805 MHz Studies in Lab G

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Fermilab's Lab G

Test Bed for High Gradient Cavities in Large Magnetic Fields; Fast Beam Detectors in environment of Large X-Ray and Dark current emission: Specifically Measure High Gradient Breakdown and Dark current emission with and without the Magnetic Field on; and methods to reduce dark current with different materials and processing.

Fermilab Linac Type Modulator and Controls

12 MW 805 MHz Klystron and Waveguide

Cavity High Vacuum System

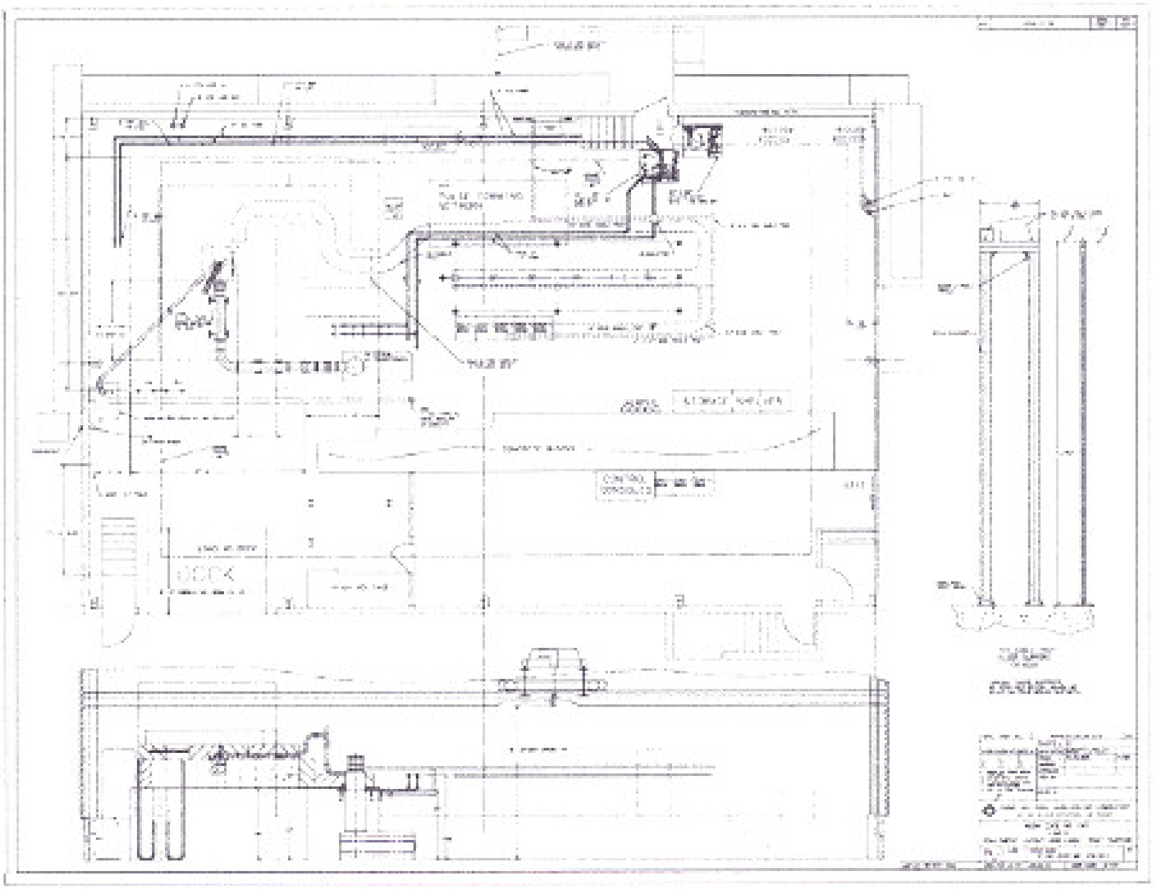
Cavity Water System

5.0 T Solenoid

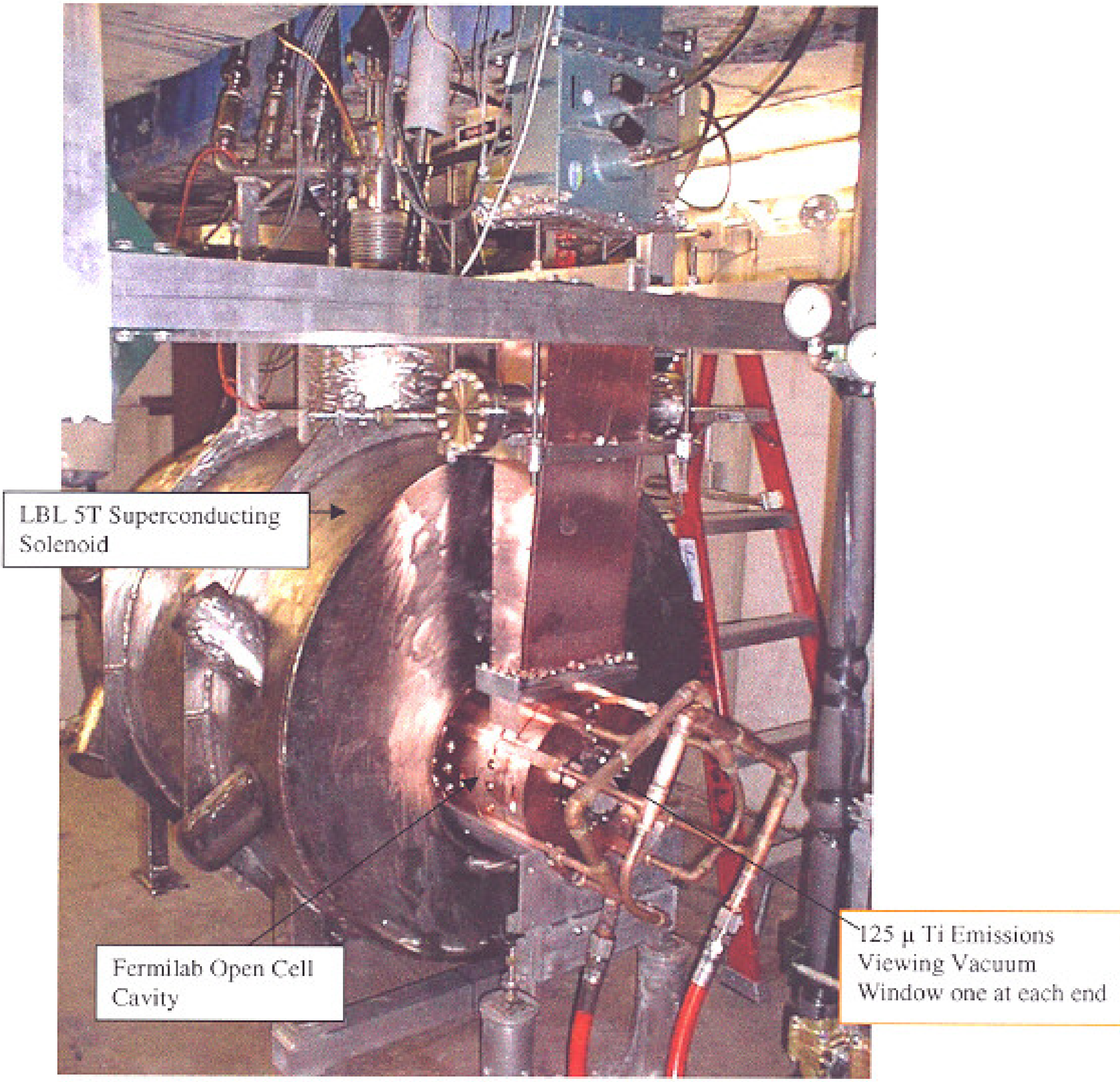
Support Cryogenic System

X-Ray Shielded Cave and X-Ray monitors
Surrounding the cavity.

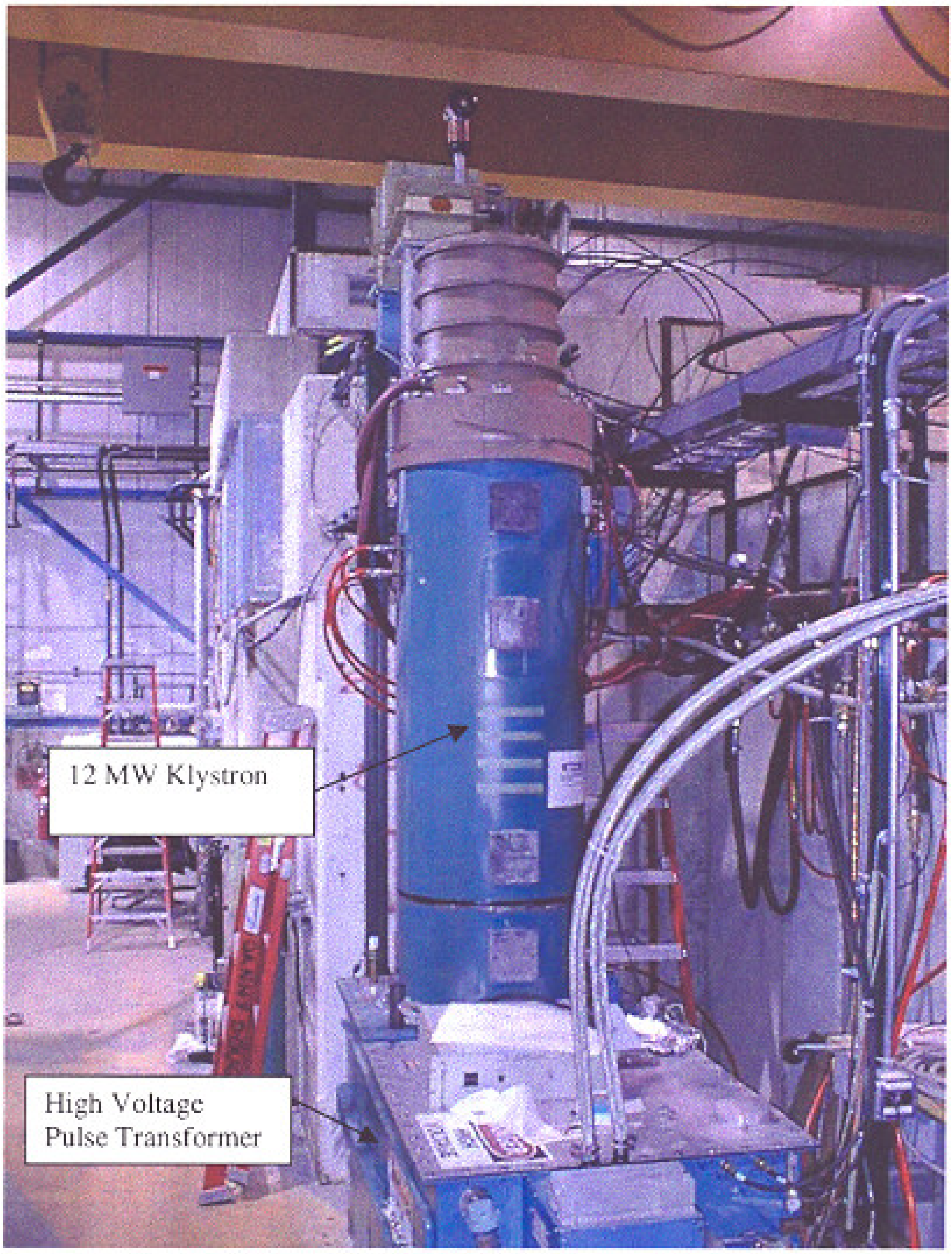
Interlocked RF with Sparking, Cavity Vacuum and
X-Ray level.



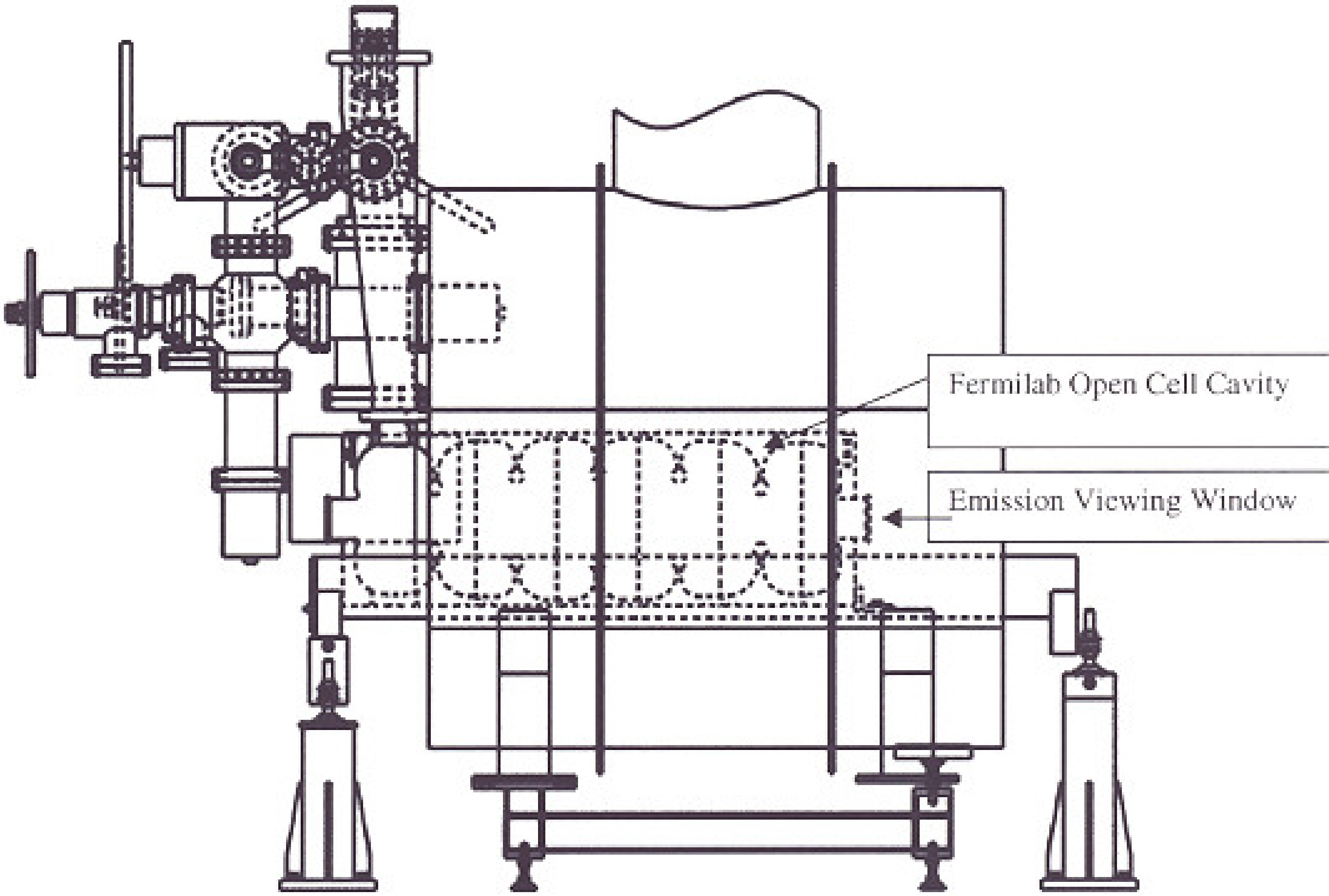
Top and Side View of Fermilab's Lab G, *High Gradient RF Cavity MuCool Test Laboratory.*



Picture of the Open Cell Cavity in the Solenoid



View of Nominal 12 MW klystron in Lab G
X-Ray Cave in Foreground

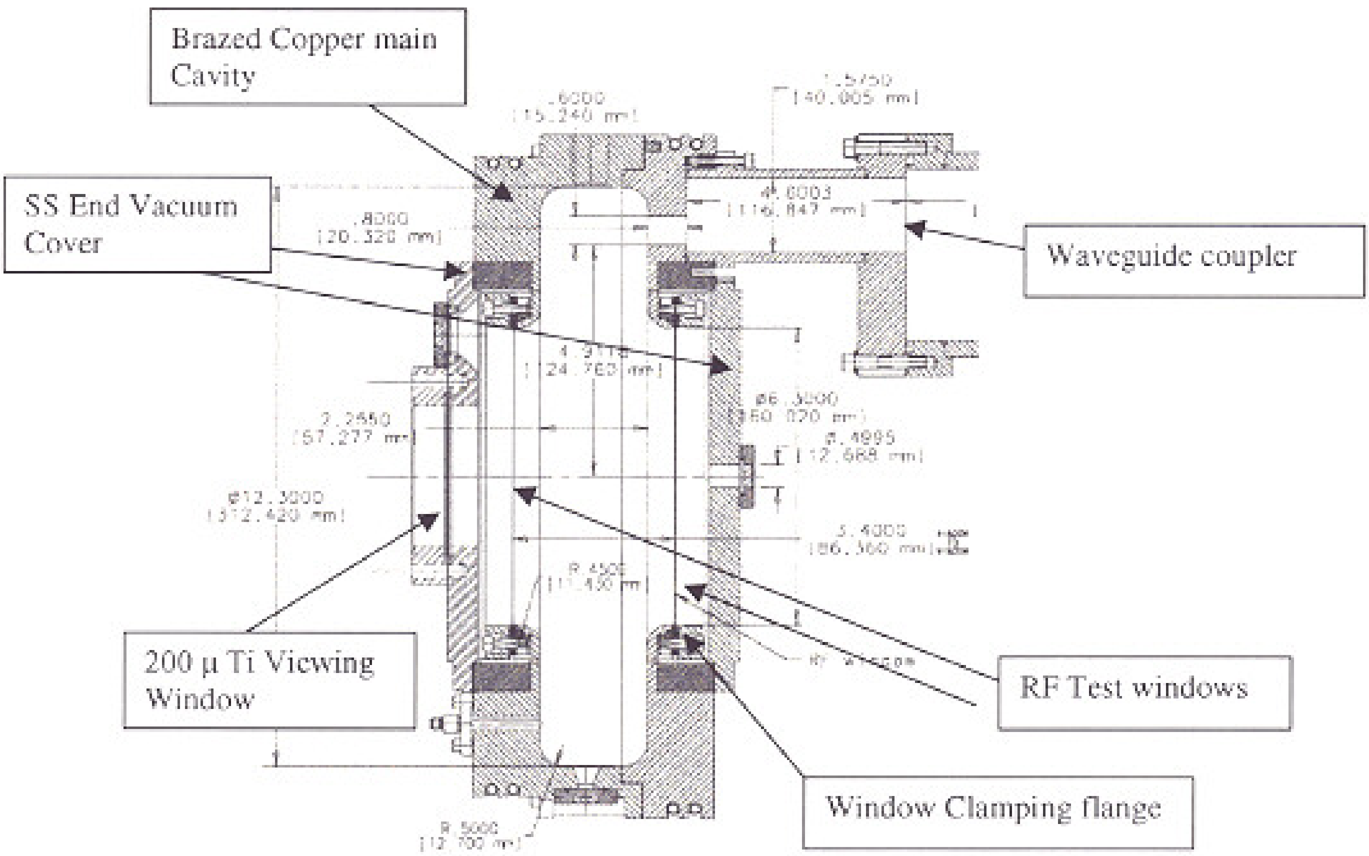


View of Fermilab Open Cell Cavity In 5.0 T solenoid and surrounding High vacuum system

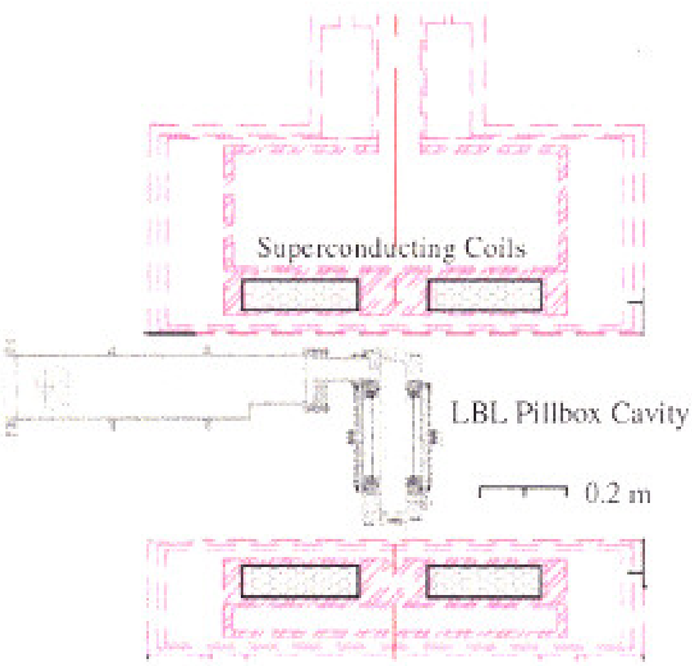
Π Mode, 6 Cells, 805 MHz

First test was conducted with the Fermilab Open Cell Cavity having six coupled cells in Π mode shown above. These test were conducted with and without the magnetic field turned on. Results are summarized later in this report.

The next set of experiments were conducted on the LBL single cell cavity. This cavity has been designed to test windows of varied design and materials.



Single Cell LBL Cavity



LBL Single Cell Cavity in Superconducting 5 T Solenoid

Experimental Results of RF Commissioning of the Fermilab Open Cell Cavity in Lab G:

Without the solenoid magnetic field ON:

Reached after 2 months of conditioning without Magnetic field;

1. AccGrad of 20.5 MV/m, PeakSurface of 54 MV/m And peak Cell AccGrad of 23.5 MV/m.

2. Peak Dark Current at the end of 2 Month Run of 100 mA at Max Gradient (much higher at start)

3. Sparking Rate at AccGrad of 20.5 MV/m of < 1/1000

4. X-Ray levels down over Factor 10 at End of Run.

With Magnetic Field ON at 2.5 T after a additional month of conditioning;

1. AccGrad of 20.5 MV/m, PeakSurface of 54 MV/m And peak Cell AccGrad of 23.5 MV/m.

2. Peak Dark Current at the end of 1 Month Run was higher by factor 2 or about 200 mA.

3. Sparking Rate at AccGrad of 20.5 MV/m of < 1/1000

4. X-Ray levels went down with running, but were still a factor 4 to 6 times higher than with out magnetic field on.
   X-Rays were converging along the magnetic Field Lines.
   At the end of this run we lost vacuum due to a pin hole leak in the downstream 125μ Ti thick Vacuum Window because of dark current guided by the magnetic field lines hitting the window.

The next set of experiments were conducted on the LBL Single Cell (Pillbox) Cavity:

Experimental Results of RF Commissioning the LBL Single Cell Cavity in Lab G:

The first RF commissioning studying of the LBL Cavity was conducted with thick copper windows without the magnetic turned on. The intent of this first study was to determine if copper without magnet field could reach the design limit of the Fermilab and BNL Cillider Studies I and II of 30 MV/m. After reaching design gradient plus about 10 %, the windows were removed and examined for spark damage. No damage was observed. In fact, the surface appeared as a just polished machined surface.

Results with the Copper windows without magnetic field are encouraging:

Reached 34 MV/m 10% over design gradient
Sparking rate low= 1 spark in 400,000
Radiation about a factor 1000 lower than Open Cell
No surface spark damage.

The second RF commissioning studying of the LBL Cavity was conducted with one 375 μ copper window replacing the undamaged thick window. The remaining undamaged thick window upstream of our X-Ray and dark current apparatus was left in place. The intent of this study was to determine the breakdown limit of copper with magnet field turned on.
It was decided to keep the first part of the RF commissioning to a low gradient of 24 MV/m without the magnet on so that any damage noted could be attributed to the field on condition. The commissioning without the magnetic field went well as before with little sparking and X-Ray emissions very low. Conditions changed dramatically when the magnetic field was turned on at 2.5 T. At a peak gradient of 21 MV/m the sparking became severe and the X-Ray emissions greatly increased. After operating at this level for several hours, it was necessary to back the gradient lower to 16.5 MV/m to achieve stable operation. The X-ray emissions were also greatly increased.

Results with the Copper windows with magnetic field on at 2.5 T:

Reached 21 MV/m for short time could not maintain; Sparking rate high had to reduce gradient to 16.5 MV/m For stable operation; Could not increase gradient any Higher without high sparking rate.

Ending Radiation emissions levels were 100 times larger Than previous run without magnetic field;

Noted a "curing effect" when running without magnetic on at High gradient for several days. The dark current emissions were reduced by large factor. However, this became less effective as time went on.

Severe sparking damage noted on windows and cavity after removal and microscope and SEM examination (Spark damage and molten copper found on high voltage area of the window and main part of Copper cavity itself).

The next RF commissioning studying of the LBL Cavity was conducted with Be windows coated with about 500 angstroms of TiN to reduce multipactoring . The window facing the dark current measuring apparatus (downstream) was 250 μ in thickness, the other 500 μ. The intent of this study was to determine the breakdown limit of Be with magnet field turned on. Again, it was decided to keep the first part of the RF commissioning without the magnetic field on to a low gradient of 24 MV/m so that any damage noted could be attributed to the field on condition. The commissioning without the magnetic field went well as before with little sparking and X-Ray emissions low. This study was extended to 4 T. Conditions changed again when the magnetic field was turned on.
It behaved much as the previous copper window experiment.
At gradients of 21 MV/m at 2.5 T and 18.5 MV/m at 4 T, the sparking became severe and the X-Ray emissions greatly increased. After operating at these level for several hours, it was necessary to back the gradient lower to 16.5 MV/m and 13.5 MV/m respectively, to achieve stable operation. The X-ray emissions were also greatly increased.

Results with the Be windows with magnetic field on at 2.5 T And 4 T:

Reached 21 MV/m at 2.5 T and 18.5 MV/m at 4 T for short time could not maintain;
Sparking rate high had to reduce gradient to 16.5 MV/m and 13.5 MV/m, respectiveley for stable operation;
Could not increase gradient any Higher without high sparking rate and high dark current emission;
Ending Radiation emissions levels were 10 times larger than previous run without magnetic field.
However this Run was cut short to inspect the windows;
Observed a "curing effect" when running without Magneticfield on at high RF gradients for several days.
Multipactoring was greatly reduced as expected with TiN.
Severe sparking damage noted on copper cavity parts;
No spark damage observed on TiN coated Be windows.
After removal and microscope and SEM examination (molten copper found on high voltage area of the window.
Figure 1 shows molten copper splatter, typically 125μ diameter, on the Be windows.

Summary of LBL Single Cell Cavity Results:

The study of the breakdown limit of the LBL single cell cavity with large applied solenoidal fields has been going on for over a year and a half. Studies were conducted with copper window inserts and for the last six months with Be windows coated with TiN. In general the breakdown limit is much lower with increase in applied magnetic field. In addition, the dark current and X-Ray emissions are much larger after the occurrence of some sparking at very high electric and magnetic fields.

The chart, Figure 2, presents the accumulated results over this period of study. The top graph shows the limit at which surface damaging sparks occur during relatively short RF commissioning period of time. Spending long periods say hours results in very large permanent increase in dark current and X-Ray emissions. Examination of the damage by SEM and optical microscope showed molten copper disks 100 to 125 μ in diameter scattered over the Be window surface, Figure 1. There was no spark damage observed in the Be, TiN coated windows. Spark damage was only observed in the copper parts of the Cavity. The copper windows inserts were observed to behaved in similar manner. This demonstrates that copper is the weak link in reaching high gradient in large magnetic fields. A research effort is being planned to find a coating that can greatly enhance the breakdown limit of copper.

The lower graph is the safe gradient operating limit in a magnetic field. Operating near this or at this limit results in little increase in dark current and X-Ray emissions. Examination of the Be window damage showed no occurrence of spark damage to the TiN coating or into the Be. However, because all of the occurrences of damage showed the presents of copper, the gradient limit in a high magnetic field is determined by copper. The breakdown limit will probability increase if we can find the magic copper coating that will suppress RF breakdown. The first choice in the planned research study will be TiN. It has demonstrated higher gradient breakdown limit than copper in the completed Be window study. Future studies of different materials and coatings are currently being planned.

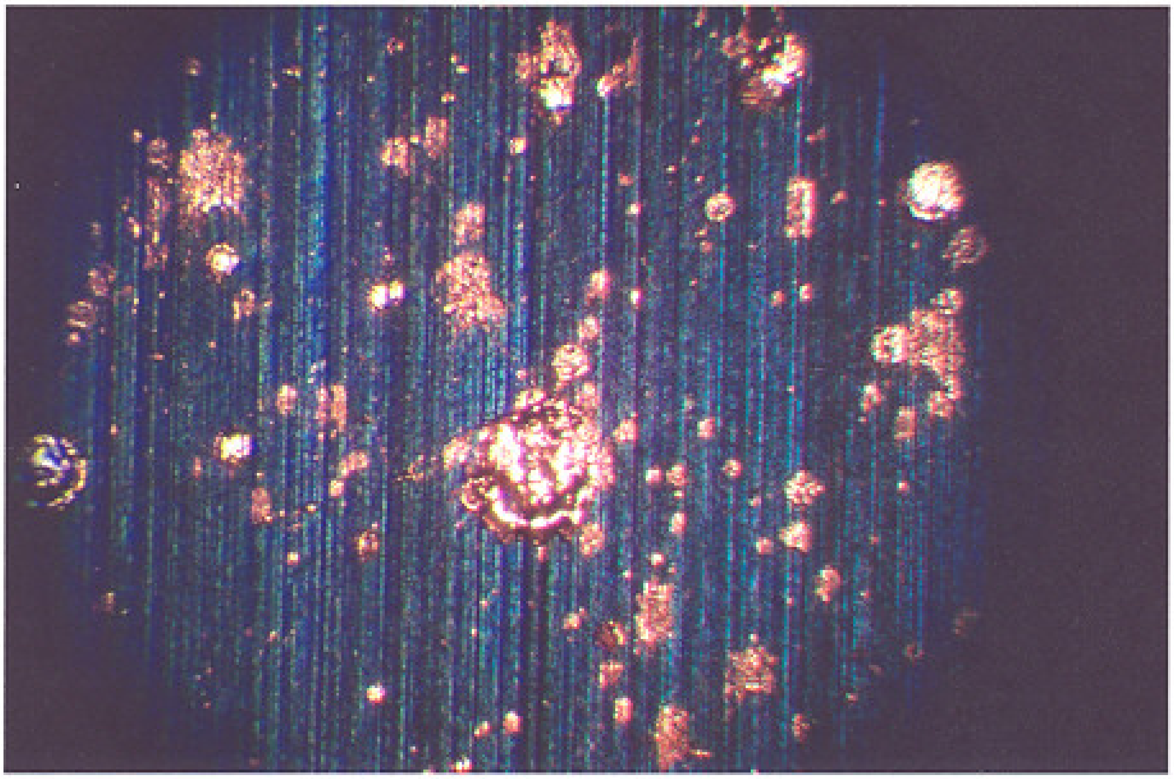


Figure 1, Copper Splatter on Be Window

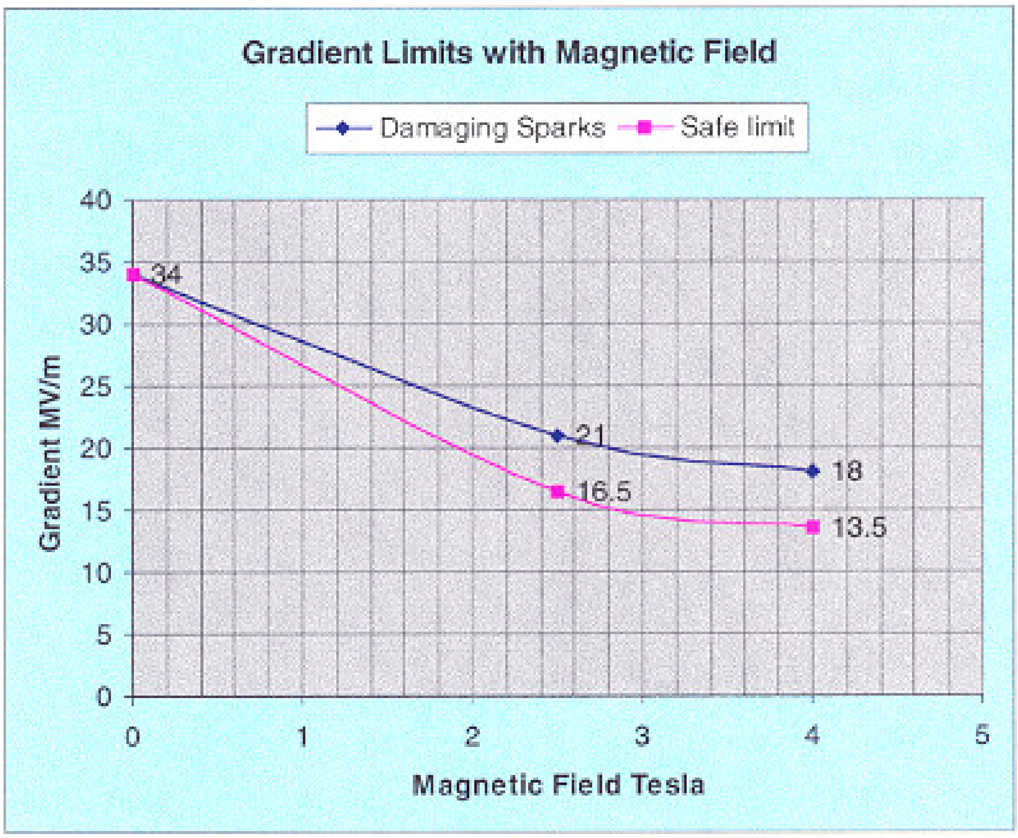


Figure 2, Gradient Limit with Magnetic Field