the breakdown field was some 15% lower, suggesting, as is speculated in the note, that there was little overdrive because of lack of initiating electrons, even though the original gaps were unirradiated. Thus the curve in Figure 1 is expected to be also very close to that applying to an irradiated gap.

The experimental breakdown field data, scaled to a time of 2.5 ns, is also shown in Figure 1 and the agreement at the high pressure end is within the expected experimental error. At low pressures the present data lies a little above the curve scaled from Switching Note 21. This is probably due to a delay in the production of initiating electrons and if the gap had been irradiated I would expect the low pressure data to drop to the curve, or slightly below it, to the dotted curve.

Thus the new data supports the results of the previous high speed breakdown note and extends the data to 2.5 ns. Less certainly (because of the limited range of the parameters), the air breakdown in this region of spacing and time scales as $Ft^{1/6}\ d^{-1/6}$. The time range over which the expression has been tested is from 40 ns to 2 ns and d has ranged from 0.8 to 3 cm.

3 HIGH SPEED ATMOSPHERIC BREAKDOWN OF SMALL, NEARLY UNIFORM GAPS

During work on a four element low voltage irradiated gap some data for the high speed well irradiated breakdown fields in air at one atmosphere was obtained. Again the data is not of exquisite accuracy, largely due in this case to possible errors in measuring the spacings. The gap was between relatively large diameter long rods, i.e., it was a near uniform rail gap.

Figure 2 gives the breakdown voltages observed when the gap was very well irradiated from a nearly surface flashover irradiator. When this was removed the breakdown fields could easily treble, as well as developing very large jitters. The voltage jitter well irradiated was difficult to measure directly, but as multichannel operation was observed regularly it was plausibly a fraction of a percent.

In Figure 2 the times are again full pulse width at 89% of peak volts. The curves for 10 and 2 1/2 ns approximately obey a $t^{1/6}$ dependency and this has been used to indicate the breakdown voltage required for 0.6 ns, which was beyond the 'scope's measuring capability.

The high speed breakdown field data over the range 0.2 mm to about 2 mm obey a relationship of the form $Fd^{1/6}$ = constant, where d now has a positive power rather than the negative one indicated by the larger gap data discussed in the previous section. The reason for the larger gaps having a breakdown field which weakly increases with gap distance is that for very fast pulses the final plasma channel streamer takes a significant time to cross the gap, and hence the larger gaps need a little more volts. For small gaps the plasma channel closure time is still very short, even at a couple of ns, and hence this field dependency disappears and is overcome by other effects.

The DC breakdown for very small gaps eventually goes as $d^{-1/2}$ and while the high speed breakdown does not seem to have as strong a dependency as this, it still exhibits some of this effect. Figure 3 sketches the breakdown field dependency for 2 1/2 ns at atmospheric pressure as a function of gap spacing indicated by the data of this and previous notes. The curve may well be changed in detail for other times and for other pressures. Indeed one would expect that Figure 3 might be more generally applicable if plotted as a function of p × d rather than as d. If this speculation is right, then pressurised small gaps would continue to obey $Ft^{1/6} d^{-1/6}$ constant down to very small gaps.

As a brief aside for those unfamiliar with previous notes, for mildly non-uniform gaps the breakdown field used above is that applying to the electrodes, that is the breakdown voltage increased by the field enhancement factor divided by the gap spacing. This is most conveniently done by using an effective gap spacing, the real distance divided by the FEF. However, in the field dependency relations d is still the real gap separation in mildly non-uniform gas as this is the distance the plasma channel has to close over.

The DC breakdown voltage shown in Figure 2 is the one obtained without pulse irradiation. With sufficiently intense uv pulse irradiation small gaps can, of course, be broken down at voltages below their DC levels.

Before closing this section it should be repeated that functional dependences suggested in this note have only been tested over very limited ranges and are known not to be true, say, for longer times and may well not be those that apply for large gaps. However, fortunately there are unlikely to be too many requirements for many atmosphere, metre spaced, few ns, breakdown air gaps, but if anyone has such a need, I would strongly advise them not to use the relations given, unless utterly desperate.

4 SMALL GAP PULSED SURFACE FLASHOVER DATA

In a previous note, "Pulse Surface Tracking in Air and Various Gases," (J. C. Martin, High Voltage Note 4, May 1974), the length tracked (1) was found to be a function of the state of DC charge on the surface, as would be expected. Also the length was observed to obey a relation of the form

$$1 = k \, (V - 5.5 \, \delta^{1/3}) \, t^{1/4}$$

where V is the voltage in kV, δ is the mylar insulation thickness (in thou., i.e., 10^{-3} inch) when 1 was more than a couple of cm or so. For the case where the surface was discharged between pulses and for t in nanoseconds, this relation becomes

$$1 = 0.3 \, (V - 5.5 \, \delta^{1/3}) \, t^{1/4}$$

In the original note the definition of t is rather peculiar but corresponds to the pulse width at about 87% of maximum volts. To adequate accuracy this is the same as the pulse width at 89% of maximum volts, which is the definition used in this note.

In those experiments it was noted that ahead of the bright discrete channels there was a faintly glowing uniform region, typically of the order of 1 to 2 cm long, for times of 100 to 1000 ns long. It was speculated that the voltage ($5.5\ \delta^{1/3}$) taken away from the applied voltage represented a drop down the uniformly glowing avalanche region prior to the development of current instabilities which lead to the formation of plasma channels. As such, the relationship really applied to the growth conditions of these channels.

For the experiments reported here the gaps were much smaller (0.3 mm to 5 mm) and hence apply to conditions where this uniformly glowing avalanche region bridges the gap before the instabilities have developed much and plasma channels formed. As might be expected, the relationship for the length tracked was very different. Firstly there was much less effect of previous non-sparking pulses on the breakdown voltage, especially for the smaller gaps. This means that there was not much hysteresis in the breakdown field for the smaller gaps, the same voltage roughly being obtained whether the voltage was slowly raised until sparking occurred, or lowered until sparking ceased. Secondly, for small gaps this sparking voltage was proportional to gap length and one could use a breakdown field relationship to adequate (±10%) accuracy. For a range of mylar thicknesses from 0.25 to 3 thou. (mil. for USA readers) the following rough relationship applied reasonably well in air:

$$F\ t^{1/6} = 36\ \delta^{1/6} \qquad F\ \text{kV/cm}$$

For one set of conditions (δ = 1 thou., t $\sim$ 30 ns) it was shown that the tracking relationship changed from the new small gap one to the old long track one, the changeover distance being as calculated, around 3 mm for these conditions.

In the experimental gaps 2 thou. steel sharply cut edges were used and some care taken to ensure that this and the mylar were tightly and permanently pulled down onto the backing metal plane.

The range of times studied were from about 2 ns to 30 ns in these experiments and once again the reader is warned that no great accuracy is claimed for the relationship given.

5 ACKNOWLEDGMENTS

It is a pleasure to thank Tommy Storr for his help in obtaining the results given for the 8 mm gap. Equally, however, he is entirely blameless for what I have done with them. My thanks are also due to Mrs. Vikki Horne, who I defeated with one horribly written word. However this victory doesn't really count, as I couldn't read it either.

Air Breakdown Field Uniform Gap $t_{eff} = 2.5$ ns

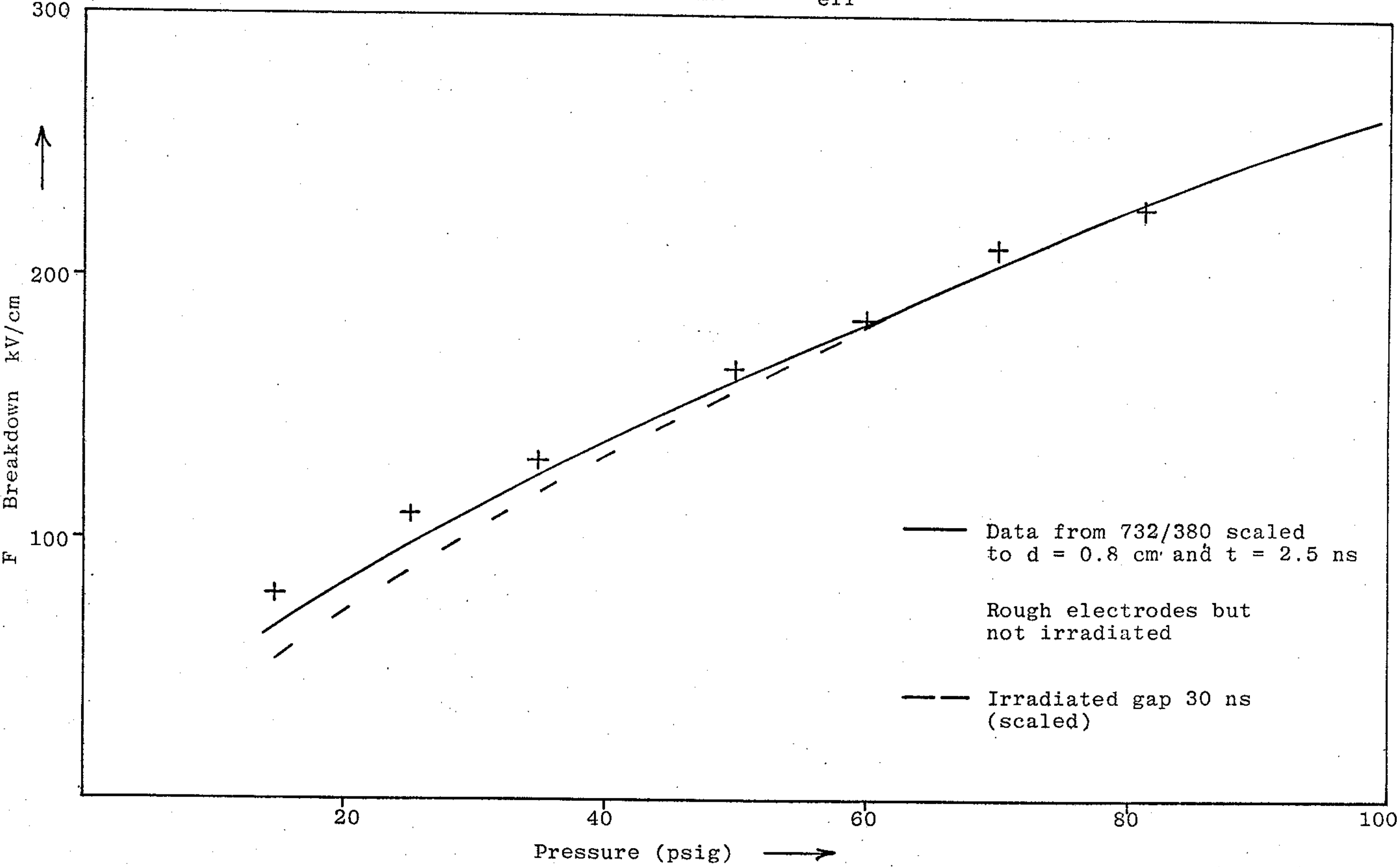


Figure 1

Irradiated Pulse and DC Breakdown Voltage of Atmosphereic Air Gap

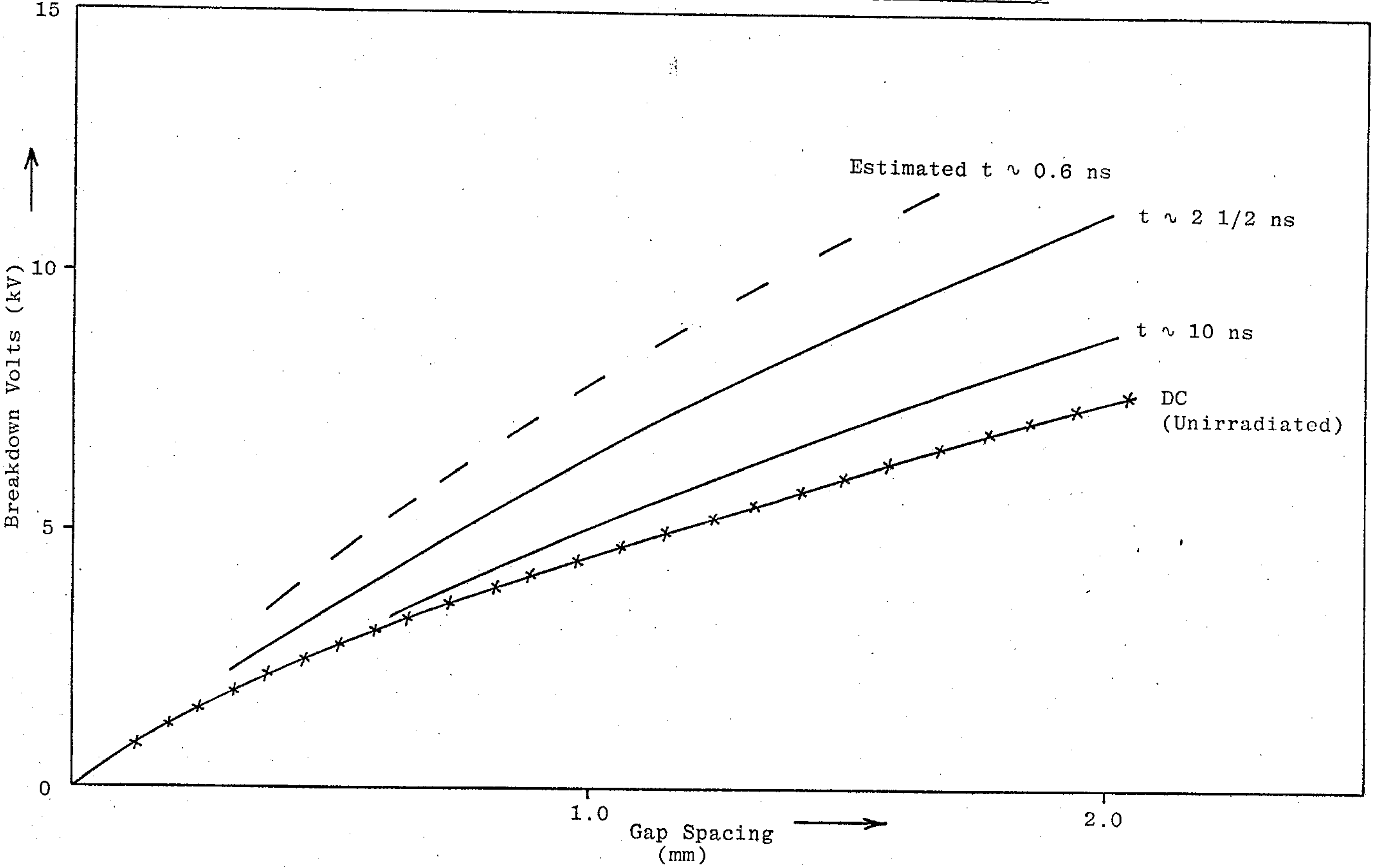
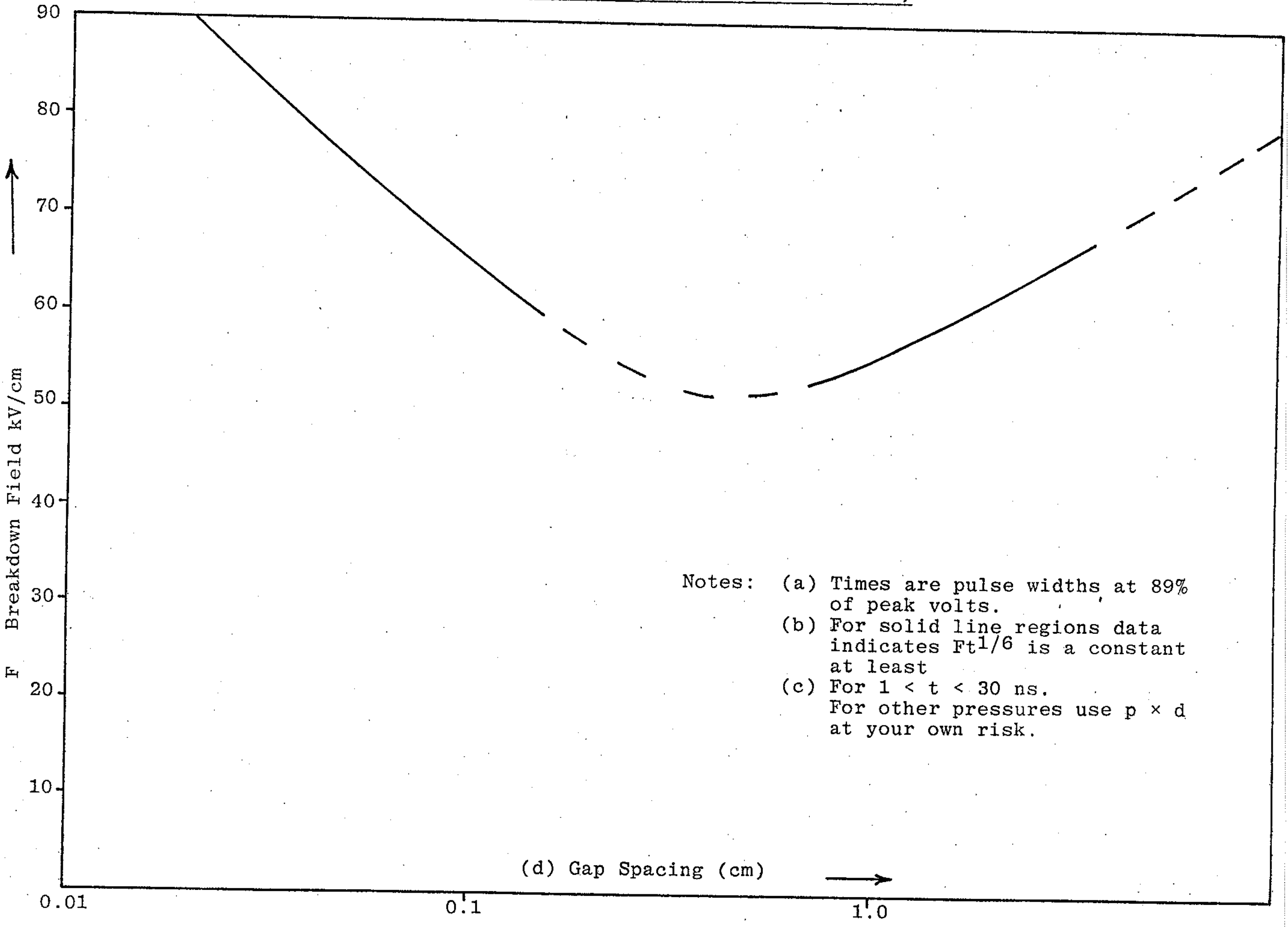


Figure 2

2 1/2 ns Breakdown Field for Air at One Atmosphere (Irradiated)



Notes: (a) Times are pulse widths at 89% of peak volts.
(b) For solid line regions data indicates $Ft^{1/6}$ is a constant at least
(c) For 1 < t < 30 ns.
For other pressures use p × d at your own risk.

Figure 3