Synopsis of Cathode # 4 Activation

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I. Introduction

The purpose of this report is to describe the activation of the fourth cathode installed in the DARHT-II Injector. Appendices have been used so that an extensive amount of data could be included without danger of obscuring important information contained in the body of the report. The cathode was a 612 M type cathode purchased from Spectra-Mat[1]. Section II describes the handling and installation of the cathode. Section III is a narrative of the activation based on information located in the Control Room Log Book supplemented with time plots of pertinent operating parameters. Activation of the cathode was performed in accordance with the procedure listed in Appendix A. The following sections provide more details on the total pressure and constituent partial pressures in the vacuum vessel, cathode heater power/filament current, and cathode temperature.

II. Handling and Installation

Recommended handling procedures for the cathode is given in Appendix B. Basically, the goal is to minimize the time the cathode was exposed to atmosphere. Documentation of the life history of the cathode is desired to allow comparison between different cathodes. The handling record for cathode #4 through installation is provided in Appendix C. The cathode was exposed to atmosphere for approximately 66 hours. The majority of this time occurred during installation and alignment in the vacuum chamber.

III. Activation Cycle

The heating of the cathode started at 0700 on Friday, 28 April 2006. A transcription of the Control Room Log Book is given in Appendix D. This section provides a time line for the heating by describing actions listed in the Log Book plus plots of recorded readings of the injector ion gauges, cathode heater parameters, and the FAR pyrometer during selected time intervals. Plots of several of these parameters for the entire 67 hours of heating are shown in Appendix E.

The pressure in the vacuum vessel was 57 nano-Torr (nT) and decreasing when the heater power supply was set to 20 W. The power was slowly increased to 120 W over the next 1.5 hours in four increments. Shortly before 0900 the filament current and power readback indicate an uncommanded 10% increase. At 0902 there was a sudden pressure increase and the heater power was secured. The recorded upper ion gauge reached about 800 nT while the recorded RGA data indicated a peak pressure of ~900 nT. The pressure remained over 300 nT approximately four minutes. Figure 1 contains a plot of heater power, filament current, and pressure during this period. Appendix F describes the Historical Data Record used to produce the plot and gives some information on the diagnostics. The requested and readback power displayed in the Control Room differed by ~50 W. A discussion of the heater power and filament current is given in Section V.

[1]Spectra-Mat, Inc., 100 Westgate Drive, Watsonville, CA 95076, www.spectramat.com

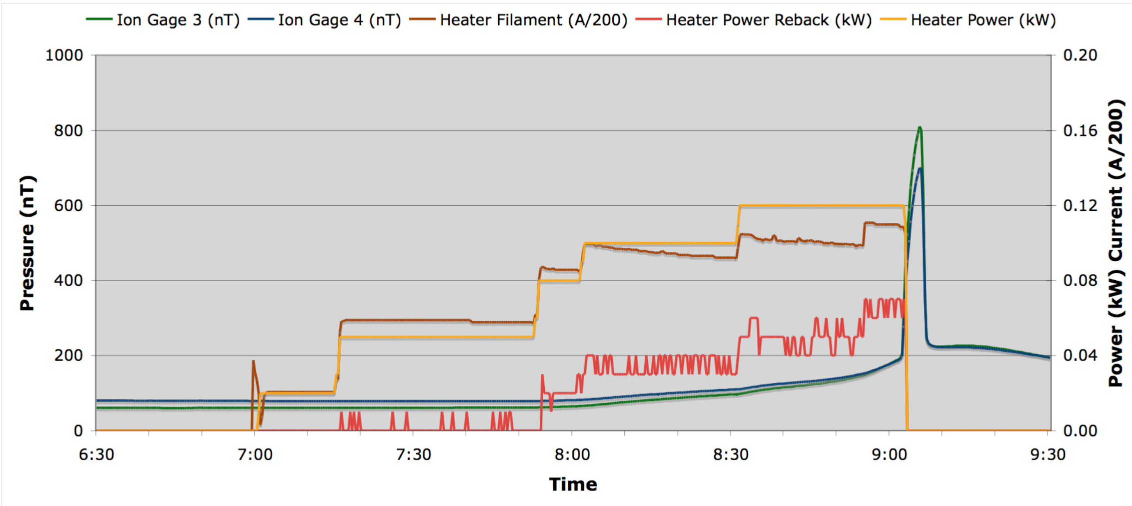


Figure 1. Time plot showing pressure and cathode heater parameters during the start of heating until the pressure spike.

After the pressure spike, the heater was left off for an hour for the vacuum to recover. At 1000 the heater was set to 100 A and left at that value for three hours. The pressure increased to ~200 nT during the first hour after the heater was reactivated then declined. At 1300 the heater power was increased to 120 W and periodically increased to a level of 350 W as the momentary pressure rises would start to decrease. Figure 2 is a plot of heater power, filament current, and pressure from 0930 to 1630. As the cathode temperature is approximately the same, the pressure peak around 1115 is most likely related to the same chemical processes as the earlier spike.

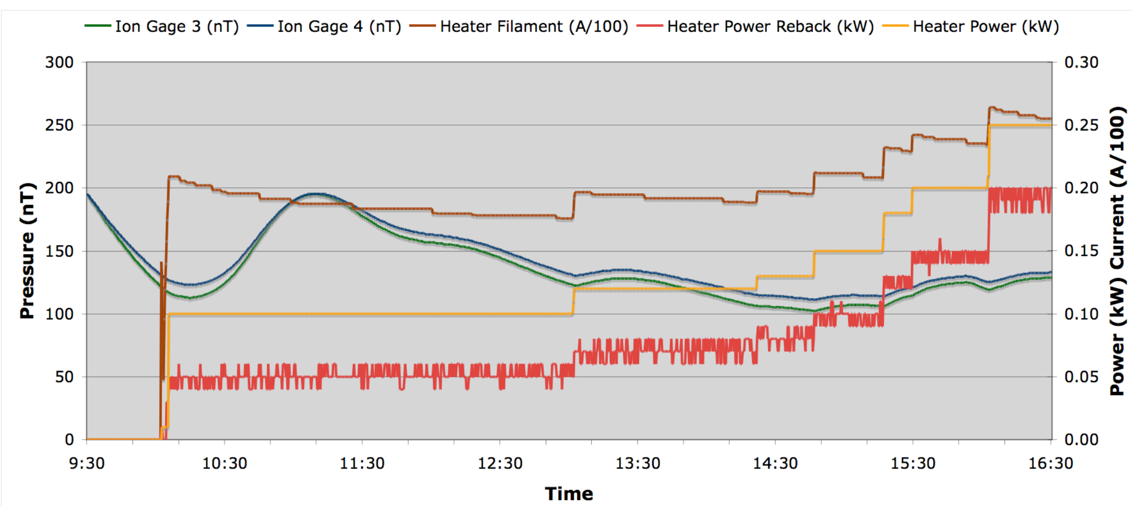


Figure 2. Time plot showing pressure and cathode heater parameters from the resumption of heating until 1630 on 28 April 2006.

At 1730 the heater power was set to 350 W and the pressure continued to increase for over an hour peaking at ~240 nT. This may be related to the break down of hydrates formed with the barium-calcium-aluminates and the out-gassing of hydrated water. This pressure peak did correspond to an increase in the partial pressure of water. The heater power was increased to 460 W at 2120 and held at this level for the 12 hours as proscribed in the activation procedure to allow for the breakdown of hydrates. Note that the readback power was 400 W. At 1900 the FAR pyrometer was energized. The pyrometer cannot be energized from the control room, but is physically turned on at the pyrometer. When the pyrometer was energized, the control system experienced a fault condition and shut down the heater. (Refer to Figure E-1 in Appendix E. The pyrometer output registered a maximum value initially at turned on and the control system interlocks shut off heater power as designed.) The operator reenergized the heater within a minute and set the power to 300 W. Figure 3 is a plot of heater power, filament current, and pressure from 1630 to 2130. There was a steady decline in pressure with the power set at 460 W indicating that the expected out-gassing of hydrated water had already occurred.

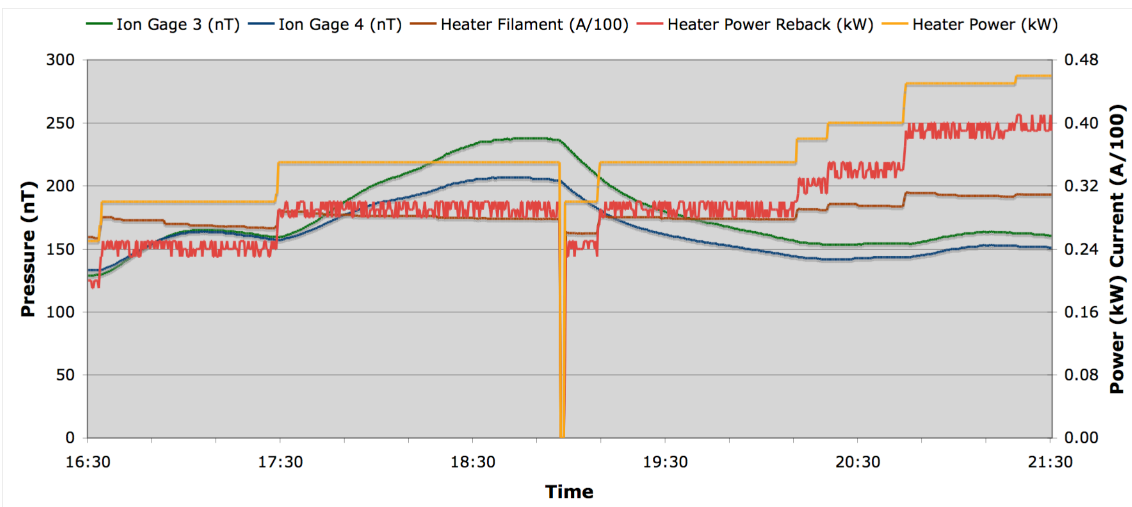


Figure 3. Time plot showing pressure and cathode heater parameters 1630 until 2130 on 28 April 2006.

The pressure decreased to 56 nT by the end of the 12 hours at the constant power setting. At 0900 on 29 April the power was increased to 0.5 kW and increased in 50 W increments every half hour until reaching 0.7 kW at 1100. Pressure peaked at ~159 nT around 1130 and power adjustments were stopped until 1230 when the power was increased to 0.75 kW. A broad series of pressure peaks occurred from 1100 on the 29th to 0200 on the 30th. Figures 4 and 5 are plots of the pressure and heater parameters during this period. The pyrometer began to register temperatures at 0037 as shown in Figure 5. The lowest temperature the pyrometer correctly registers is about 850°C_T. The plot subtracts 800° from the reading so that the actual temperature range of the plot is 800° to 1,100°. The pressure increase during this period is probably related to the breakdown of W_2O_5 and residual carbonates in the impregnate expected around 850°C. The power was set at 1.25 kW at 0130 with the pressure at 178 nT and held at that value until 1300. The temperature reached a constant value of 891 by 0230. The pressure began decreasing at 0150 from a peak value of 201 nT.

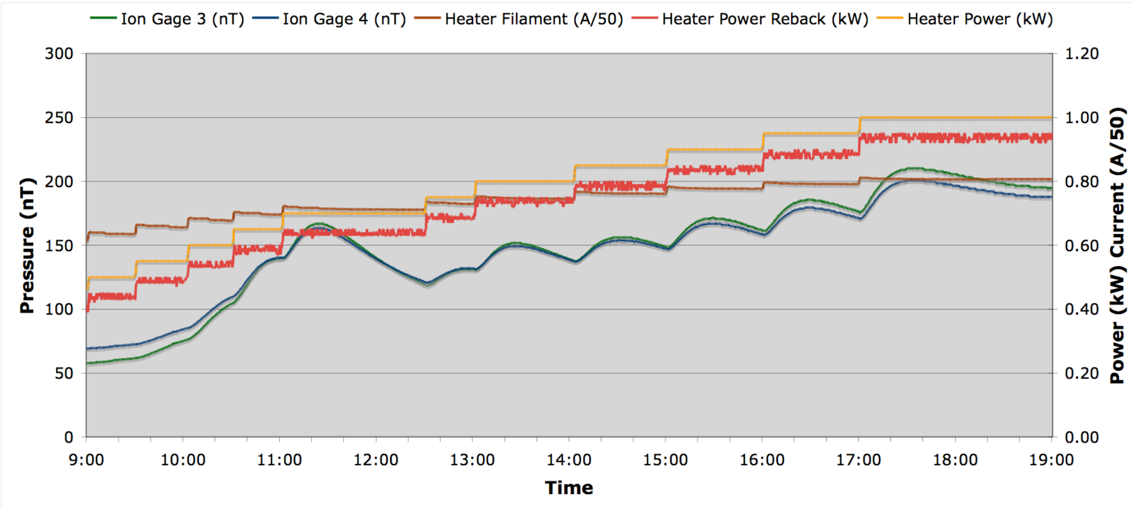


Figure 4. Time plot showing pressure and cathode heater parameters from 0900 until 1900 on 29 April 2006.

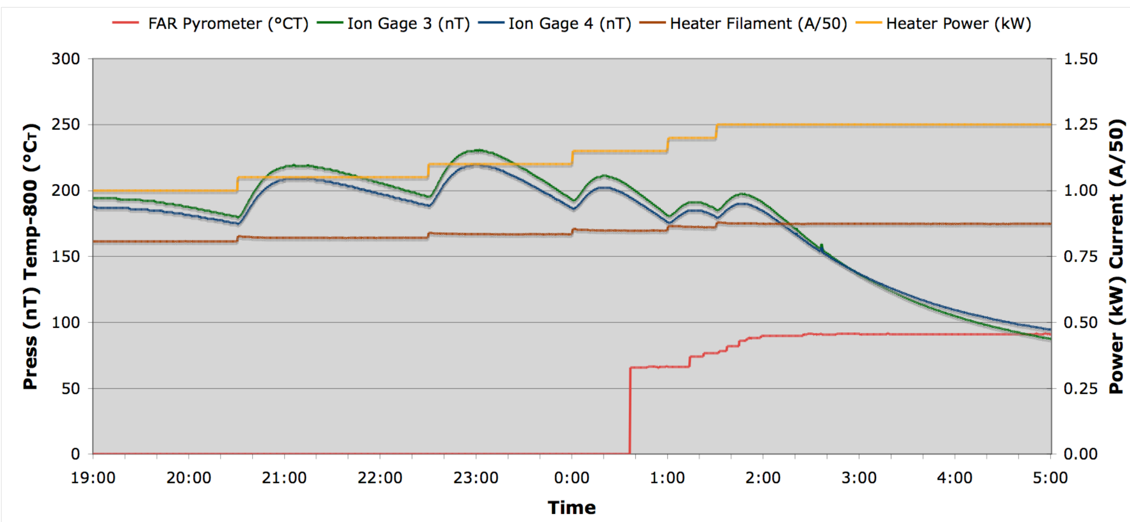


Figure 5. Time plot showing pressure, cathode heater power, filament current, and cathode temperature (FAR Pyrometer) from 1900 on 29 April until 0500 on 30 April.

Incremental increases of the heater power resumed at 1300 on the 30th starting at 1.3 kW. Heater adjustments were stopped for two hours when the pyrometer registered 995°C_T and again an hour later at 1021°C_T. At 1140 with the heater power at 2.42 kW, the pyrometer registered 1101°C_T. Power was held constant for the next two hours with the temperature stabilizing at 1103°C_T and the pressure dropping from 125 nT to 99 nT. At 0145 the heater power was set to 0 and at 0205 the heater was secured. Figure 6 plots the pressure, cathode temperature, and heater power for the last 10 hours of the activation.

There was some concern that for a "soft" activation, two hours at 1,100°C may not be sufficient. The cathode was heated on 4 May to 1,100°C (momentarily) and on 5 May to 1,100°C (held for 9 hours). Plots of the data for these heating cycles can be found in Appendix E.

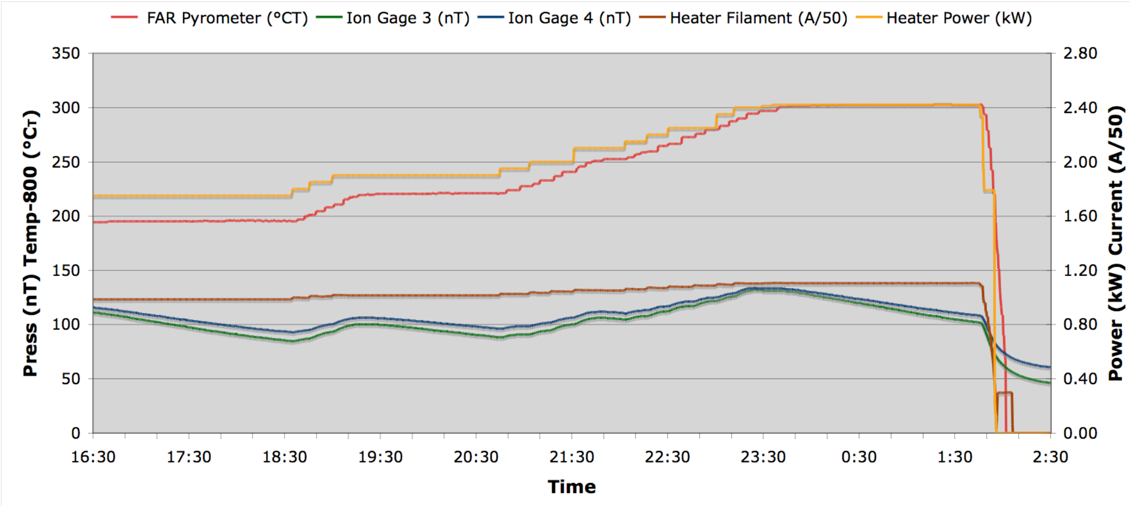


Figure 6. Time plot showing pressure, temperature, and cathode heater parameters 1630 on 30 April 2006 until 0230 on 1 May.

IV. Total and Partial Pressures

The total pressure in the vacuum vessel was maintained below 250 nT except for the one pressure spike. Pressure at the RGA normally was about 20% higher than the ion gauges presumably because of heating in the sensor head. Figure 7 is the RGA partial pressure display at the start of the activation cycle. Partial pressures are listed in Table 1 for some of the more important components at various times in the activation cycle. RGA displays corresponding to the different rows in Table 1 can be found in Appendix E. Note that the RGA display figures are high resolution and can be enlarged to read values. The primary reason for presenting the large number of RGA displays in Appendix is to have a readily assessable record with which to compare future cathodes.

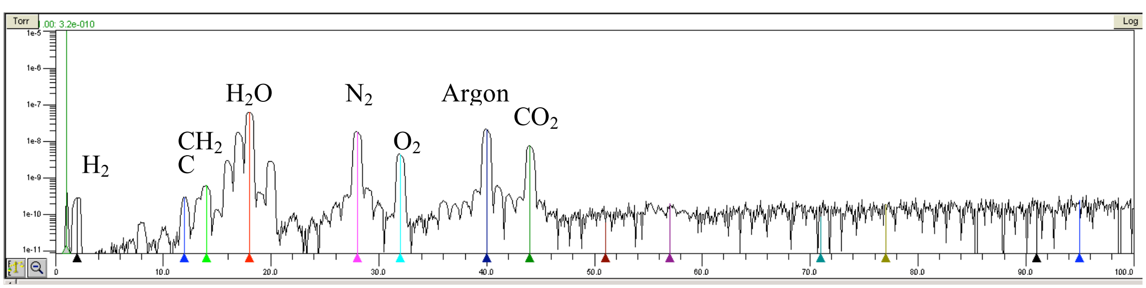


Figure 7. RGA display at start of the activation cycle.

From Table 1, it can be seen that water was the main constituent of the pressure spike. During the second pressure peak around 1900 on the 28th, hydrogen, nitrogen and carbon dioxide increased with respect to water. The hydrates being released may have split into hydrogen and oxygen that combined with carbon. The pressure increases around 2100 on the 29th were dominated by nitrogen and, unlike the previous pressure peaks, exhibited less “cracking”, i.e. evidence of breaking apart heavier hydrocarbons. Refer to Figures E-2 through 10 in Appendix E. At the end of the activation cycle, water, nitrogen and carbon dioxide were the primary constituents of the background gas. Interestingly, atomic weights 69 and 81 (see Fig E-11) became prominent possibly indicating radiant heating of the beam line leading to migration of oils.

LBNL’s heating of a used cathode showed pressure increases that correspond to the first and third pressure peaks during the activation cycle. See Figure G-2 in Appendix G. Water absorption and reaction of the tungsten to oxygen in the atmosphere during transport and handling are probably responsible for the outgassing associated with these two peaks. Apparently, the barium, calcium, and aluminates did not acquire significant amounts of hydrates during transport resulting in the absence of the second pressure peak.

Table 1. Partial pressures at start, end, and during peak pressures in nanoTorr.

	Atomic Weight	Total	2	12	14	18	28	32	40	44	51
Start	7:00 4/28/06	81	0.3	0.3	0.6	63	18	4.3	21	7.6	0.06
1st Peak	8:50 4/28/06	169	0.5	1.0	0.9	88	27	4.5	24	30	0.1
	9:05 4/28/06	919	2.1	2.9	4.0	266	107	11	124	69	0.3
	9:20 4/28/06	276	0.8	1.1	1.4	107	33	4.5	36	12	0.2
2nd Peak	18:40 4/28/06	281	13	1.7	3.4	66	64	3.8	22	32	0.8
	18:55 4/28/06	276	12	1.8	3.5	65	63	3.9	22	32	0.9
	19:10 4/28/06	239	9.3	1.5	3.2	63	52	3.8	22	26	0.8
3rd Peak	08:32 4/29/06	62	2.1	0.4	0.6	42	20	3.4	21	8.5	0.2
	21:08 4/29/06	267	3.6	4.3	1.2	40	231	3.1	21	77	0.2
	06:58 4/30/06	76	1.3	0.9	0.6	36	46	3.0	21	13	0.1
End	01:53 5/01/06	90	1.3	0.9	0.6	39	28	2.8	21	23	0.4

V. Power versus Temperature

The heater power was used to estimate the cathode temperature for temperatures below the range of the FAR pyrometer. Data taken at the LBNL cathode test stand with a thermocouple attached to the face of a used cathode was used for this estimate. Refer to Appendix G. A number of questions were raised regarding the validity of the LBNL test stand data to the DARHT configuration and also earlier data taken at Spectra-Mat (see Appendix H). The concerns were generally in regard to the immediate environment of the cathode and how this would effect the reflected radiated energy. Spectra-Mat took temperature measurements with the cathode in a bell jar with no immediate heat shields. The LBNL setup did not use heat shields but had shrouds and a relative close vacuum vessel wall. The DARHT configuration would be intermediate to these two cases. Appendix I contains sketches of the three configurations.

Figure 8 shows a comparison of data taken at LBNL, Spectra-Mat and DARHT. Measurements taken with the thermocouple at LBNL and with the FAR Pyrometer at DARHT are true temperatures. The pyrometer measurements taken at LBNL are brightness temperatures and 50° was added to these values to approximate true temperatures. The cathode temperatures from Spectra-Mat were measured with a Raytek Marathon two-color IR pyrometer set for "true" temperatures. The 3 lowest temperature data points for DARHT are based on temperature sensitive chemical reactions that could be associated with outgassing during the activation cycle: 100°C for the first peak (H_20 vaporization), 400°C for the second peak (hydrate breakdown), and 800°C for the wide third peak (W_2O_5 breakdown). The requested power setting was used for the DARHT data. To give some perspective to the data correlation, error bars of ±50°C were added to all pyrometer measurements. For DARHT data, error bars of -50W/+0W were added to reflect the difference between requested and read back power. Error bars of ±20°C, ±25°C, and ±100°C were assigned based on the pressure peak sharpness for the DARHT data estimated from the three pressure peaks. The thermocouple data was arbitrarily given error bars of ±5% for both power and temperature.

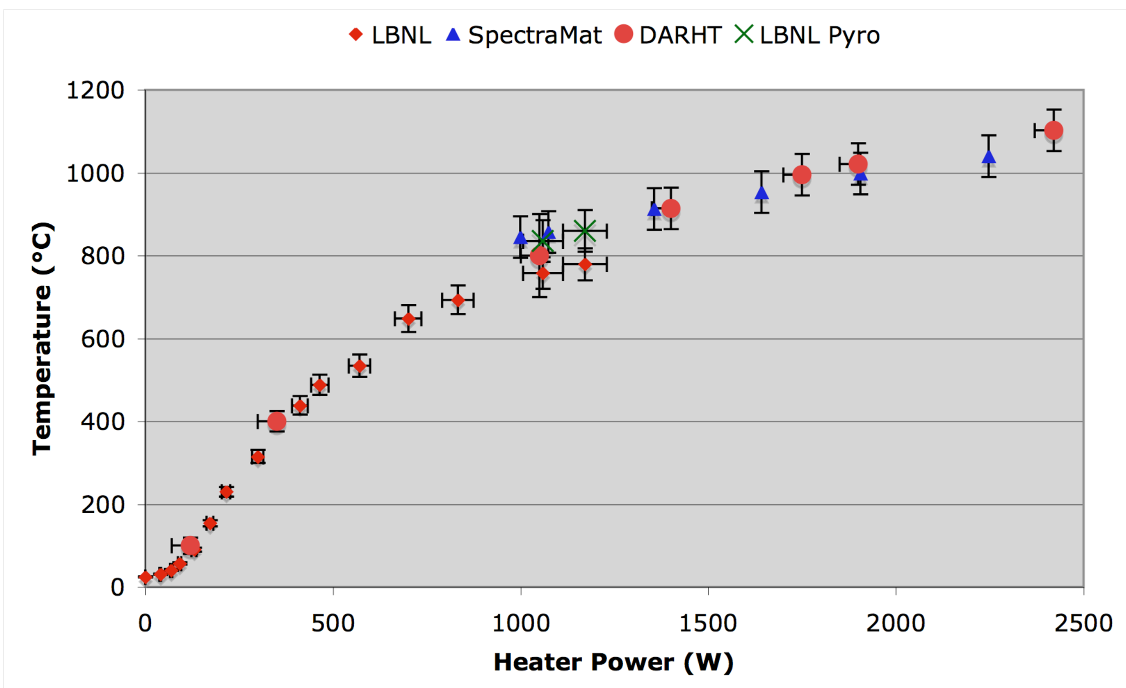


Figure 8. Plot of cathode temperature as a function of heater power.

There was some confusion regarding the cathode heater controls at DARHT. Complete details of the cathode heater power supply are beyond the scope of this report. The power supply consists of an 80V DC power supply that drives a 30-kilohertz switching inverter. It is the output of the DC supply that is shown on the control console. The AC power output of the inverter is determined by a 400 Hz pulse-width modulation of the DC input voltage. The output of the inverter passes through a filter that removes the 30 kHz and then an isolation transformer. The magnitude of the 400 Hz modulation is controlled by a 0-10V reference signal (Power Supply Request). The inverter's AC voltage and current (Heater Filament Current) output are used to generate a 0-10V reference power signal (Readback Power) that is compared to the input reference in a feedback loop. Note that for the reference power signal, 1V corresponds to 1 kW.

VI. Temperature Uniformity and Equilibrium

Temperature uniformity across the face of the cathode was measured using the Cathode Area Temperature (CAT) diagnostic system[2]. A CAT image assuming an emissivity of 0.6 taken when the FAR pyrometer showing 1,102°C_T (cathode center) is shown in Figure 9. Absolute temperature does not agree with the pyrometer, but relative variation is assumed to be approximately correct. Additional images are given in Appendix E.

The ~20°C variation from the hottest to coldest sections of the cathode is consistent with previous cathodes. However, the location of the coldest section is approximately 180° opposite of that of Cathode #3. The position that the filament leads enter the cathode is annotated in Figure 9. The cold section is not associated with the "missing turn" at the point where the return lead leaves the cathode. A possibility exists that there are shorted turns. However, at this time there is no correlation of the cold spot with azimuthal orientation in the shroud or position of filament leads.

The temperatures of the mounting plate and cathode shroud during the 12 hour period that the cathode was held at 890°C_T are shown in Figure 10. These temperatures continued to increase for a considerable period after the center of the cathode reached an equilibrium temperature: rising approximately 8°C during the four hours after cathode equilibrium. The issue of varying thermal expansion of the cathode relative to the shroud and possible mechanical interference has been described elsewhere[3]. In addition to the mechanical interference, the issue of varying edge emission needs to be considered. Significant effort was expended in determining the proper position and angle of the shroud with respect to the cathode to minimize emittance due to emission from the edge of the cathode. A study needs to be performed to determine the tolerance with respect to thermal equilibrium. For example, is there a minimum time required between heating the cathode and extracting a quality beam?

[2] D.F. Simonds and C.F. Fortgang, "Using Multispectral Imaging to Measure Temperature Profiles & Emissivity of Large Thermionic Dispenser Cathodes," DARHT Technical Note No. 192, 12 Feb 2001

[3] B. Prichard, "LANL Cathode Thermal Observation," PowerPoint Presentation at the 4/25/06 VTC between LBNL/LANL

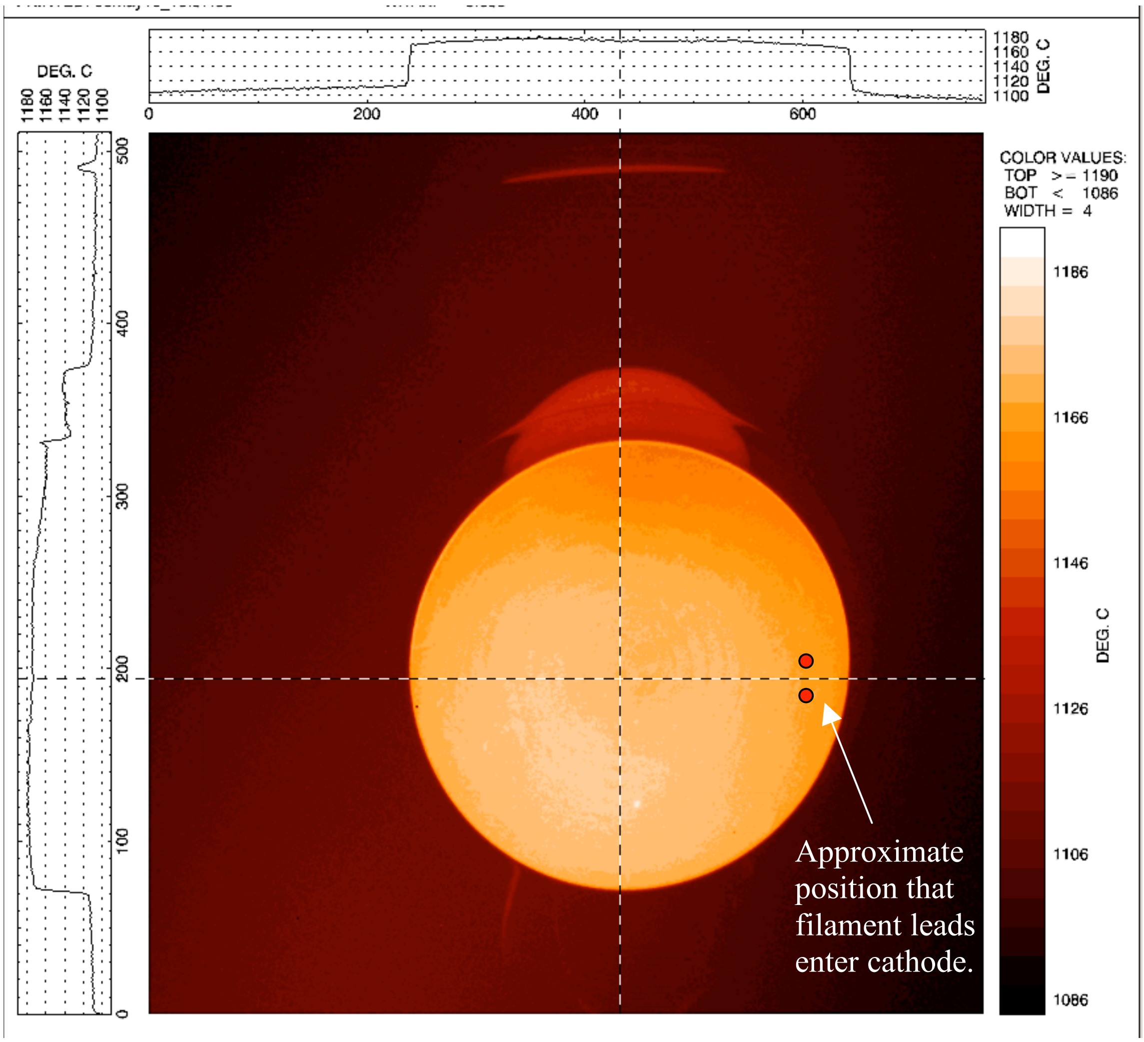


Figure 9. Thermal image (CAT_CAM.13 5/5/06, Background CAT_CAM.1 5/4/06) of cathode. Pyrometer temperature for center of cathode: 1,102°C_T.

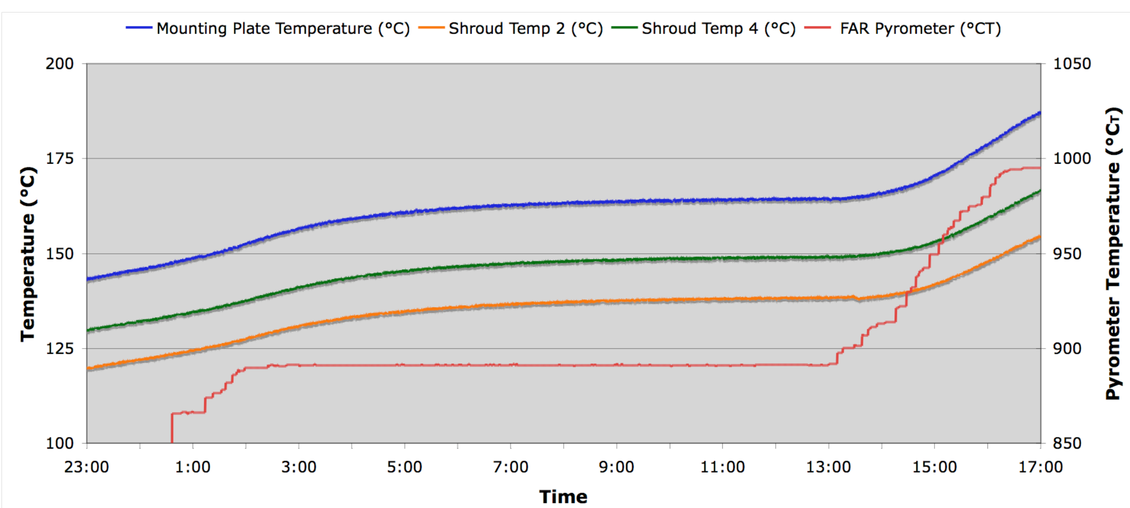


Figure 10. Shroud and mounting plate temperatures continued to increase after the cathode temperature reached a constant value.

VII. Miram Curve

Data for the Miram Curve was taken on 8 May 2006. The Miram Curves and Practical Work Function Distributions (PWFDs) for the first four cathodes are plotted in Figures 10 and 11. The data for Cathode #4 was taken as the cathode was heated as compared to Cathode #3 where the data was taking as the cathode cooled. In theory, the cathode and its environment should be in thermal equilibrium for the measurement of the Miram Curve. However, as noted in Section VI, this could take a considerable time to realize in practice. The significantly higher work function of Cathode #4 with respect to #3 is most likely due to the differences in how the measurements were made. A fixed procedure for the measurements would make the data comparable for different cathodes and the same cathode measured at different times.

Table 2. Miram Curve Data taken 8 May 2006

Shot #	Voltage (MV)	Pyrometer (ºC)	Temperature (ºK)	Current (A)
3193	2.26	1109	1382	685
3194	2.26	1111	1384	730
3195	2.25	1113	1386	749
3196	2.25	1117	1390	795
3197	2.25	1122	1395	853
3198	2.21	1126	1399	903
3199	2.20	1131	1404	948
3200	2.20	1133	1406	952
3201	2.18	1136	1409	986
3202	2.18	1140	1413	1006
3203	2.18	1142	1415	1016
3204	2.17	1142	1415	1016
3205	2.19	1143	1416	1016
3206	2.18	1146	1419	1016
3207	2.18	1149	1422	1019

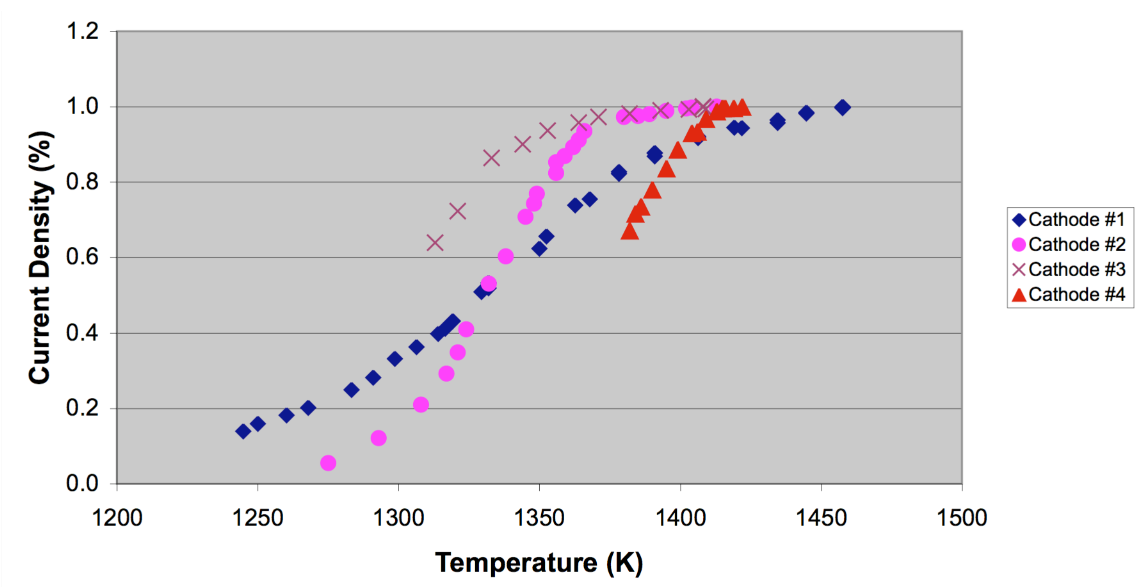


Figure 10. Miram curves for the first four cathodes.

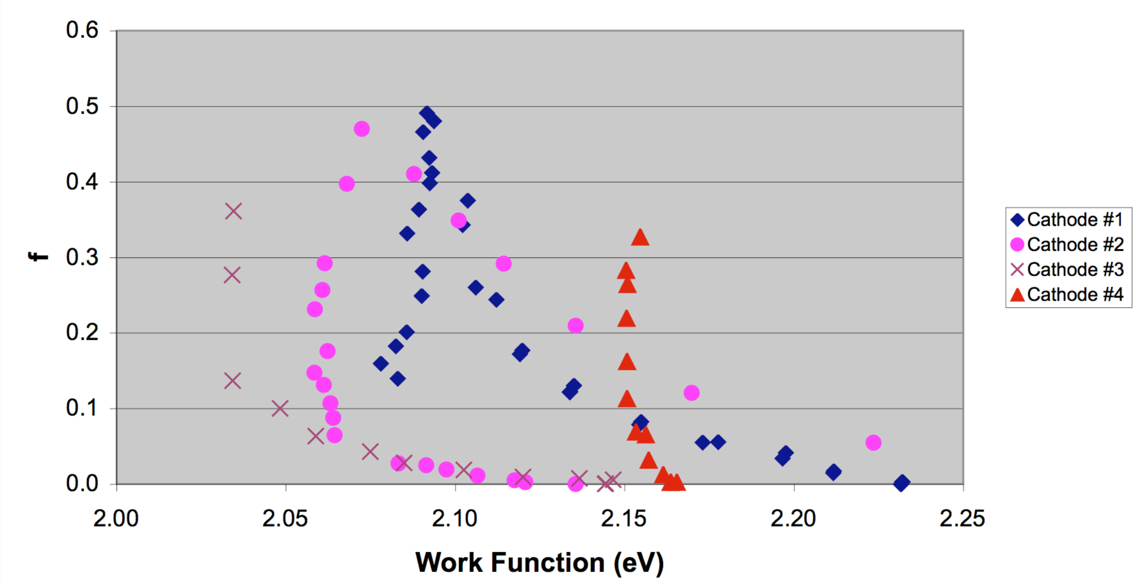


Figure 11. Practical Work Function Distributions (PWFDs) associated data in Figure 10.

VIII. Comments and Recommendations

Several observations can be made looking over the data. The recommendations are subjective and represent the biases of the editor.

- Changing the original 100 nT limit to 300 nT in the activation procedure appears to have been a prudent decision. Keeping the pressure to no more than 250 nT required 67 hours. The 100 nT limit may have doubled the time.
- An alternative to activating the cathode in the injector vacuum vessel is to do it in a smaller vacuum vessel then install the cathode in the injector. This approach has several advantages including minimizing the time the injector is not available for operations, better vacuum monitoring of the activation (gauges are closer to cathode surface), and the ability to extend the activation cycle, e.g. to maintain a 100 nT pressure limit.
- Longer time at "activation" temperature (4 – 12 hours) for the soft activation. This was actually done on Cathode #4 when the cathode was given another heating cycle finishing with 11 hours at 1,100°C_T. Replacing the time requirement with an outgassing/pressure requirement may be a better approach.
- During the activation of Cathode #4, the operators normally followed an informal requirement of not increasing the heater power if the pressure is still rising. This should be made a formal requirement called out in the activation procedure. It is not obvious that this requirement would have avoided the pressure spike, but it is easy to implement.
- Add more people to activation team with assignments for specific diagnostics – the operators are being overworked attempting to do all requests for information. Although much of the data acquisition has been automated, it needs to be routinely checked to verify that all the automated systems are working.

Unfortunately an abnormal event, e.g. power surge, most likely will effect multiple systems and the operator has to set priorities with the protection of the injector being first and data acquisition last.

- If enough personnel are available, it would be nice (not required) to take thermal images of the cathode during activation. Images can be taken anytime after activation, but a baseline set of images during activation may prove useful for diagnosing problems with future cathodes.
- The inoperative temperature sensors on the shroud and cathode housing should be replaced during the installation on the next cathode. During initial operations there were six RTD's at various positions. There are only three left and one of these (Shroud #2) is failing. Refer to Appendix E, Figure E-16. With sufficient temperature data from different locations, the mechanical engineers can determine heat flow and relative thermal expansions.
- The CAT should be recalibrated and brought into agreement with the FAR pyrometer.

Appendix A
Activation Process for the DARHT Cathode #4

- Increase the Cathode Heater Power in small increments (typically 0.05 kW per step) keeping the injector vacuum at or below $3x10^{-7}$ Torr.
- When the Cathode Heater Power set point reaches 0.40 kW, hold this Power setting for 12-16 hours before resuming Heater Power ramp and pressure control.
- Ensure the FAR Pyrometer is on when Heater Power reaches 1kW.
- When the Far Pyrometer reads a stable temperature of 875 ± 25^oC, hold the Cathode Heater Power constant for 12-16 hours before resuming Heater Power ramp and pressure control.
- When Far Pyrometer temperature reaches 1000^oC hold this power setting and temperature for 2 hours before resuming Heater Power ramp.
- When Far Pyrometer temperature reaches 1100^oC hold this power setting and temperature for 2 hours
- The activation is considered finished at this point.

Notes:

1. If at any time it is felt there is a need to vary from this process, check first with Trent McCuistian and Ray Scarpetti before instituting changes.
2. This process assumes around the clock activation without planned interruption.
3. A time–stamped printout of the RGA spectrum will be taken every half hour and collected in a binder for the entire duration of the cathode #4 activation.
4. The purpose of the hold at 0.40 kW (~400^oC) is to break down the hydrates formed with the barium-calcium-aluminates in order to out-gas the hydrated water.
5. 0.40 kW is an approximate value determined by LBNL on their Cathode Test Stand, and a more refined value may be available at the start of activation.
6. If the pressure goes above 3×10^{-7} torr, back off on the heater power to the cathode until the pressure recovers.
7. The purpose of the hold between 850°C and 900°C is to allow W_2O_5 to break down and combine with any available hydrogen, reducing the tungstate to clean tungsten as well as reducing any residual carbonates found in the impregnant. Care must be taken to assure the temperature approaches but does not exceed 900°C.
8. Steve Eversole will request Jim Harrison to produce an activation summary spread sheet which will collect the following data every half hour plus every time the cathode heater power is changed: Pyrometer Temp 2. Heater PS Power, Heater PS Filament I, Mounting Plate Temp, Shroud Temp 2, Shroud Temp 4, Injector Tank Ion Gauge Press 1, Injector Tank Ion Gauge Press 2, Injector Tank Ion Gauge Press 3, Injector Tank Ion Gauge Press 4,
9. Since we are not bringing the cathode to the 1200°C level, the activation is considered a slow one and the cathode may continue to improve it emission characteristic over time. It is recommended, as soon as is practicable, to characterize the emission by plotting beam current density vs. cathode temperature at the lowest possible beam voltage (around 2 MV for DARHT). The administrative limit is 1100°C. The "Miram Plot" and the practical work function distribution (PWFD) thus produced will characterize the cathode and can be used to predict it performance at higher beam voltage.

Appendix B
Cathode Handling and Usage Documentation Guidelines (Joe Kwan)

The cathode contains BaO which can be easily poisoned by moisture and other contaminants. To insure optimum performance, the cathode should not be exposed to atmospheric conditions for too long. There is no sharp threshold for this, and to be accurate, one would have to specify the moisture and particulates content in the air, flow rate, etc. Therefore the basic principle is to minimize exposure. The most recent bulletin from Spectra-Mat suggested limiting the exposure to less than 48 hours, but their earlier version indicated 8 hours.

For storage, the cathode should be kept in inert gas such as nitrogen or argon, or alternatively in a partial vacuum of 10^{-3} torr or better. Since this level of vacuum is difficult to verify from the gauge on the shipping container, the inert gas method is preferred.

All direct handling should be done with reasonable clean room processes, e.g., wear clean gloves (use the type without powder) and a lab coat, and if possible work in a room with filtered air. Avoid touching the cathode surface. In case if any debris is found on the surface, use a pair of tweezers to remove it or use dry nitrogen to gently blow it off. A vacuum cleaner with a clean tip may also work well. Do not try to "clean" or wipe the surface. For protection, use UHV grade aluminum foil instead of lint free paper. The UHV foil shall be essentially free from contamination and residual rolling oils (certified to ASTM B479 (3.1.4 & 10.3.1).

Apply the principle of 5P's (**P**rior **P**lanning **P**revent **P**oor **P**erformance) to minimize the exposure time and reduce risk of damage. This often means using a dummy for a trial run to practice beforehand, or make a special fixture to hold the cathode in place. In some case, setting up a staging area with inert gas purge will help to reduce the exposure to moisture.

We want to keep detail records on the history of each cathode, starting from the beginning when it was made in the factory, to the end of its useful life. Perhaps the best way is to write things down in a logbook that follows the cathode wherever it goes. Of course any potential damage must be recorded and no entry is too trivial to be included. As a guide, enter the date, time, the worker's name, what was done to it, how much was the estimated time of exposure, and the work environment. Also write down the condition of the cathode (visual description) before and after working on it, and how and where it was stored afterward.

After the cathode is installed on a test stand for operation, the record keeping should continue. We would like to know what kind of base pressure is in the vacuum system, the main components that show up in the RGA, the number of hours while the cathode is hot, and typical emission current and pulse length. Obviously, any vacuum leak incident, or frequent high voltage breakdowns (inside the injector region) must be recorded in the logbook.

Appendix C
Handling and Usage Records of the DARHT Cathode #4

Entry made by: Matthaeus Leitner
4/10/2006
The cathode vacuum shipment container had been opened by Ken Chow and Dave Anderson briefly (15 minutes) when it arrived the first time. I was not present at that time.

Entry made by: Matthaeus Leitner
4/10/2006
9:57 am up to air
10:25 am under vacuum
total exposure time: 28 minutes
handling according to UHV practice, cathode surface never got touched
Notes: put cathode on source mounting flange, measured alignment on CMM

Entry made by: Matthaeus Leitner
4/11/2006
12:10 pm up to air
1:05 pm under vacum
1:10 pm up to air
1:45 pm under vacuum
total exposure time: 90 minutes
handling according to UHV practices, cathode surface never got touched
Notes: put cathode on source mounting flange, measured alignment on CMM, brought cathode within alignment specs, after alignment: installed heater lead feedthroughs, put briefly under vacuum during heater lead installation since we had to look for installation hardware, installed finished cathode in larger shipping container, mounted UHV cleaned heatshield, sent to Los Alamos

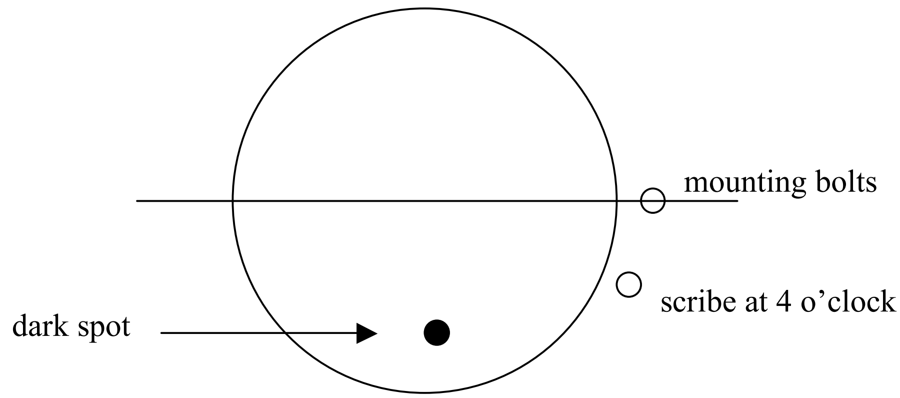
Following is a partial transcription of the Cathode Logbook kept in the Control Room

4/17/2006
Cleaned "splatter" from cathode shroud – Examination of shroud showed that within the darkened area (3 o'clock position) was slight roughness with either a peak or crater with peak in center. A light tangent to surface yielded a bright spot.

- Alcohol would not remove spots
- Buehler METAD/Diamond Suspension Water Base, 1 micron was successful at removing spots
- No spots could be seen on anode, even on backside where it rolls under

4/19/2006
Prepare for installation of Cathode #4 (Cathode #3 was removed yesterday)
Cathode #4 container pressure at ~23 inches Hg. Container has not been open since receipt at LANL. Shipping package tilt/tip indicators showed that the cathode container had been tilted during shipping.

4/20/2006
Opened cathode #4 at 10:30 AM. Noticed a little spot on the cathode.
Installed Cathode #4 as shipped.



4/21/2006
Realigned cathode, centered moly plate within 0.002 T/R
6 PM reinserted cathode in shipping container and pumped down to 22-23 inches Hg

4/25/2006
9:30 AM removed cathode from shipping container
Took number of alignment measurements
Removed and replaced cathode
Installed shroud

4/26/2006
Recentered cathode on moly plate
Reinstalled shroud
Remounted shroud after polishing

Note: 1615 Started roughing vacuum vessel

Appendix D
Transcription of Logbook

26 April, 2006 Wednesday

1615 Started roughing vacuum vessel
2015 Switched to cyro's

28 April, 2006 Friday

Begin activation of Cathode #4 this morning
RGA recipe = cathodedatasave6-28-02.rcp
Setup Hypersnap to capture RGA screen every 1800 seconds (on hour and ½ hour)
C:\Documents and Settings\darhtLAN\D2kicker\CathodeActivationScreens
RGA also set to automatically save data to
C:\TWare32\Sensor3_P1_TSP2\DATA\cathodesave_0000.sod
With auto increment filenames checked

iHistorian; storing info in database and person (operator) activating cathode (we will go 24/7 until activated) monitoring vacuum and cathode parameters on screen as operator increases power setpoint gradually maintaining injector vacuum vessel below 300 nT.

Activate with Anode Gate Valve CLOSED
Before starting vacuum levels are:

56 nT: upper
61 nT: middle
61 nT: lower
79 nT: RGA (RGA is on which increases this reading)

Operator: Trent

Time	Power Setpoint Request (kW)*	Vacuum Upper Section (nT)
0650	0.00	56.6
0700	0.02	56.6
0715	0.05	56.9
0753	0.08	62.0
0800	0.10	62.0
0830	0.12	93.0
0902	Sharp pressure increase! RGA also shows cracking	

*Cathode heater power read back is ~50 W less than request

Turned off cathode heater at ~0902 to allow pressure to reduce to normal. Pressure spike reached **~700 to 800 nT** and dropped back to 220 nT in about 4 minutes. Left cathode heater off for 1 hour to allow vacuum to drop to 110 nT.

Time	Power Setpoint Request (kW)*	Vacuum Upper Section (nT)
1000	0.10	117

1300	0.12	121
1422	0.13	102
1445	0.15	98.8
1516	0.18	102
1530	0.20	110
1600	0.25	116
1630	0.30	124
1730	0.35	151

*Cathode heater power read back is ~50 W less than request

Cathode Heater Fault at 1857 (loss of power)
Cathode Heater Power restored by 1858
Turned on FAR pyrometer at 1900

Operator: Nick Observer: Kurt

Time	Power Setpoint Request (kW)*	Vacuum Upper Section (nT)
1858	0.30	223
1909	0.35	201
2009	0.38	149
2020	0.40	146
2045	0.45	147
2120	0.46	155
2400	0.46	92.4

*Cathode heater power read back is ~50 W less than request

29 April, 2006 Saturday

Operator: Mano
End 12 Hour Temperature Hold/Start Heater Power Ramp at 0900

Time	Power Setpoint Request (kW)*	Vacuum Upper Section (nT)
0900	0.50	55.7
0930	0.55	59.1
1000	0.60	72.1
1030	0.65	100
1100	0.70	133
1130	Did not adjust power. Vacuum reached 159 nT before coming down	
1230	0.75	114
1300	0.80	125
1330	No adjustment	144
1400	0.85	132
1430	No adjustment	149
1500	0.90	142
1530	No adjustment	164
1600	0.95	155
1630	No adjustment	177
1700	1.00	168

1730	No adjustment	201
1800	No adjustment	197
1830	No adjustment	189

Operator: Trent Observer: Juan

1900	No adjustment	186
1930	No adjustment	185
2000	No adjustment	182
2030	1.05	173
2100	No adjustment	208
2130	No adjustment	208
2200	No adjustment	197
2230	1.10	188
2300	No adjustment	222
2330	No adjustment	207
2400	1.15	1.85

*Cathode heater power read back is ~50 W less than request

30 April, 2006 Sunday

Operator: Trent Observer: Subrata

Time	Power Request (kW)*	Vacuum Upper Section (nT)	FAR Pyrometer (°C)
0030	No adjustment	200	---
0100	1.20	174	866.00
0130	1.25	178	876.41
0200	No adjustment	183	883.83

Keep this setting for “W2O5 breakdown” ~ 12 hours from reaching 875° - keep this power setting until 1300 or later

0230	No adjustment	155	890.92
0300	No adjustment	130	890.9
0330	No adjustment	113	890.9
0400	No adjustment	101	890.9/891.7
0430	No adjustment	91.3	890.9/891.3
0500	No adjustment	84.4	890.9
0530	No adjustment	78.9	890.9
0600	No adjustment	74.2-74.6	890.9
0630	No adjustment	70.9	890.9
0700	No adjustment	67.8	890.9

Operator: Nick

0730	No adjustment	65.2	890.9
0800	No adjustment	63.0	890.9
0830	No adjustment	61.3	890.9
0900	No adjustment	59.6	890.9
0930	No adjustment	57.9	891.3
1000	No adjustment	56.6	890.9
1030	No adjustment	55.4	890.9

1100	No adjustment	55.0	890.9
1130	No adjustment	53.5	890.9
1200	No adjustment	52.6	890.9
1230	No adjustment	51.7	890.9
End 12 hour hold			
1300	1.30	50.9	890.9
1330	1.35	52.9	901.3
1400	1.40	56.0	912.9
1415	1.45	58.9	922.6
1430	1.50	63.0	931.2
1445	1.55	68.2	941.6
1500	1.60	75.0	953.2
1515	1.65	81.6	962.6
1530	No adjustment	89.8	973.1
1545	1.70	90.8	975.2
1600	1.75	96.6	982.2
Start 1,000°C hold time for 2 hours			
1630	No adjustment	106	994.7
1700	No adjustment	102	994.7
1730	No adjustment	93.4	995.5
1800	No adjustment	86.3	995.5
End of hold time			
1830	1.80	81.6	995.0
1845	1.85	84.0	1,000.5
1900	1.90	89.3	1,009.6
Operator: Ed Observer: Juan			
Start 1,000°C hold time for 2 hours, 1845 to 2045			
1930	No adjustment	95.0	1,020.4
2000	No adjustment	91.3	1,021.0
2030	No adjustment	86.8	1,021.0
2045	1.95	84.9	1,021.0
2100	2.00	87.3	1,028.0
2115	2.05	91.3	1,035.4
2130	2.10	96.6	1,043.7
2200	2.15	100	1,052.8
2215	2.20	103	1,059.5
2230	2.25	108	1,066.5
2245	2.30	112	1,074.8
2300	2.35	117	1,082.3
2315	2.40	121	1,088.5
2330	2.41	126	1,096.4
2335	2.42	125	1,098.7
2340	No adjustment	125	1,100.6

Start 1,100°C hold time for 2 hours, 2340 to 0140

*Cathode heater power read back is ~50 W less than request

01 May, 2006 Monday

0000	No adjustment	122	1,102.2
0030	No adjustment	115	1,102.2
0100	No adjustment	106	1,102.6
0140	No adjustment	98.8	1,102.6
0145	0.00	97.7	1,102.6
0205	Cathode Heater Off	53.8	Off

Appendix E
Plots of Pressure, Temperature, and Heater Power

The pressure, cathode temperature, heater power, and heater filament current for the entire activation cycle are shown in figure E-1. The pressure peaks/spike are annotated.

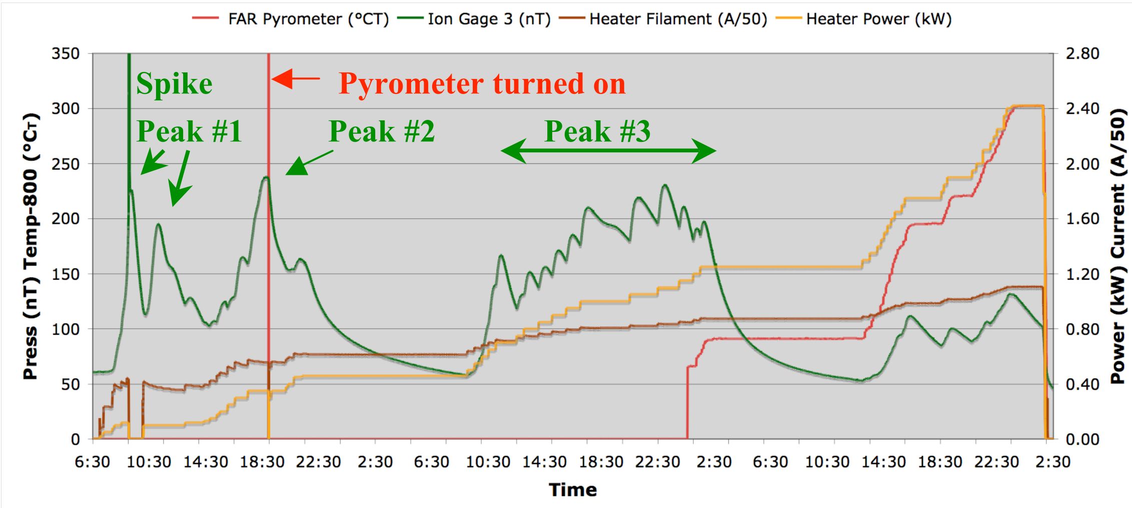


Figure E-1. Time plot for activation cycle showing total pressure, FAR Pyrometer, heater power and heater filament current.

The following figures are RGA displays for the times shown in Table 1. Although the printing is small, the resolution is high and plots can easily be expanded to read. The principle purpose of recording the displays is to establish a base line to compare with future activations.

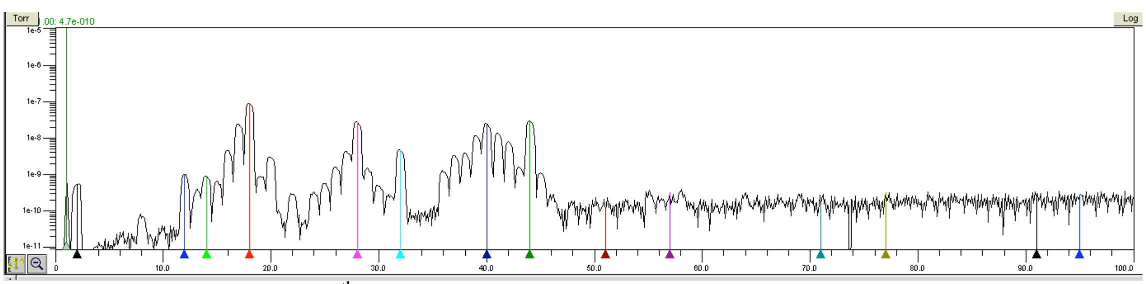


Figure E-2. 08:50 28th 169 nT: RGA display shortly before the pressure spike.

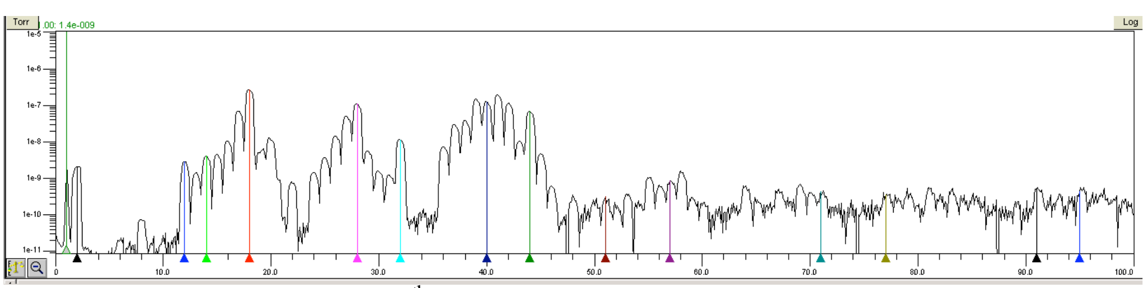


Figure E-3. 09:05 28th 919 nT: RGA display during pressure spike.

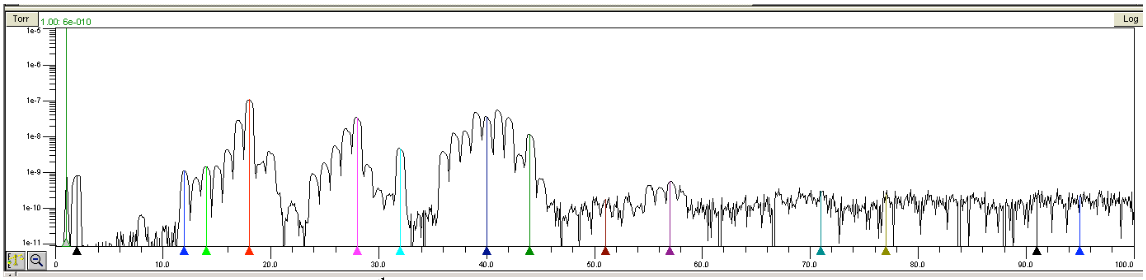


Figure E-4. 09:20 28th 276 nT: RGA display shortly after pressure spike.

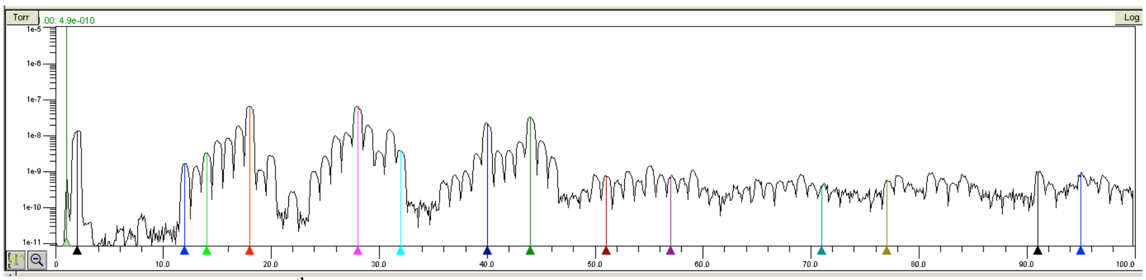


Figure E-5. 18:40 28th 281 nT: RGA display near maximum of second pressure peak.

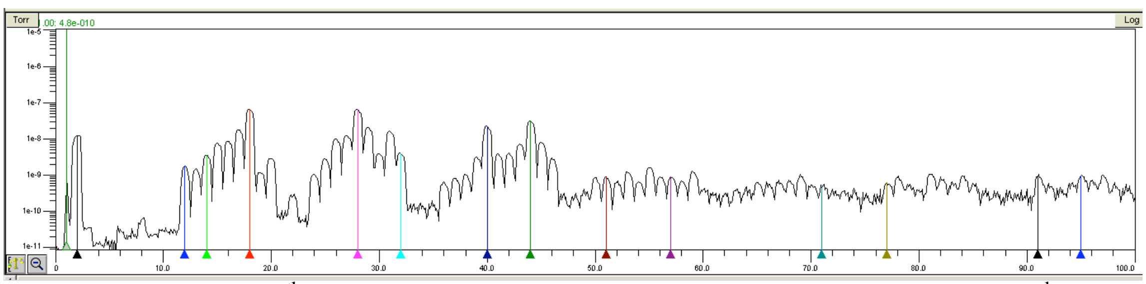


Figure E-6. 18:55 28th 276 nT: RGA display as pressure was decreasing after 2nd peak.

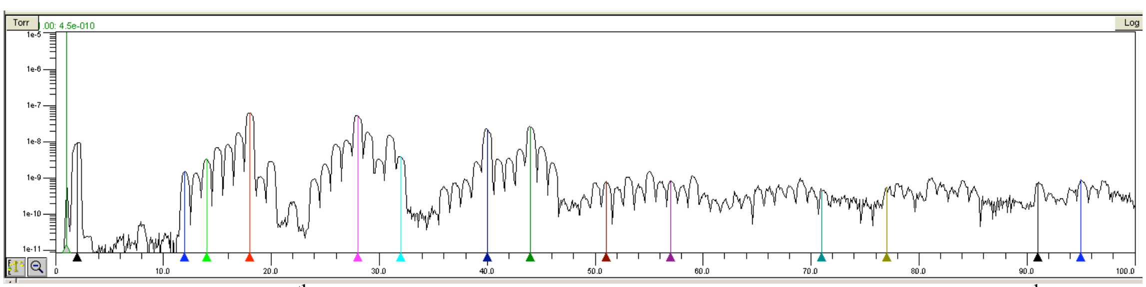


Figure E-7. 19:10 28th 239 nT: RGA display while power was secured after 2nd peak.

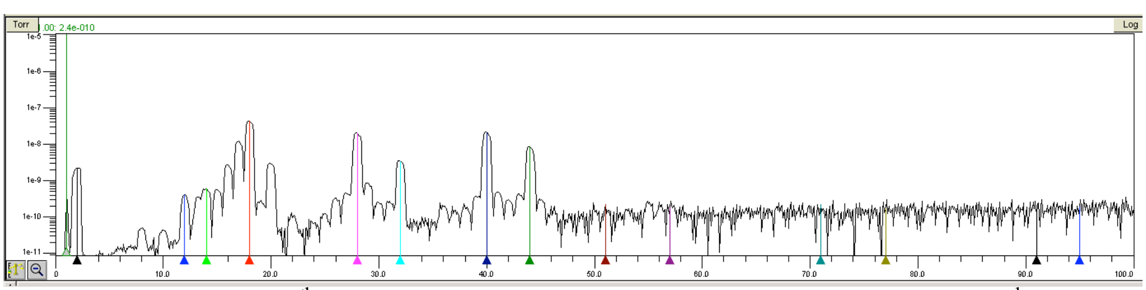


Figure E-8. 8:32 29th 62 nT: RGA display at end of 12 hour hold prior to 3rd peak.

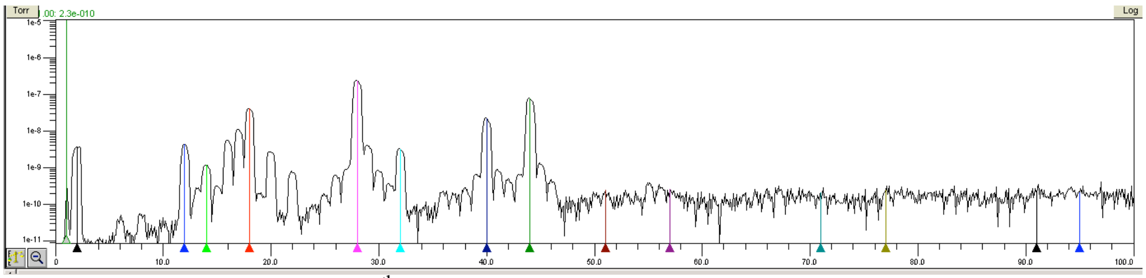


Figure E-9. 21:08 29th 267 nT: RGA display during third pressure peak.

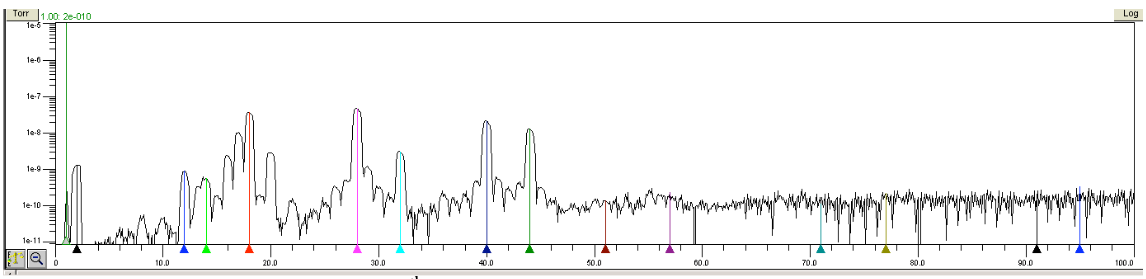


Figure E-10. 06:58 30th 76 nT: RGA display after third pressure peak.

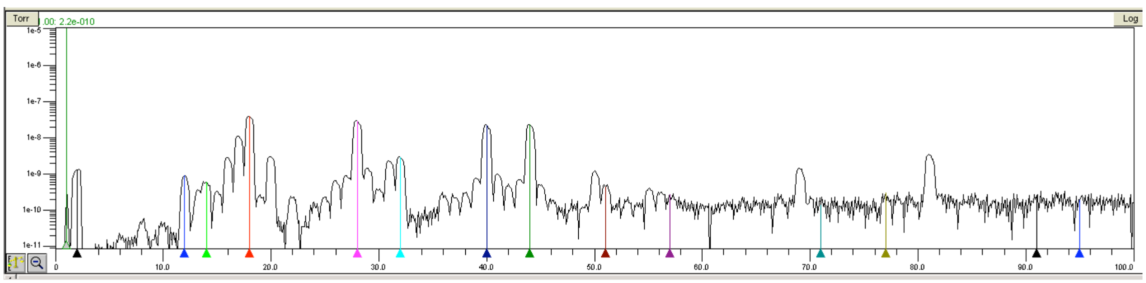


Figure E-11. 1:53 1st 76 nT: RGA display at end of activation cycle.

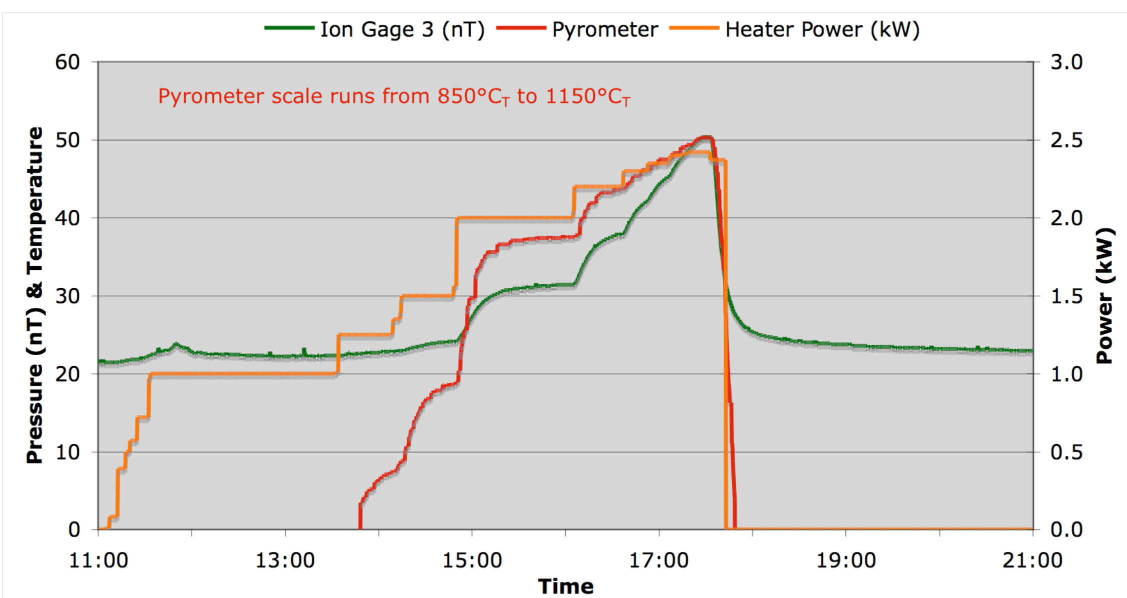


Figure E-12. Time plot showing pressure, temperature, and cathode heater on 4 May.

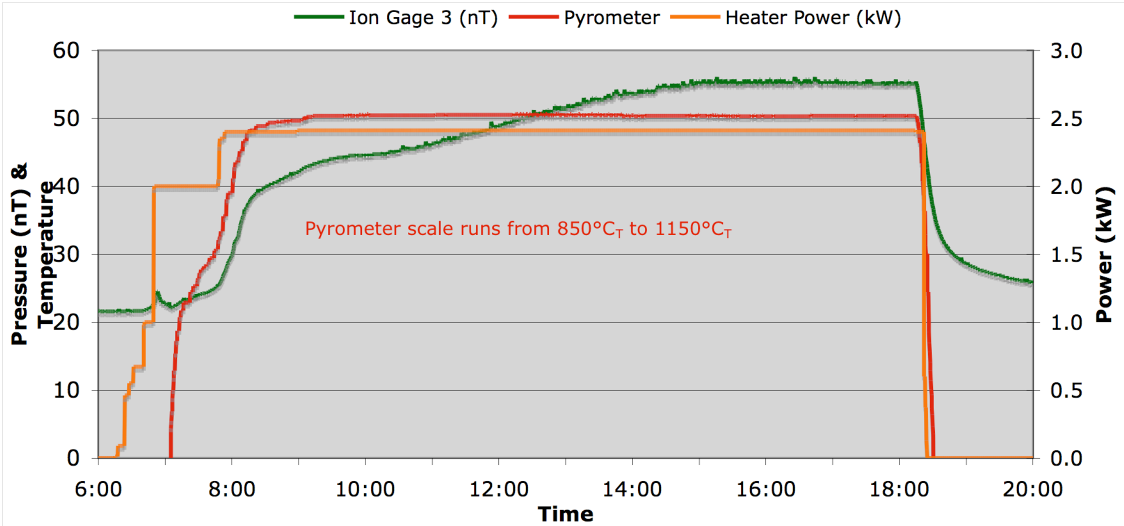


Figure E-13. Time plot showing pressure, temperature, and cathode heater on 5 May.

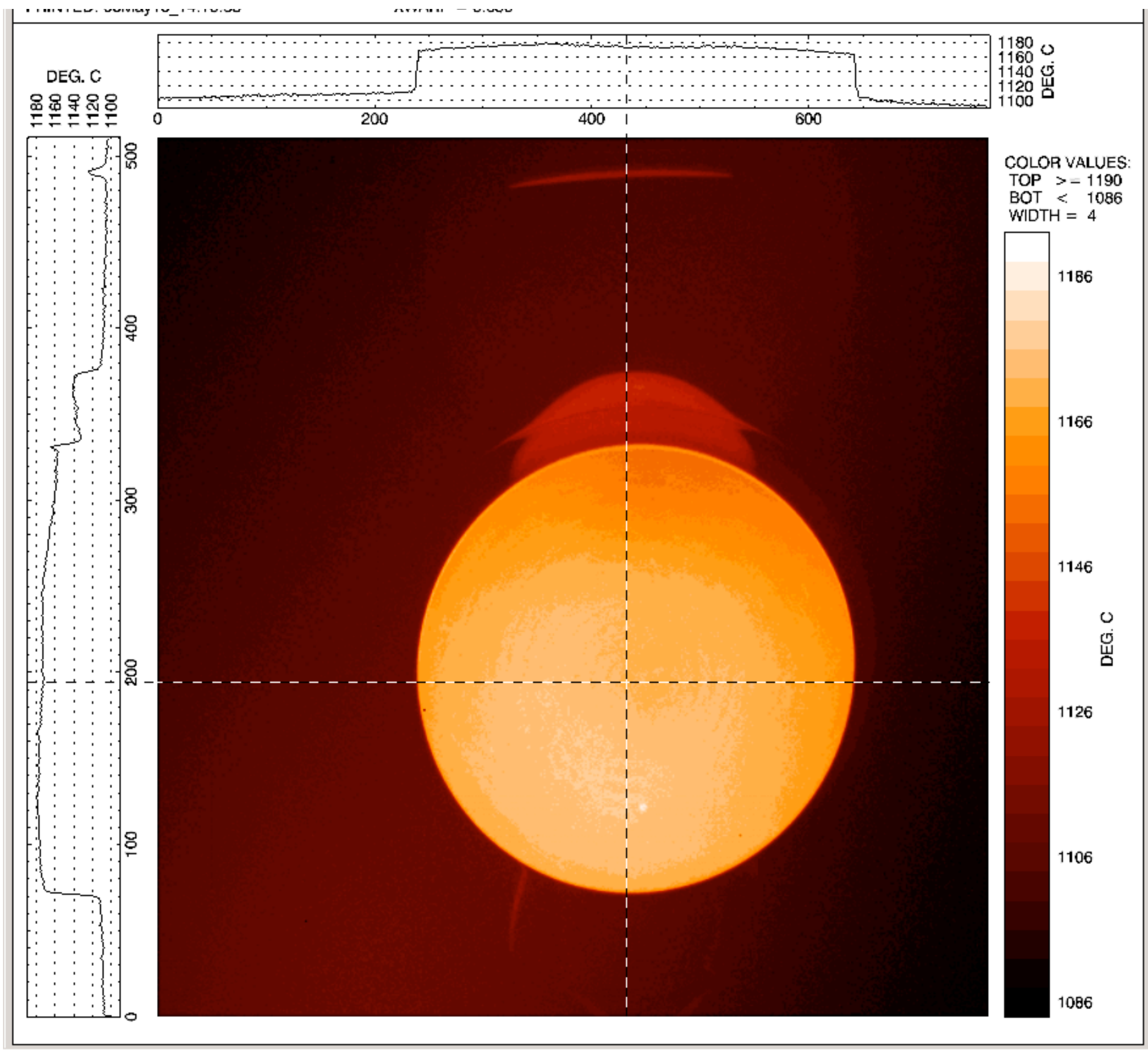


Figure E-14. Thermal image (CAT_CAM.9 5/4/06, Background CAT_CAM.1 5/4/06) of cathode. Pyrometer temperature for center of cathode: 1,101°C$_T$.

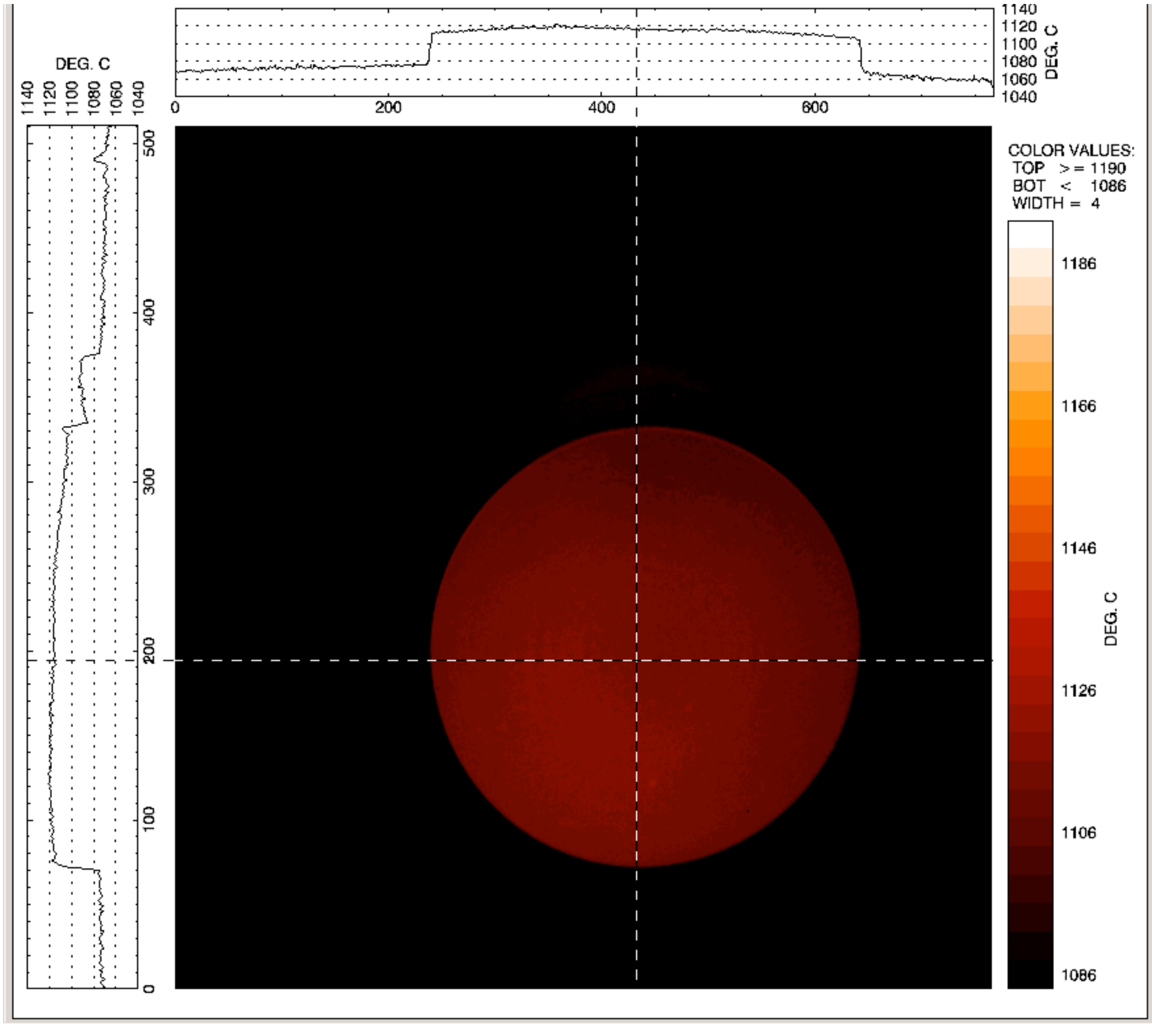


Figure E-15. Thermal image (CAT_CAM.8 5/4/06, Background CAT_CAM.1 5/4/06) of cathode. Pyrometer temperature for center of cathode: 1,037°C_T. Color coding same as in Figure E-14, but the range scale is different.

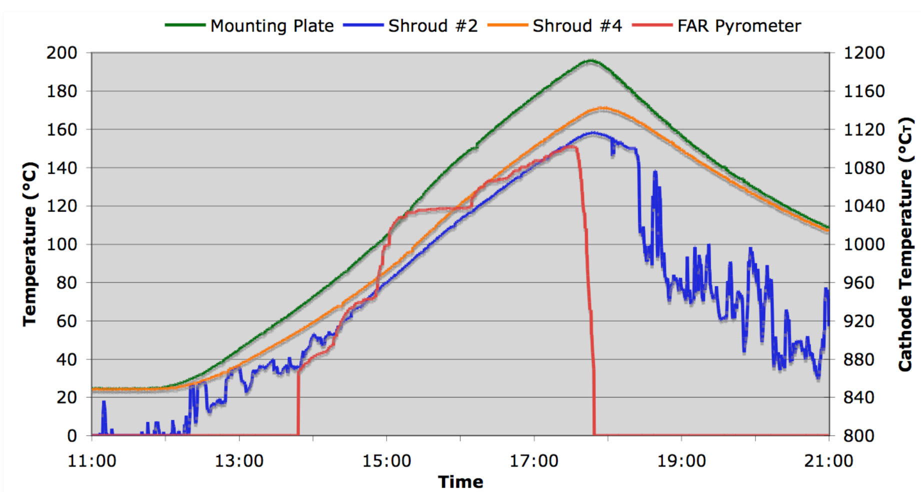


Figure E-16. Plots of cathode and shroud temperatures on 4 May 2006.

Appendix F
Historical Data Record

Information on a large number of instrument readings is recorded on a continuous basis with typical sample rates of once every 20 seconds to 1 minute. Sample rates can be increased. The data can be recalled and displayed on screen as a plot or saved as CSV files at a sample rate equal to or slower than the recorded data. Below is a small example similar to the file used to generate the plots in this report. Some editing of the header was performed to improve readability. The instruments chosen were those of interest to the cathode activation. Other sets of data can be selected for specific studies, e.g. magnets or pulsed power. 68 hours of data recorded every 20 seconds for the 11 instruments listed in the table below was stored in a 1.8 Mb Excel Worksheet.

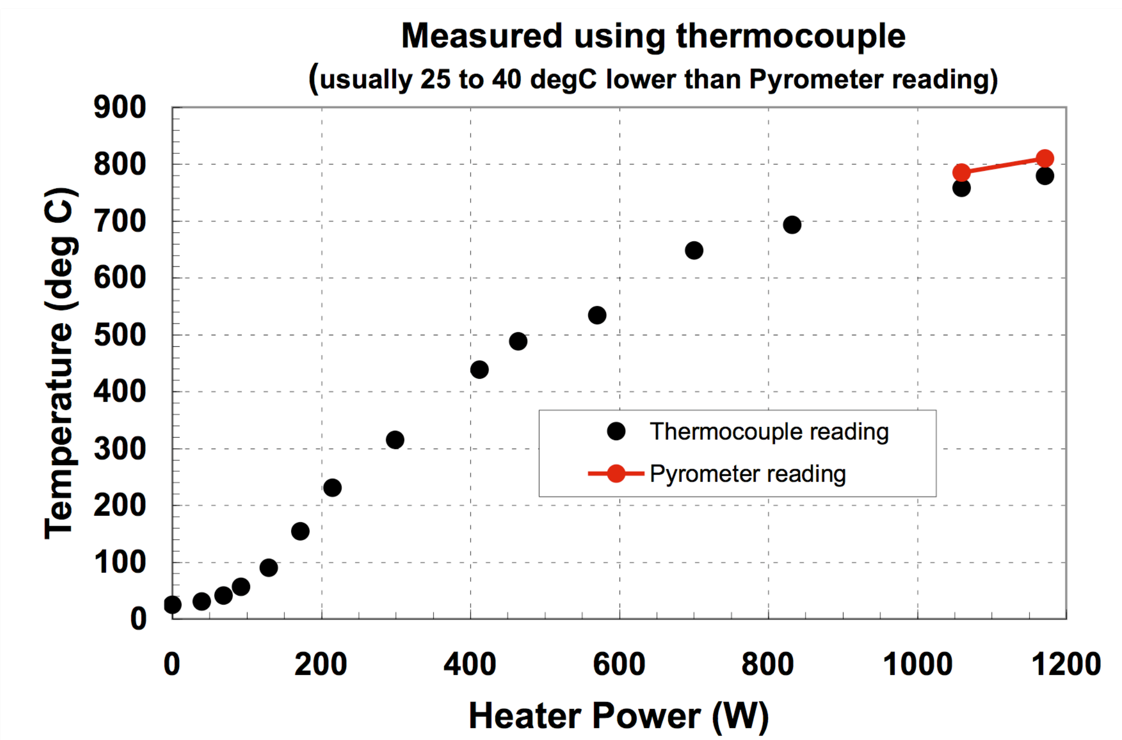
Generated 5/3/2006 10:27:04 AM				Start Time: 4/29/06 18:00:00					End Time: 5/1/06 09:00:00			
Date	Time	Heater Filament (A)	Heater Power Readback (kW)	Heater Power (kW)	Mounting Plate Temp (°C)	FAR Pyrometer (°CT)	Heater Power (kW)	Shroud Temp 4 (°C)	Ion Gage 1 (nT)	Ion Gage 2 (nT)	Ion Gage 3 (nT)	Ion Gage 4 (nT)
4/29/06	18:00:00	40.29	0.95	1.00	127.84	800	1.00	115.4	196.4	210.1	205.4	196.4
4/29/06	18:00:20	40.29	0.92	1.00	127.84	800	1.00	116.0	196.4	210.1	205.4	196.4
4/29/06	18:00:40	40.29	0.94	1.00	128.82	800	1.00	116.0	196.4	210.1	205.4	196.4
4/29/06	18:01:00	40.29	0.92	1.00	128.08	800	1.00	115.4	196.4	210.1	205.4	196.4
4/29/06	18:01:20	40.29	0.94	1.00	128.08	800	1.00	115.4	196.4	210.1	205.4	196.4
4/29/06	18:01:40	40.29	0.95	1.00	128.08	800	1.00	115.8	196.4	210.1	205.4	196.4
4/29/06	18:02:00	40.29	0.95	1.00	128.08	800	1.00	116.2	196.4	210.1	204.2	196.4
4/29/06	18:02:20	40.29	0.95	1.00	128.08	800	1.00	116.2	196.4	210.1	204.2	196.4
4/29/06	18:02:40	40.29	0.92	1.00	128.08	800	1.00	115.5	196.4	210.1	204.2	196.4
4/29/06	18:03:00	40.34	0.92	1.00	128.08	800	1.00	116.1	196.4	210.1	204.2	195.3
4/29/06	18:03:20	40.34	0.93	1.00	128.94	800	1.00	115.5	196.4	210.1	204.2	195.3
4/29/06	18:03:40	40.29	0.94	1.00	128.69	800	1.00	115.5	196.4	208.9	204.2	195.3
4/29/06	18:04:00	40.29	0.94	1.00	128.69	800	1.00	116.1	196.4	208.9	204.2	195.3
4/29/06	18:04:20	40.29	0.94	1.00	128.69	800	1.00	116.1	196.4	208.9	204.2	195.3
4/29/06	18:04:40	40.29	0.92	1.00	129.06	800	1.00	115.9	195.3	208.9	204.2	195.3
4/29/06	18:05:00	40.29	0.92	1.00	128.45	800	1.00	115.9	195.3	208.9	204.2	195.3
4/29/06	18:05:20	40.29	0.92	1.00	128.82	800	1.00	116.2	195.3	208.9	204.2	195.3
4/29/06	18:05:40	40.29	0.95	1.00	128.33	800	1.00	115.8	195.3	208.9	204.2	195.3
4/29/06	18:06:00	40.29	0.95	1.00	129.06	800	1.00	116.5	195.3	208.9	203.1	195.3
4/29/06	18:06:20	40.29	0.93	1.00	128.69	800	1.00	116.5	195.3	208.9	203.1	195.3

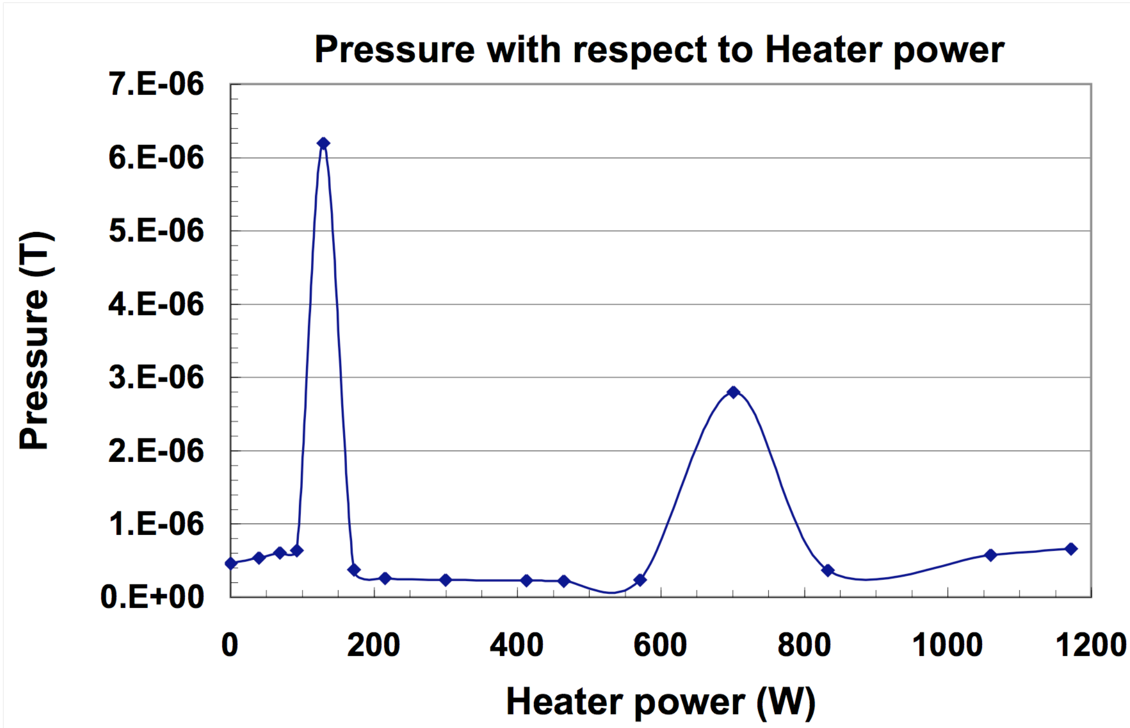
Locations and photograph of the shroud temperature sensors are given in T. Houck, "Cathode Heating and Related Diagnostic Testing in Support of the DARHT-II Injector," DARHT Technical Note No. 258, 19 August 2002. Information on the ion gauges and vacuum system can be found in P. Shoaff and K. Kishiyama, "DARHT-II Injector and Accelerator Vacuum Systems Design & Analysis Report," DARHT Technical Note No. 249, 15 May 2002.

Appendix G
LBNL Cathode Test Stand Data (courtesy of Prabir Roy)

Time	Voltage (V)	Current (A)	Power (W)	Pressure (Torr)	Resistance (Ω)	Thermocouple Temp (°C)	Pyrometer Temp (°C)
10:48	0.0	10	0.0	4.6E-07	0.000	24.7	
10:15	2.2	18.3	39.8	5.4E-07	0.119	31.0	
10.35	3.1	22.4	68.9	6.1E-07	0.137	41.2	
10.55	3.9	23.7	92.0	6.4E-07	0.164	56.8	
11:24	5.3	24.6	129.6	6.2E-06	0.214	90.3	
11:55	6.8	25.5	172.1	3.8E-07	0.265	154.0	
12:30	8.2	26.2	215.1	2.6E-07	0.313	230.3	
13:01	10.5	28.4	299.3	2.4E-07	0.371	315.0	
13:46	13.4	30.7	412.3	2.3E-07	0.437	438.6	
14:35	14.7	31.6	464.5	2.2E-07	0.465	487.9	
15:05	16.9	33.8	570.5	2.4E-07	0.499	534.4	
15:36	19.3	36.3	700.6	2.8E-06	0.532	648.1	
16:05	21.7	38.4	832.5	3.7E-07	0.565	693.0	
16:37	25.5	41.5	1059.5	5.8E-07	0.615	758.5	785
16:52	27.1	43.3	1171.3	6.6E-07	0.625	779.3	810

Note: Voltage and current values are rms values.





Pressure with respect to Heater power
7.E-06
6.E-06
5.E-06
4.E-06
3.E-06
2.E-06
1.E-06
0.E+00
Pressure (T)
0
200
400
600
800
1000
1200
Heater power (W)

Appendix H
Spectra-Mat Factory Test Data on First Production Run DARHT Cathodes

Filament Current (A)	Heater Voltage (V)	Power (W)	Filament Resistance (Ω)	Estimated Heater Temp (°C)	Cathode Temp (°C_T)
0.0	0.0	0			
13.4	3.0	40	0.224	303	
19.5	5.3	103	0.272	389	
19.6	6.3	123	0.321	483	
25.8	9.9	255	0.384	604	
28.2	12.3	346	0.436	701	
31.7	14.9	473	0.470	768	
34.4	18.0	619	0.523	867	
37.0	20.6	763	0.557	931	
40.0	25.0	999	0.625	1057	845
41.3	26.0	1074	0.630	1067	857
45.2	30.0	1356	0.664	1131	913
47.6	34.5	1641	0.725	1294	953
50.4	37.8	1905	0.750	1245	998
53.6	41.9	2247	0.782	1354	1040

Note: Voltage and current values are rms values.
Data transcribed from Spectra-Mat Report, ba_test.doc, "Report on the Impregnant Test and Temperature Test of a 6.5 Inch Planar Dispenser Cathode," March 2000

Appendix I
Test Stand Configurations for Temperature versus Heater Power Measurements

The configurations for temperature measurements used at Spectra-Mat and LBNL are shown below. Spectra-Mat modified an existing vacuum furnace by removing furnace elements and water cooling-structure, and adding feedthroughs for the cathode power. A cylindrical molybdenum heat shield was placed around the inside of the bell jar to minimize heating of the glass. The bell jar pressure, filament voltage and current, and cathode temperature (>845°C_T) were monitored. Refer to Figure I-1.

LBNL modified an existing induction injector to construct their Cathode Test Stand as illustrated in Figure I-2. The test stand can be configured for heating and temperature studies and for low current density electron emission. For heating studies the cathode is instrumented with thermal couples and viewed with pyrometers and a filtered camera (Figure I-3). Pressure and filament voltage/current are also monitored.

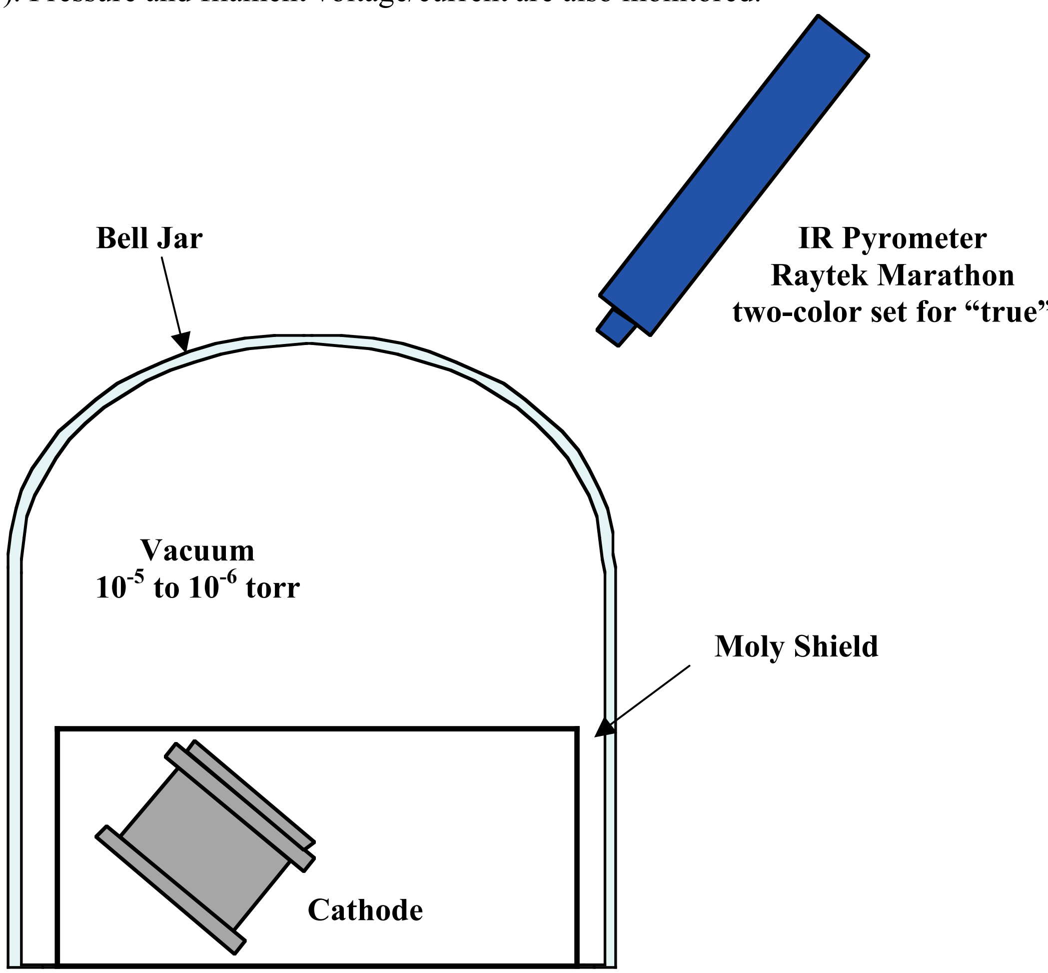


Figure I-1. Spectra-Mat’s bell jar configuration for cathode heating tests.

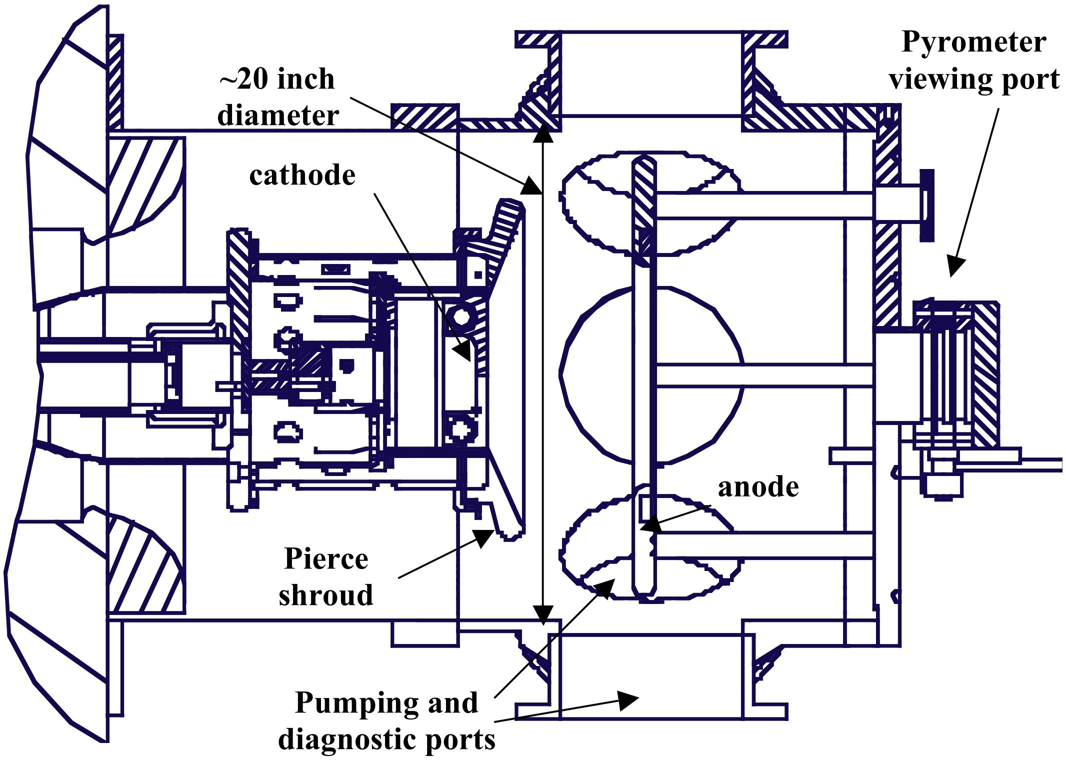


Figure I-2. Schematic of LBNL Cathode Test Stand showing cathode, cathode housing, Pierce shroud, open anode, and vacuum vessel.

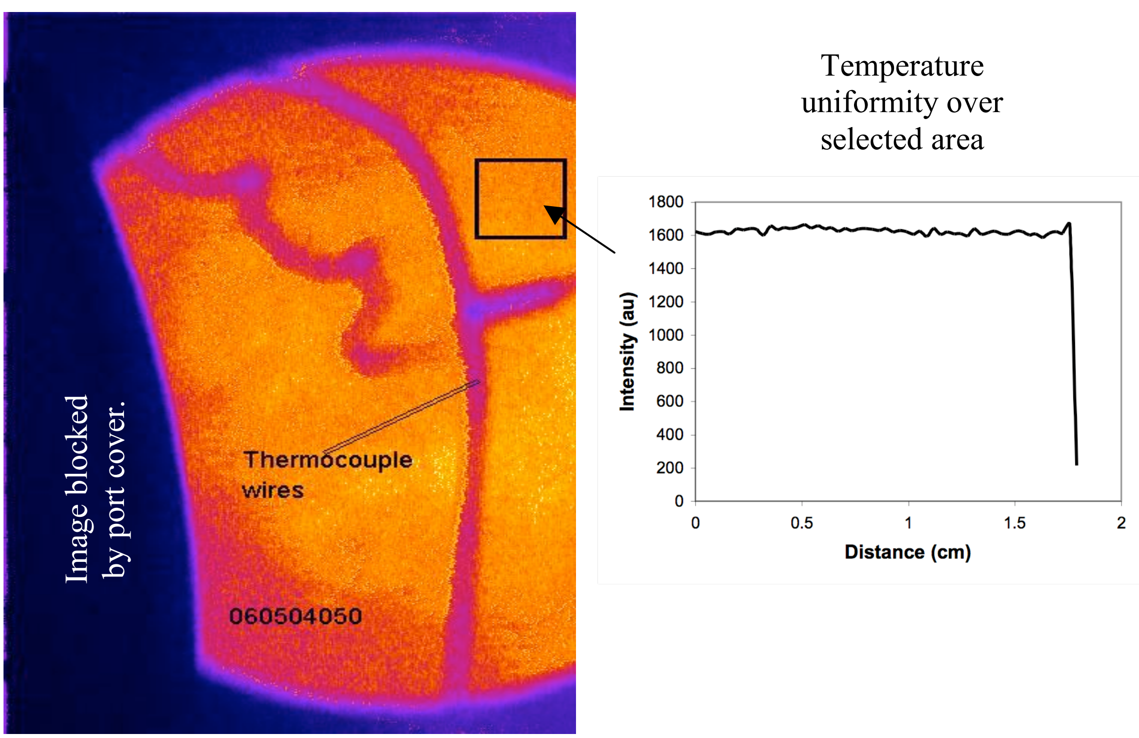


Figure I-3. Sample photograph of heated cathode in the LBNL Cathode Test Stand.

The arrangement of the DARHT-II cathode with respect to the shrouds and temperature diagnostics is shown in Figure I-4. Both the FAR Pyrometer and CAT Camera view the cathode surface at an angle of about 51° with respect to the normal and at a distance of nearly 2 meters due to mechanical constraints.

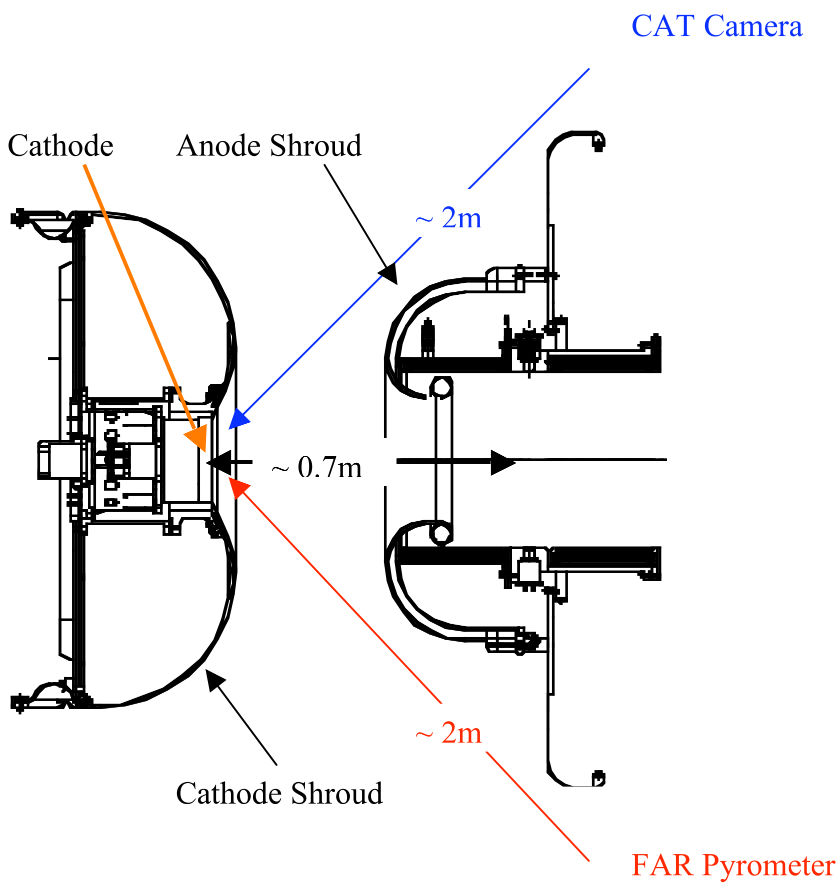


Figure I-4. Schematic of the DARHT-II Diode with line-of-sight for the FAR Pyrometer and CAT diagnostic indicated.