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STREAMER CHAMBER DEVELOPMENTS AT SLAC*

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The recent work on streamer chambers at SLAC has mainly concentrated on the construction of very large chambers. Two experimental groups here have been involved in the developments. One is the group designing the e^+e^- colliding beam ring, and the other is interested in photoproduction. Before I discuss the work on large chambers, I will describe the work done on small chambers. A subgroup of the photoproduction group put a small chamber (30 cm × 40 cm with a 13-cm gap) in a magnetic field. There was no top pole piece so that the chamber could be photographed parallel to the electric field. The pulsing system was conventional—a Marx generator with a shorting gap across it. The object was to try to do some physics with it and to test some ideas for use with large chambers. The chamber and the magnet are at the Mark III 1.2-GeV linac at the Stanford campus in a parasite beam. Figures 1, 2, and 3 are photographs taken with this system. Tracks of tridents and bremsstrahlung are shown. Those involved are D. Benaksas, D. Drickey and R. Morrison.

Work on ionization measurements with small chambers has been done by F. Bulos of the colliding beam group, and F. Villa and myself of the photoproduction group. This work was done when news of the peak in the Brookhaven quark experiment arrived. What was desired was a means for telling the ionization of a particle. It was first thought that by partially evacuating a streamer chamber, one could separate the ions enough so that the number of streamers per cm was directly proportional to the ionization. A plot of the number of streamers per cm vs. the pressure of neon was made. As one evacuated the chamber, the number of streamers per cm remained constant at ≈ 2.5 until the pressure reached 0.2 atm. The number per centimeter then decreased. Extrapolating the slope at zero pressure to one atmosphere gave about 10 streamers/cm (Fig. 4). Unfortunately, as one reduces the pressure the electric field must also be lowered, as there exists the relationship $E^2T/P = \text{const.} \approx 4$, where E is the electric field in kV/cm, T the pulse width in nsec, and P the pressure in torr. This relationship holds for the production of constant length streamers. On the other hand, for a given length streamer, the luminosity varies approximately as E^2. Thus the streamers at low pressures are faint, for constant pulse width. This produces photographic problems and one is not certain that the film can pick up all of the faint streamers. It was therefore decided that this was not the way to do ionization measurements.

Instead, another approach was tried. The high-voltage pulse was delayed with respect to the passage of the particle and the electrons allowed to diffuse away from each other. A plot of the number of streamers per cm vs. the delay of application of the high-voltage pulse showed that the number per cm increased with delay till about 50 μsec, where it reached 10 per cm (Fig. 5). From 50 - 200 μsec, the number remained constant, showing little recombination effects. At this point the quark peaks disappeared and the project was dropped.

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FIG. 1

FIG. 2

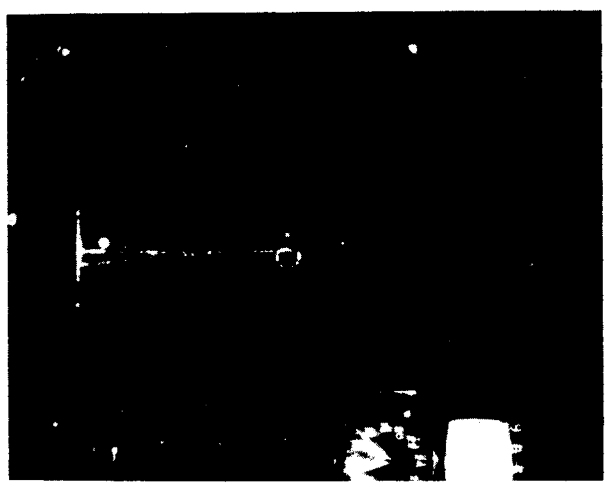
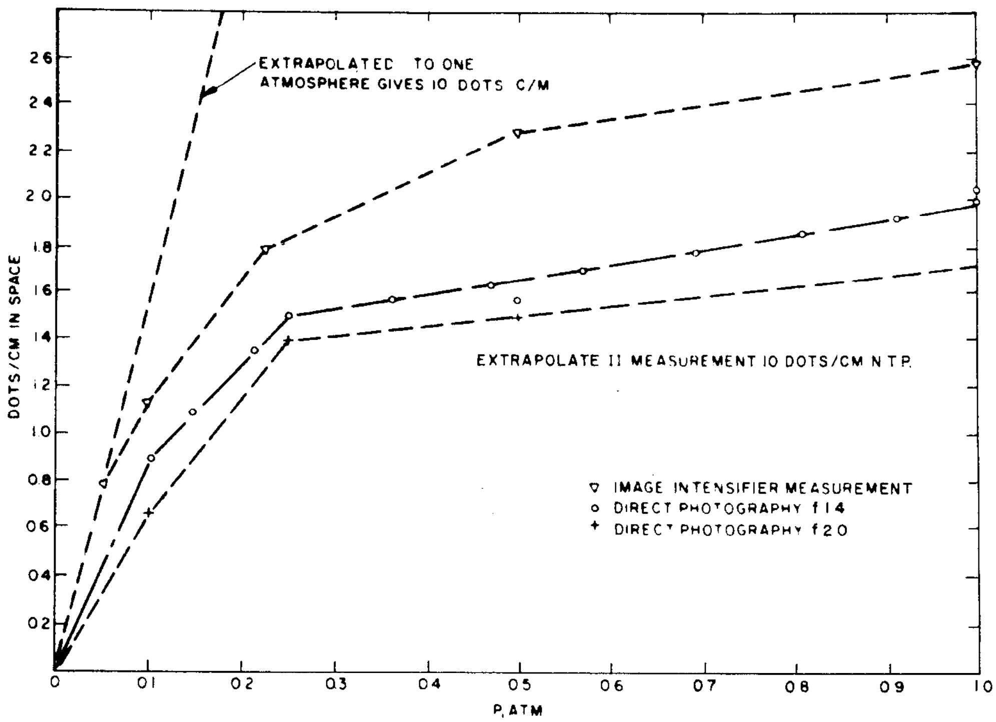
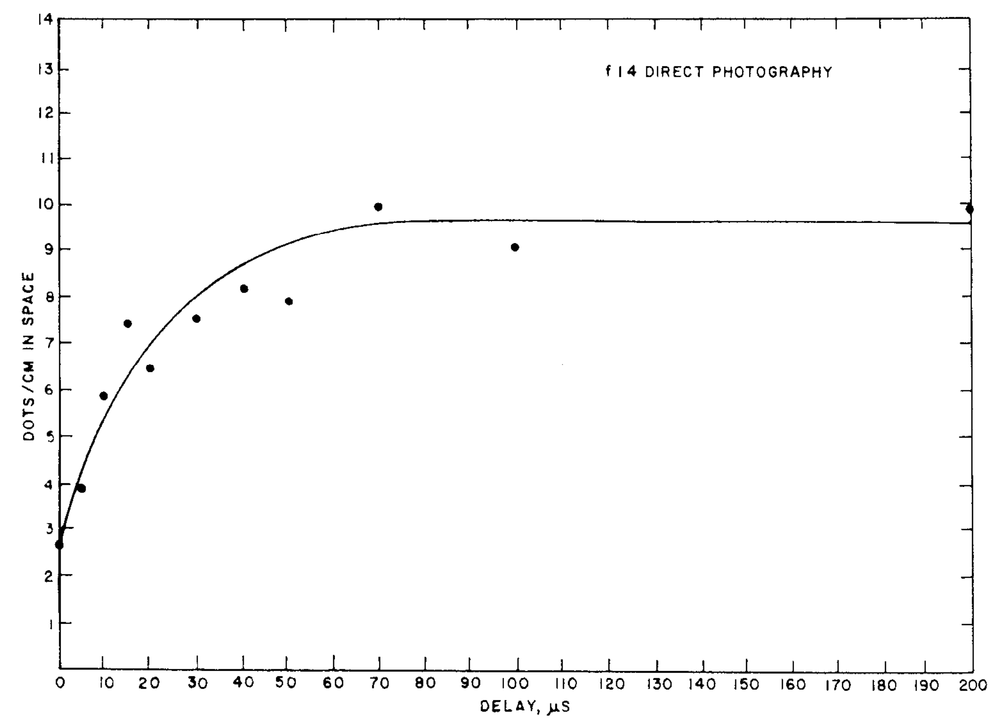


FIG. 3



EXTRAPOLATED TO ONE ATMOSPHERE GIVES 10 DOTS C/M
EXTRAPOLATE II MEASUREMENT 10 DOTS/CM N.T.P.
▽ IMAGE INTENSIFIER MEASUREMENT
○ DIRECT PHOTOGRAPHY f 14
+ DIRECT PHOTOGRAPHY f 20
DOTS/CM IN SPACE
P, ATM

FIG. 4



f 14 DIRECT PHOTOGRAPHY
DOTS/CM IN SPACE
DELAY, μS

FIG. 5

Now to the work on large chambers. Once the length of a chamber gets of the order of the pulse width, a streamer chamber must be treated as a transmission line and be terminated at the end in order to insure that all parts of the chamber have the same pulse shape and amplitude. One cannot rely on multiple reflections from an unterminated end to build up the voltage, as the pulse shape would be a function of position. This would lead to streamers of unequal length and brightness as E^2T/P must be a constant. If the chamber is wide as well as long, the characteristic impedance of the chamber is low. It is even further lowered if a two-compartment chamber is used. Two-compartment chambers are useful for halving the voltage needed to drive a given depth chamber. Furthermore, one can close the sides and greatly reduce the problems of pickup on transistor electronics. Typically, the impedance of a large chamber will be between 20 - 50 ohms. A chamber of such impedance cannot be driven directly from a Marx generator as the inductance in the generator is large, $\approx 1/\mu H$. This would lead to a very slow risetime as $\tau \approx 2.2$ L/Z $\approx$ 44 nsec for a 50-ohm chamber and 110 nsec for a 20-ohm chamber. The only proper solution is to charge a transmission line and switch it to the chamber.

There are many different systems of transmission lines for producing the required low impedance source. Among these are the mercury switch type pulser, which consists of a section of transmission line that is pulse charged. A series spark gap in one of the electrodes is switched, giving at the output a rectangular pulse of amplitude half the voltage to which it is charged, and whose duration is twice the length of line charged. The main difficulty with this line is the loss of the factor of two in the output amplitude. A second system is one similar to the first but in which the charged section of the line is dielectrically loaded. This lowers its impedance and hence raises the output voltage. This system was first proposed by Soviet groups in their work on streamer chambers. The main difficulty with this system is that the pulse shape is no longer rectangular. A third system is the Blumlein system. Here a third electrode whose length determines the duration of the pulse is introduced in the transmission line. It is charged and then switched to the ground electrode. The output is a rectangular pulse of amplitude equal to the voltage to which it is charged. The three systems are compared in Fig. 6. In the last column under impedance across the switch is this parameter. It determines the best possible risetime.

The explanation of the Blumlein system is rather complicated, but in any case, you can see that you have twice the capacity to the lower plate and twice the capacity to the upper plate in comparison to the mercury switch type pulser. Conservation of energy of $1/2\ CV^2$ tells you that the pulse will be the full amplitude in comparison to the 1/2 amplitude. There are also so-called stacked Blumleins—you can pile one on top of the other to get voltage gain. However, as one reduces the impedance across the switch, the rise time will be degraded. If you try to get too much voltage gain, you lose risetime.

Now for the big systems. The colliding beam group is interested in having a large streamer chamber as a detector, and for this F. Bulos has built a test system which consists of the chamber shown in Fig. 7. The chamber is driven with a 600-kV, 600-pf Marx generator which charges up a glycerine condenser

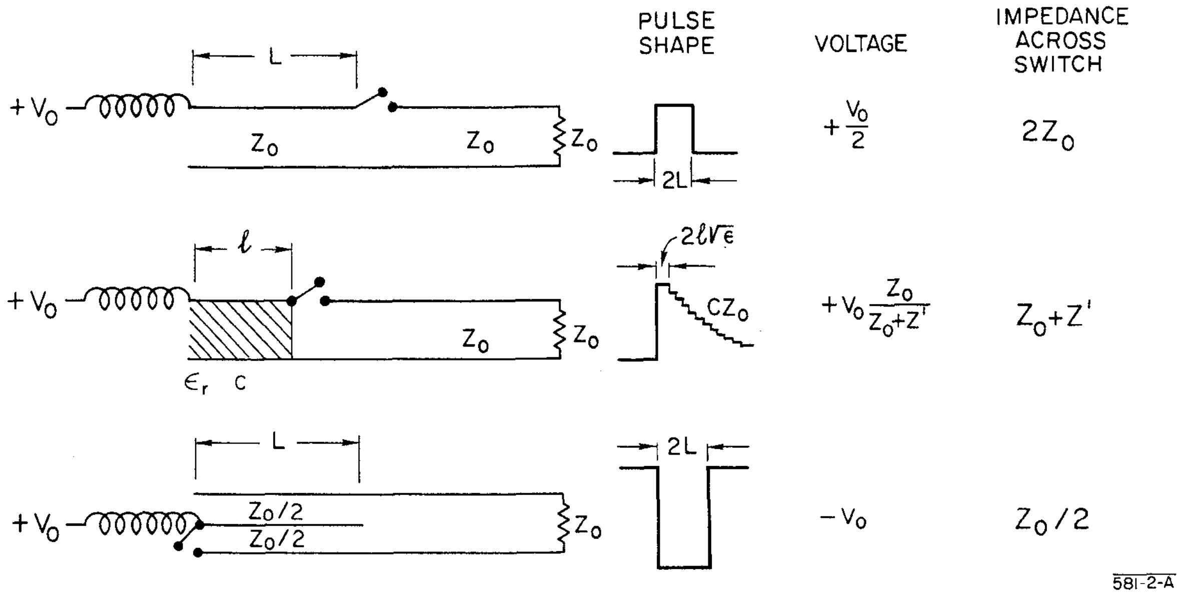

PULSE SHAPE
VOLTAGE
IMPEDANCE ACROSS SWITCH
+V0
L
Z0
Z0
Z0
2L
+V0/2
2Z0
ℓ
2ℓ√ε
CZ0
εr C
+V0 Z0/(Z0+Z')
Z0+Z'
Z0/2
Z0/2
-V0
Z0/2
581-2-A

FIG. 6

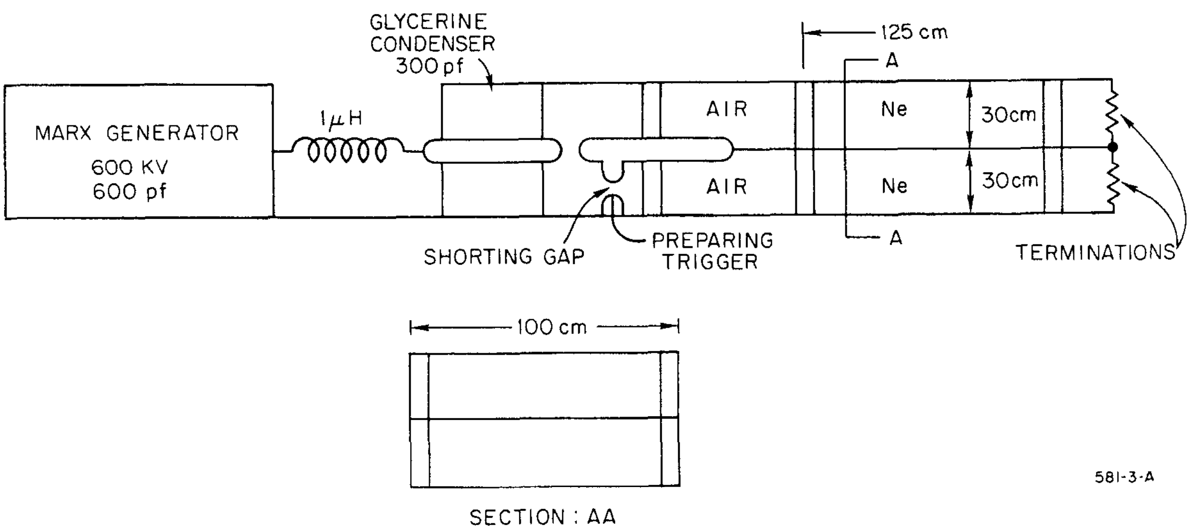

GLYCERINE
CONDENSER
300 pf
125 cm
A
MARX GENERATOR
600 KV
600 pf
1μH
AIR
AIR
Ne
Ne
30cm
30cm
SHORTING GAP
PREPARING
TRIGGER
TERMINATIONS
100 cm
SECTION : AA
581-3-A

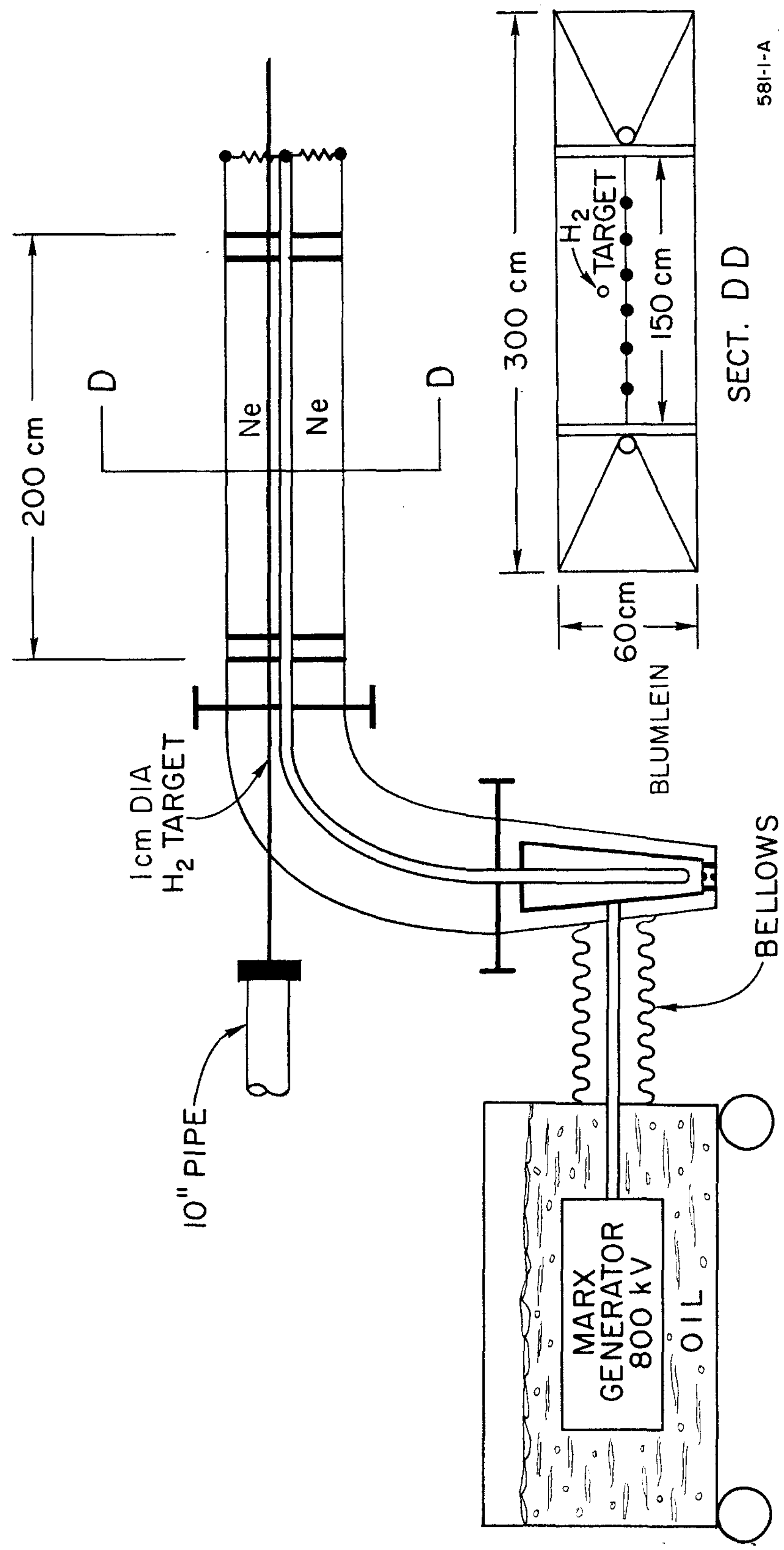
FIG. 7

of 300 pf. When that is fully charged, a series gap fires, applying the pulse to the chamber, and a shorting gap chops the pulse. This chamber is 125 cm long, 100 cm wide, and has two 30-cm gaps. Bulos has made a test removing one of the compartments, and he got tracks in the chamber that were quite good. He has tried terminating and not terminating the chamber. It is not quite clear whether it is absolutely necessary to terminate a chamber of this size or not; that is, it has not been shown to be experimentally necessary, although I believe that it is.

The other group that is interested in streamer chambers is the photoproduction group. Here F. Villa and I have worked on the pulser and D. Yount has worked on the chamber. We are more stressed in that we have to have a chamber ready for experiments shortly. Our system is illustrated in Fig. 8. An 800-kV, 1000-pf Marx generator charges up a double-sided Blumlein. You can think of the Blumlein which was shown in Fig. 6 as a figure of revolution. The spark gap is on the bottom. The voltage builds up, the spark gap fires, and out comes the pulse. It bends around 90° and goes into the chamber. The useful region of the chamber is 2 meters long, each gap is 30 cm, and it is 1-1/2 meters wide. The photon beam will pass through the upper compartment in a mylar tube filled with hydrogen gas. This makes it useful to SLAC; we have so much photon intensity that we can use gas targets. For people who want liquid hydrogen targets, it may be slightly difficult to put one in when these things pulse up to many hundreds of kV. The terminators are at the end. A common disease of lucite wall chambers is a surface breakdown. We have replaced lucite by polyurethane foam. The dielectric constant is about the same as air, and therefore there should be no electric field concentrations near the surface.

Now to the problem of photography—light. This is the problem that everyone who considers streamer chambers worries about. Photography...they say, well, there is a depth of field problem, and how can you have big chambers when there is so little light that comes from the streamers. It is impossible. Well, we are stating here that it isn't impossible. If you can photograph a small streamer chamber in focus, you can photograph a large depth of field as well. And the trick is demagnification.

It turns out that if you photograph a point source out of focus, the circle of confusion on film has a size that depends inversely on the demagnification squared. Thus if you reproject into space, the circle of confusion varies inversely as the demagnification. What has to be done is to crudely match the circle of confusion in space to the actual source size of the streamers. If the circle of confusion gets much bigger, you lose intensity, and you lose the tracks at the extremes of the chamber. All you have to do is to go far away from the chamber, and you can photograph as far as photographic density goes. However, the thing that hurts in photographing big chambers is that the more you demagnify, the worse your errors get. You have to take the errors. In our big chamber, I would expect most of the errors to come from photographic problems. The projected errors in space we estimate conservatively to be ± 1/2 mm. That sounds terrible; but if you have a 2-meter chamber and a 10-GeV photon which makes a rho, you can determine the mass to 1%. There is no multiple scattering, so you can use the whole track to determine the momentum.



200 cm
D
Ne
Ne
D
300 cm
H_2 TARGET
150 cm
SECT. D D
60cm
BLUMLEIN
581-I-A
1cm DIA
H_2 TARGET
BELLOWS
10" PIPE
MARX
GENERATOR
800 kV
OIL

FIG. 8

We have looked at various films, and until recently the best film had been one called 2475 put out by Kodak. Recently we have gotten a new film called Special Order 340 from Kodak. Figure 9 shows some of the characteristics of the two films when hand developed. Shown is the density versus time for 3 minutes, 6 minutes, 8 minutes, and 10 minutes of development. After about 8 minutes you don't gain much, so forcing the development doesn't help.

Figure 10 shows a comparison of hand and machine development. The right-hand graph is hand developed. The SO-340 film is faster than the 2475, but the comparison of the two shows that if you machine develop them, you gain speed, and that is true for both films. Figure 11 shows the effect of force developing. The standard developing plot is on the right and force developing is on the left. Figure 12 shows two resolution charts. For 2475 film, the large box has fuzzy edges. The edges are considerably sharper on the left-hand side for the SO-340 film.

Various parameters have been used in comparing films: resolution, modulation transfer function, etc. I would like to stick my neck out and say that you can evaluate films that way, but there is a much easier way. The way to evaluate a film is not resolution but acutance. This is the same thing as frequency response vs. risetime in a pulse circuit; you don't want to speak of frequency response, but risetime. Tracks have edges, and it is important how sharp the edges are. For instance, if one contact exposes some film to form an edge and then puts it under a microscope, 2475 film will have little hairy arrays of grains that stick out from the developed region into the undeveloped region. This gives you a statistical error on where the edge is. Similarly, to find the center of a circle, the edges are very important. If the circle of confusion were perfectly circular, you could find the center of it quite accurately. The fuzziness of the edge determines the accuracy that can be obtained. For lenses, problems such as coma give a fanlike image. Where is the center of such an image? The error gives the acutance of the lens.

Those are the major parts of the streamer chamber which I wanted to mention. However, I did want to say something about the high-voltage technology that we have learned from the J. C. Martin group at AWRE, Aldermaston in Great Britain. It turns out that high-energy physicists and high current, high voltage switching people are two non-intersecting groups. We found out that we were just infants in the field. There are various commercial groups in the field, one of which is building a 10-mV Marx generator and a 10-mV Blumlein with a 0.75-megajoule capacitor bank and 3/4 of a million amperes. They make flash x-rays. It is absolutely fantastic. One piece of information we got from the English group that I have never seen anywhere is on the risetime of a spark gap. They claim that the risetime T is a combination of two terms, τ_L and τ_R. The inductive part τ_L can easily be calculated; it is about 2.2 times the inductance over the impedance. If there is a spark gap across a strip line, then the impedance is that of the strip line, and the inductance is that of the spark and its electrodes. L consists of two terms, the L of electrodes plus the L of a spark, and the typical radius for a spark should be 0.05 mm. τ_R is due to the formation of a plasma in a conducting column. It has been calculated theoretically and it turns out experimentally reasonably correct:

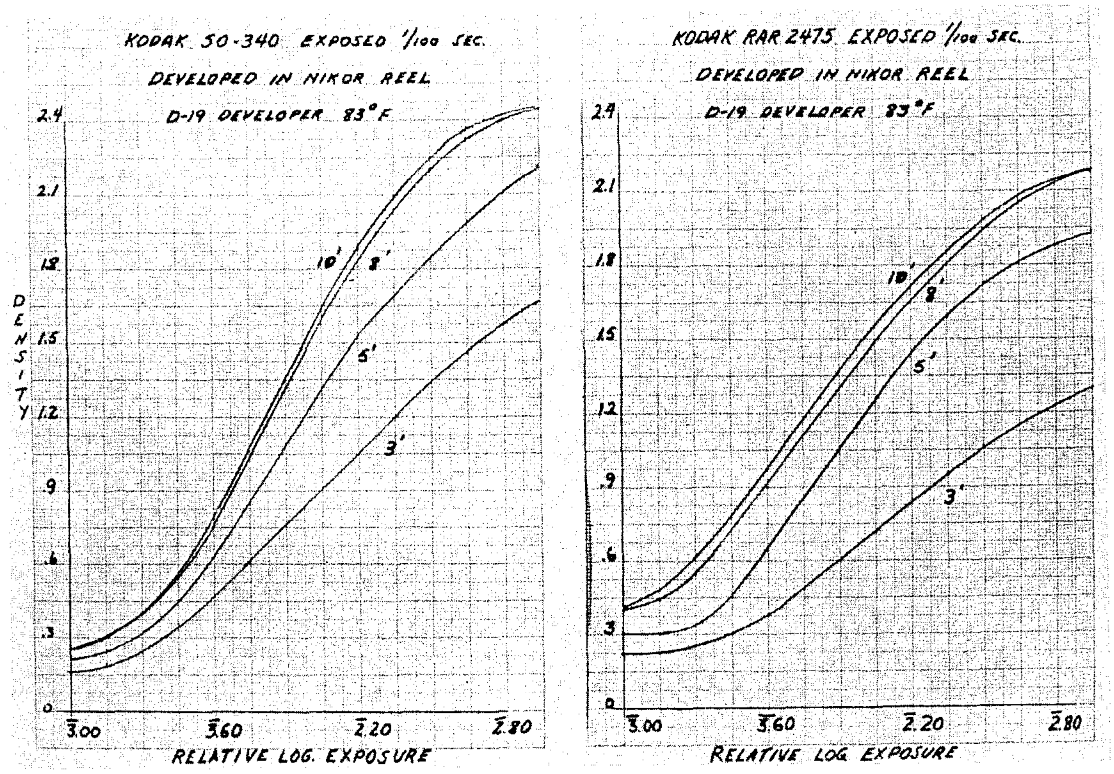

KODAK SO-340 EXPOSED 1/100 SEC.
DEVELOPED IN NIKOR REEL
D-19 DEVELOPER 83°F
DENSITY
2.4
2.1
1.8
1.5
1.2
.9
.6
.3
0
10'
8'
5'
3'
3̄.00
3̄.60
2̄.20
2̄.80
RELATIVE LOG. EXPOSURE
KODAK RAR 2475 EXPOSED 1/100 SEC.
DEVELOPED IN NIKOR REEL
D-19 DEVELOPER 83°F
2.4
2.1
1.8
1.5
1.2
.9
.6
.3
0
10'
8'
5'
3'
3̄.00
3̄.60
2̄.20
2̄.80
RELATIVE LOG EXPOSURE

FIG. 9

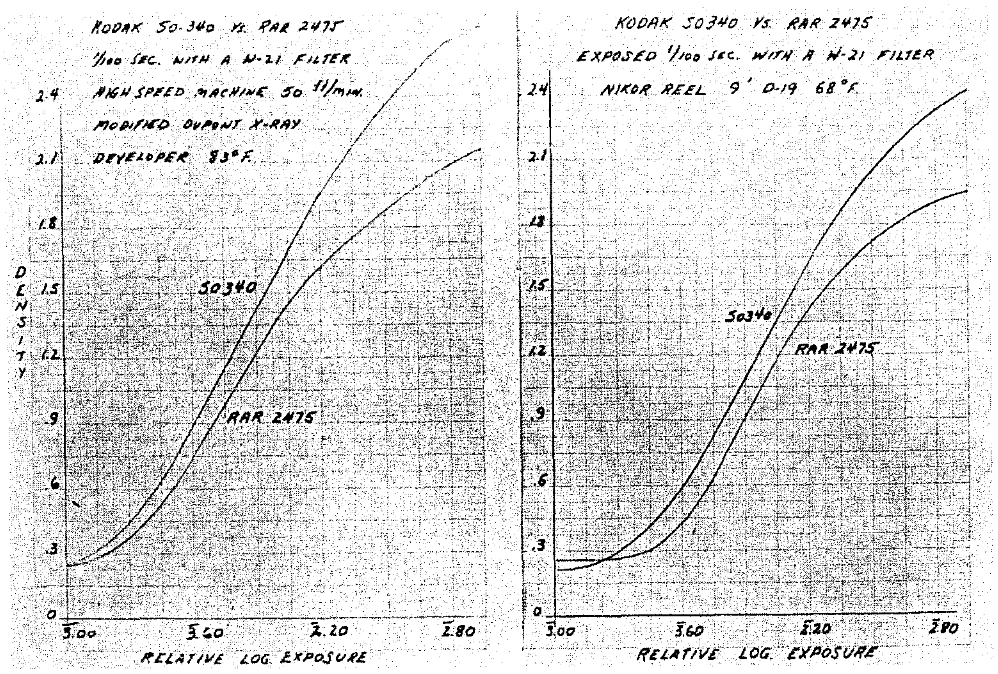

KODAK SO-340 VS. RAR 2475
1/100 SEC. WITH A W-21 FILTER
HIGH SPEED MACHINE 50 ft/min.
MODIFIED DUPONT X-RAY
DEVELOPER 83°F.
DENSITY
2.4
2.1
1.8
1.5
1.2
.9
.6
.3
0
SO340
RAR 2475
3̄.00
3̄.60
2̄.20
2̄.80
RELATIVE LOG. EXPOSURE
KODAK SO340 VS. RAR 2475
EXPOSED 1/100 SEC. WITH A W-21 FILTER
NIKOR REEL 9' D-19 68°F.
2.4
2.1
1.8
1.5
1.2
.9
.6
.3
0
SO340
RAR 2475
3̄.00
3̄.60
2̄.20
2̄.80
RELATIVE LOG. EXPOSURE

FIG. 10

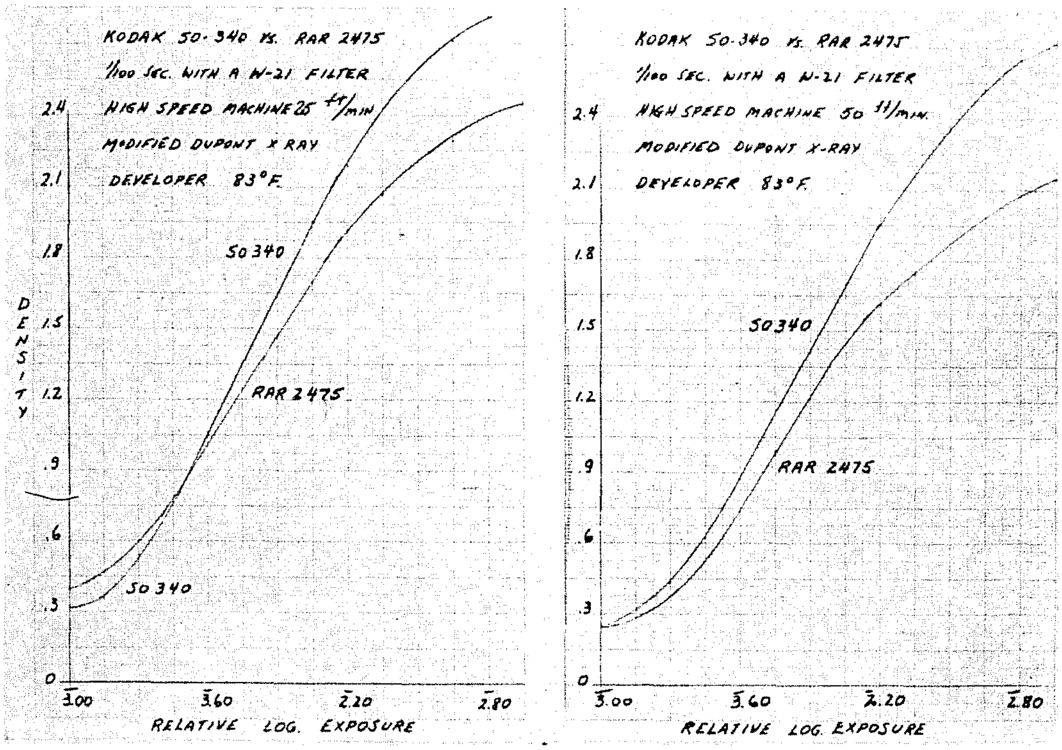

KODAK SO-340 VS. RAR 2475
1/100 SEC. WITH A W-21 FILTER
HIGH SPEED MACHINE 25 FT/MIN
MODIFIED DUPONT X RAY
DEVELOPER 83°F.
SO 340
RAR 2475
SO 340
DENSITY
RELATIVE LOG. EXPOSURE
KODAK SO-340 VS. RAR 2475
1/100 SEC. WITH A W-21 FILTER
HIGH SPEED MACHINE 50 FT/MIN.
MODIFIED DUPONT X-RAY
DEVELOPER 83°F.
SO 340
RAR 2475
RELATIVE LOG. EXPOSURE

FIG. 11

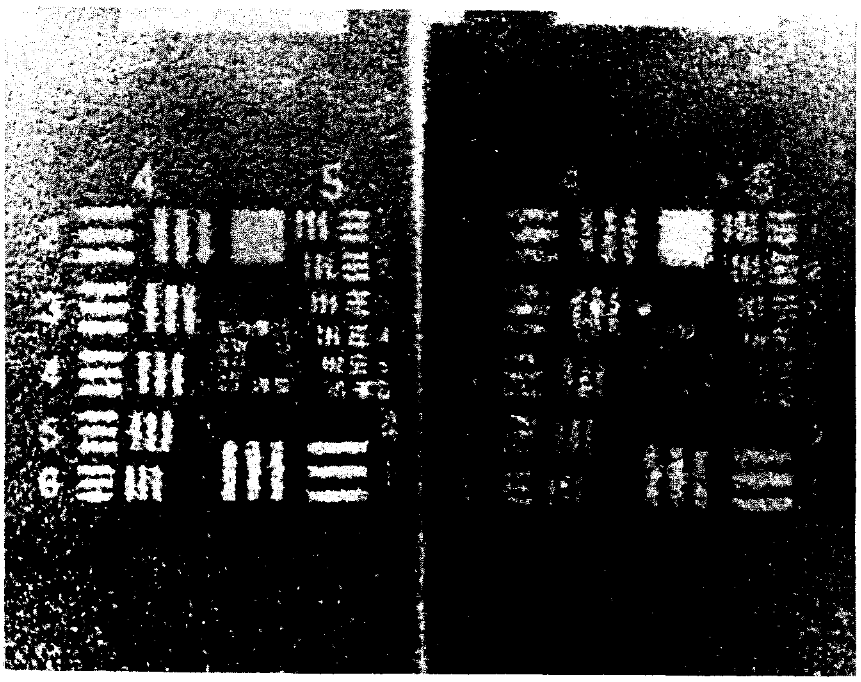


FIG. 12

$$\tau_R = \frac{200}{Z^{1/3}\,F^{4/3}}\left(\frac{\rho}{\rho_{air,\ 1\,atm}}\right)^{1/2} \quad \text{(in nanoseconds)}$$

where Z is the impedance across the switch in ohms
F is the electric field across an untriggered gap in units of 10 kV/cm
ρ is the density of the gas used relative to air at atmospheric pressure

The risetime varies inversely as the cube root of the impedance Z that is shorted—that is why the impedance across the switch was listed in Fig. 6. However, this is a slow dependance. You can see that you want high pressure, since the density goes as the 1/2 power while the electric field goes as the 4/3 power. Thus, τ_R varies roughly inversely as the 5/6 power of the pressure. High pressure gaps have fast risetimes. Fields above 600 kV/cm lead to instabilities in the breakdown fields, thus limiting F to a maximum of 60. We have also gotten information on how much voltage oil can hold off as a function of time and how much the volume breakdowns of plastics are. There are just an infinite number of parameters, too many to discuss here.