(and some theory in the work of Knobloch and Karetnikov) that surface plasma formation plays an important role in dark current generation, and in the subsequent breakdown. Rf breakdown is explained by these authors in terms of three separate mechanisms involving a surface acting as a cathode (micro-protrusions), or as an anode being bombarded by electrons or ions. Also involved, is the space between the two surfaces, where collisions can occur among various species of electrons, ions or neutrals.

This theory, although semi-empirical, fits the observations made in the SLAC ring experiments, and is consistent with our experience in processing S and X-band klystrons, as well as X-band waveguide components and accelerator structures. These observations are summarized below:

- The number of potential emission sites due to micro-particle contamination, as determined by SEM scanning of sample test cavity "buttons", does not seem to correlate with the magnitude of dark current measured (indirectly) through X-ray production in ring tests. Also, only a fraction of these contamination sites are found, through subsequent SEM examination, to have been involved in rf breakdown.
- In contrast, a definite correlation has been found between the number of emission sites along grain boundaries observed after rf runs, and previous vacuum firing. It is presumed that gas issuing from these boundaries is involved in breakdown events, and that vacuum firing reduces adsorbed gasses, making these events less likely.
- In processing both klystrons and waveguide components, it has become obvious that only with an excellent pressure (better than $10^{-8}$ Torr at the pump) can processing be performed with positive results. At higher pressures, discharges take place which liberate so much gas that processing must be interrupted until the vacuum can recover sufficiently.
- An established practice in processing new (or repaired) 5045 klystrons is to limit the drive pulse to a fraction of a microsecond and to process at that pulse length up to full output power. Subsequent full pulse length processing can then proceed, with a minimum of breakdown events.
- There is evidence with both klystrons and waveguide components that irreversible damage can result from processing at long pulse lengths, and/or poor vacuum.

From all of the above, one can postulate a "straw-man" scenario, which can be put to the test and subsequently acted upon. It is the following:

- Rf breakdown is a consequence of excessive dark current production and the ionization of desorbed gases caused by electron impact on surfaces or surface coatings, such as copper oxides. The "cathodic" part of the process is due to impurities and/or protrusions in the material, but the "anodic" effects of ionization and field enhancement are essential for the dark current to result in a discharge. A high background pressure is probably also sufficient in itself for breakdown to occur.
Since there will always be some emission sites, it is important to treat those with rf, but it is equally important to limit the energy in the rf applied by using a short pulse length while gradually increasing the peak power. This is entirely analogous to the technique used for decades in the processing of electron guns. It is called "high-potting", or more descriptively, "spot-knocking", and involves a high voltage supply in series with a high resistance to limit current.

Given the foregoing considerations, a tentative protocol for component and structure fabrication and processing, to be verified by the cavity experiments described below, is the following in broad outline: Prepare parts for assembly as usual, but under Class-1000 clean-room conditions. Vacuum-fire (or bake and pump) the finished assembly above 500 °C. Store under vacuum. Install with klystron and vacuum bake in place at 200 °C overnight. Process with 50 nsec pulses (or more, as determined by experiment) as fast as maintenance of 8-scale vacuum will allow. Continue, until the desired operating power is exceeded by 20%. Reduce power level, double the pulse length and repeat, until rated power and pulse length are reached.

3. The high-Q cavity series of experiments.

The SLAC X-band rf breakdown research conducted until now has been handicapped by two equipment limitations: Vacuum in the cavity is the same as the ring vacuum and samples cannot be baked to a better vacuum. And the pulse length is at least as long as the ring filling time, which is at least 500 nsecs. In the new experimental setup, the cavity is equipped with two windows and the entire assembly is baked at 550 °C and pinched off. It is also provided with a controlled leak valve to independently control the pressure of a specific gas. The experimental setup is discussed below:

The setup for the rf breakdown experiment is outlined in the block diagram shown below. The rf source is the XL-1 klystron. It can produce up to 50 MW for 1.5 μs at 11.424 GHz. The output of the klystron is fed to a 3 dB magic-T. The components inside the dashed box are all bakeable to 550°C. The cavity, and associated hardware are isolated from the rest of the experiment with two TE11 windows. Since the cavity is pumped separately from the rest of the experimental setup, a controlled leak valve can be used to vary the background pressure in the experiment. The background pressure is monitored using an extractor gauge that will read down to 1x10^-10 torr. An RGA is used to monitor the gas species that are introduced or desorbed during the experiment.

There are several key features in this experimental setup. The first is the direct feed from the klystron that allows the pulsewidth to be adjusted from < 50 ns up to 1.5 μs. The second feature is the ability to vary the background gas pressure and introduce different gases into the cavity. The ability to bake out the cavities after assembly is critical to model the rf breakdown behavior of real structures that are baked out before operation.
The following experiments are proposed:

a. At least two pairs of buttons are prepared using good vacuum technique, fitted into the cavity and the entire assembly baked at 550 °C to 10-scale vacuum. The buttons are processed with 50-nsec pulses, 20% above the calculated desired gradient of 250 MV/meter. Processing is automated to allow increasing the power at a pre-established rate, while pressure is monitored, and to do this in identical fashion, every time. The time necessary to reach 300 MV/meter is recorded and the process repeated at 100 nsecs, then 200, and finally 350 nsecs. The peak gradient is reduced each time, so that at the final pulse length of 350 nsecs, it is the target 250 MV/m. A second, and possibly a third set of buttons are prepared and the identical process is repeated. Total time to complete processing is compared for the three samples. It is assumed that this protocol will allow processing with few breakdown occurrences. After a breakdown event, the computerized procedure will provide for vacuum recovery, or will recycle to the starting power level, or both. At the end of the experiment the noses are examined by SEM.

b. The above experiment will be repeated, omitting the bake-out step. Average processing times are compared.

c. a) and b) are repeated, beginning with 100 nsec, rather than 50 nsec pulses, and the processing times are compared.

d. Other experiments, including the introduction of various gases during processing, and the direct measurement of dark current will
be planned and will be instrumented, but will not take place until the results of the a-to-c series are applied to the processing of a suitable structure in ASTA.

4. **ASTA processing of high power rf components**
   
   ASTA processing to date has proceeded in two steps. Initially, high average power at low peak power is used to remove water vapor and other gaseous contaminants from the inner surfaces. This is done by disabling the PSK so that the SLED-II pulse compressor is not phase-shifted. In this way the highest power at the output of SLED-II is nominally only twice the klystron power. In this step the limiting factor in conditioning is the high gas load on the vac-ion pumps. In the second step, the pulse compressor is phase shifted and peak power levels of four times the Klystron input power are generated.

   In the new protocol, the first step will be omitted. Processing will be identical to a) in the previous section. The peak-power pulse-width from the pulse compressor can be made arbitrarily narrow by delaying the phase shift pulse to a later time.

   It is proposed that a waveguide component, which is known to have the highest gradient in NLC operation, be selected for processing. Experiments a) and b) of the previous section will be performed on two samples in a similarly automated fashion, so that uniformity of processing and adherence to the protocol are guaranteed.

5. **NLC processing.**
   
   A similar technique would be used to process the entire NLC “8-pack waveguide and accelerator structure system. In the multi-mode DLDS pulse compression system, the rf pulse width can be programmed to any desired width from 0-1.5 $\mu$s simply by adjusting the low-level rf generator width. This permits a conditioning process whereby narrow rf pulses (50 nsec) are used initially to condition the total rf system to its maximum power level (and, as before, 20% higher); Subsequently, the pulse is widened and the process repeated several times, decreasing the ultimate power level until the desired operating level is reached.

   It is believed, and the TM02 cavity experiments will hopefully prove, that this procedure will result in relatively speedy conditioning, with minimum damage to rf structures.