

# DC gun high voltage conditioning with Krypton gas

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## Background

High voltage conditioning in DC guns is nominally performed under vacuum conditions. The purpose of the process is to achieve the desired operating voltage without field emission and without voltage-induced gas load. Field emission, believed to be from dielectric particles or metal whiskers on the electrode surface, is commonly present during the voltage conditioning. Usually the field emitters can be processed out by slowly increasing the voltage and controlling the field emission current. In the FEL gun, field emitters are typically encountered below 250kV. Once the emitters are processed at that voltage, a new phase in the processing begins; something we have called "voltage-induced gas desorption". With every 1 kV increment, the pressure in the gun vacuum chamber increases by 2 orders of magnitude, and takes about 5 to 10 minutes to recover (or 30 minutes at voltages beyond 350kV) as shown in Figure 1.

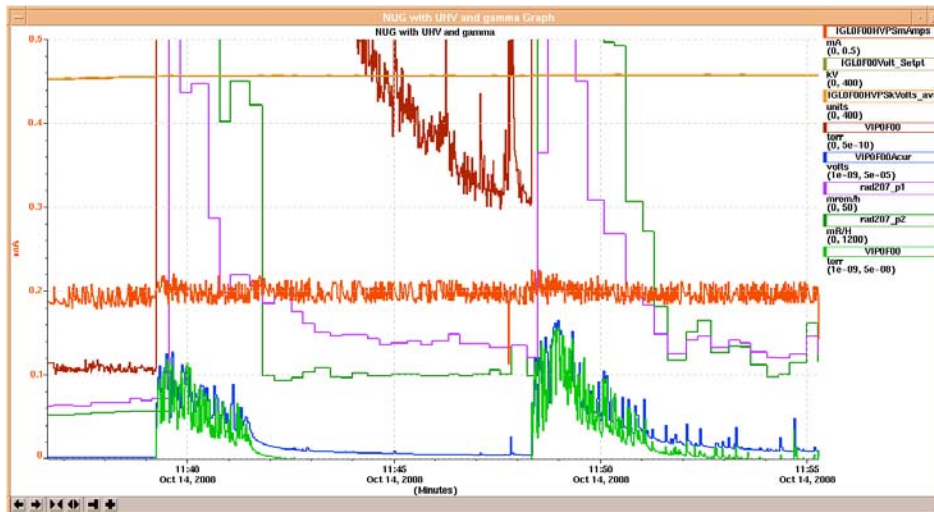


Figure 1. Gas desorption phase under vacuum conditions at 260kV.

It is also seen in Figure 1 that the signal from both radiation monitors track both the current and the ion pump current. This is the first time radiation monitors are used in the FEL gun for high voltage processing. The RGA reports increases in Hydrogen, Methane, CO and CO<sub>2</sub> with each step up in voltage. This gas desorption phase is not fully understood yet, but it has been observed every time the gun has been conditioned, and it has a very sharp onset. For example, if the gun is fully conditioned to 350kV, it can operate for years at that voltage, but if the voltage is increased by 1 kV, then gas desorption is present again.

Field emitters will also be present at voltages higher than 250kV, the problem in processing them out is dealing with the gas desorption at the same time, because the current also increases sharply (about 10 uA increase with 1 kV step) when the voltage is stepped up, and decays slowly (exponentially?) tracking the vacuum behavior in a very consistent way. The current behavior is barely seen in Figure 1, red trace, but it is very clear in the strip chart recorder.

Despite these complications, the FEL gun has been successfully conditioned in several occasions up to 450 kV, taking about 100-man hours in the process. However, during the September 2008 FEL gun high voltage conditioning, the first field emitter was encountered at 270 kV. After ~50 hours of processing under vacuum conditions, the emitter could not be processed out. At that point it was decided to try gas processing.

### **High voltage processing with Helium gas**

When the field emitter cannot be processed under the nominal conditioning (i.e. the excess current is above 100 uA at voltages below 150kV and is self-sustained for hours, or if the emitter returns at the same voltage it first appeared after several hours of processing), an inert gas can be used in combination with the voltage.

Helium is commonly used and has shown good results for the Cornell gun (See Appendix 1). However, there is always a risk to develop a leak especially in the ceramic insulator due to the lack of vacuum diagnostics at the  $1 \times 10^{-5}$  Torr level where the inert gas processing takes place. Most ion gauges do not operate at that pressure and the ion pumps need to be turned off. The NEG pumps keep pumping though, and do not pump inert gasses. Actually, at the  $1 \times 10^{-11}$  Torr range most of the pumping is provided by the NEGs and the ion pumps are mostly used as gauges.

Stephen Benson 10/20/08 12:17 PM

**Comment:** We should note here that the RGA can be used and was used to monitor the argon and fluorine pressures to look for a leak.

One diagnostic that proved essential in the recent FEL gun conditioning is radiation monitors. Two ionization chambers were installed next to the gun, one on the stainless steel vacuum chamber (closest to the ball cathode) and one more on the SF<sub>6</sub> aluminum tank to monitor field emission from the support tube electrode, which is coaxial to the ceramic insulator (See Figure 9).

It is believed that the gas molecules are ionized by the field emission current and are accelerated towards the negatively biased electrode, effectively “back-ion” bombarding the field emitter until the geometry (or the chemical properties, i.e. work function) is altered. Once the field emitter is burned off, the gas is pumped out and the regular high voltage processing under vacuum conditions continues until the next field emitter is found, and the gas processing is applied again. We did not proceed in this way. Instead, the helium processing continued for hours, without opening a leak or punching-through the ceramic insulator.

In the FEL gun, Helium processing worked very effectively in the sense of processing field emitter at voltages below 270kV. The current was at baseline (see Appendix 2) and the voltage could then be increased up to 375kV, under Helium conditions. Several field emitters were found and processed in the way, although not entirely at voltages beyond 350kV. When the Helium was pumped out and the voltage was ramped up back to where the field emission first started at 270kV, the gas desorption phase was observed, but at 274 kV the field emission started again and the emitter could not be processed out. In conclusion, Helium processing for that particular emitter in the FEL gun did not work.

#### **High voltage processing with Krypton gas**

Since processing with Helium showed some improvement, it was proposed to use a heavier gas. Ideally one would start with Neon, or perhaps Argon, but the only gas available at the time was Krypton, which is about 20 times heavier than Helium.

Starting with  $5 \times 10^{-6}$  Torr instead of  $1 \times 10^{-5}$  Torr for Helium, Krypton processing quickly burned off some emitters at voltages below 250kV (Figure 2).

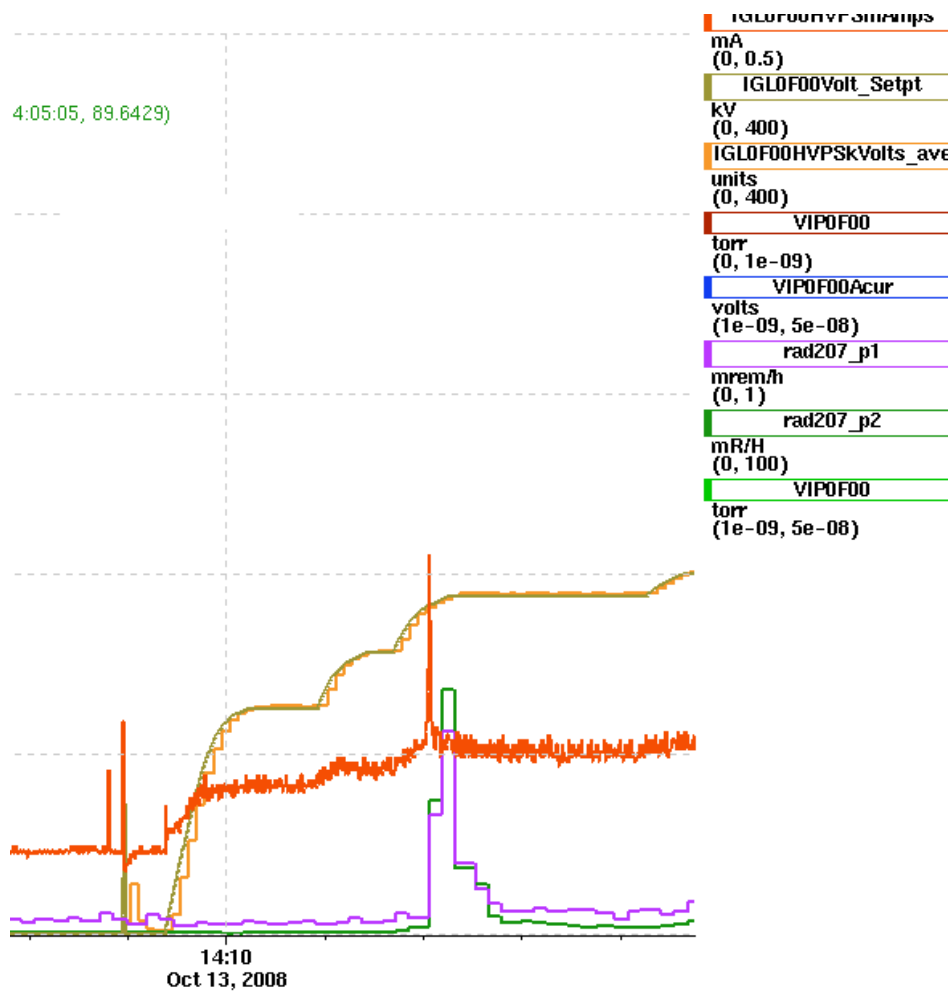


Figure 2. Emitter burning off while ramping up to 250kV. Red trace is the current, purple and green traces are the radiation monitors signals.

Then at around 300kV more processing took place, with the current being erratic and the radiation tracking the current, but signs of improvement were observed as the voltage was increased in 5 kV steps when the current was either stable or when it had dropped (Figure 3).

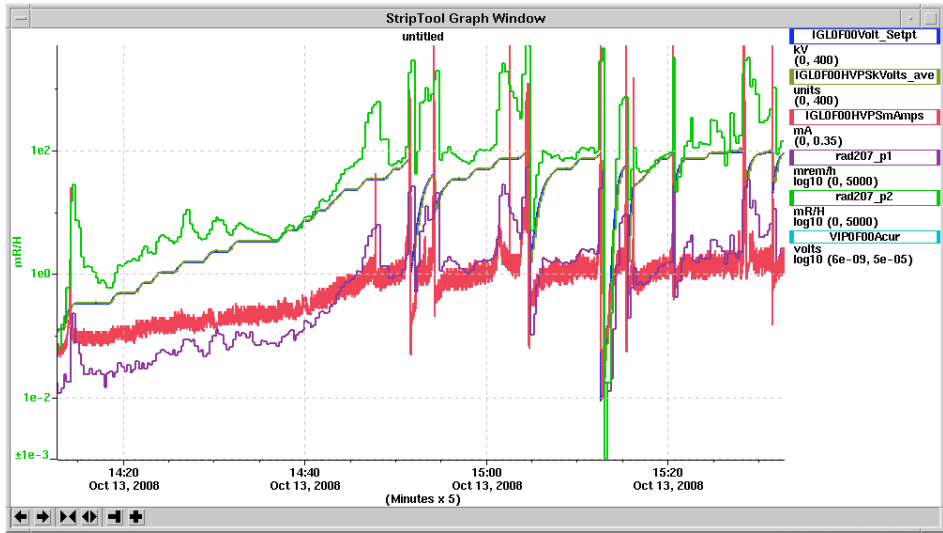


Figure 3.

After about one hour of processing between 290 and 315kV, the current was at baseline (see Appendix 2) and was very steady. The radiation, though, was high. At that point a pattern was observed in the current and radiation with every 1 kV increase. The pattern resembled the gas desorption phase under nominal vacuum conditions, only this time the diagnostic was the signal from the radiation monitors instead of the current from the ion pumps. The radiation tracked the current perfectly, showing a sharp rise and an exponential decay with every 1-kV step (Figure 4). The Krypton processing was then successful in eliminating the emitter at 300kV and at the same time the processing had evolved into the gas desorption phase.

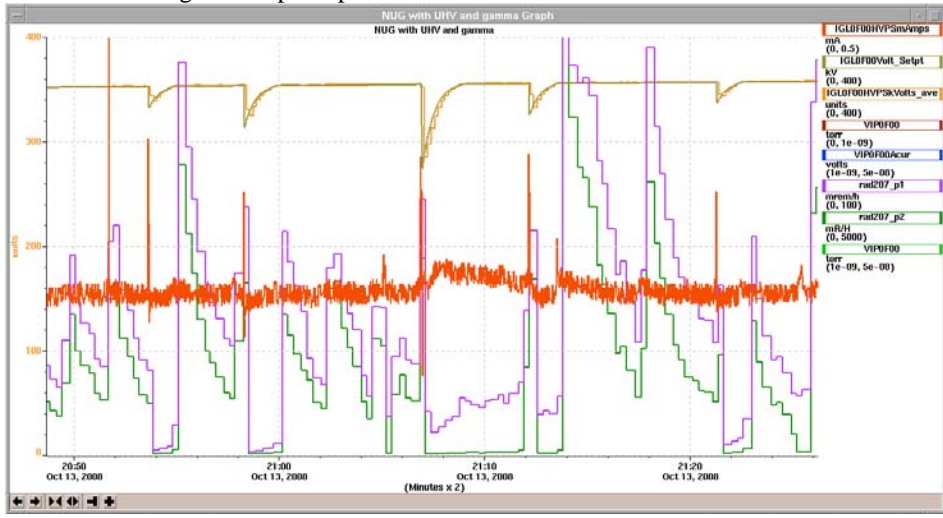


Figure 4. Gas desorption phase with Krypton processing.

As observed in Figure 4, the gas load was sometimes so high that drew too much current (more than 300  $\mu\text{A}$ , see red spikes) causing the high voltage power supply to react and lower the voltage, which almost immediately was ramped up back again by the operator.

Since progress was being made and gas desorption was taking place, the processing with Krypton continued up to 375kV for hours, but the field emitter at that voltage was not fully processed yet, as shown in Figure 5.

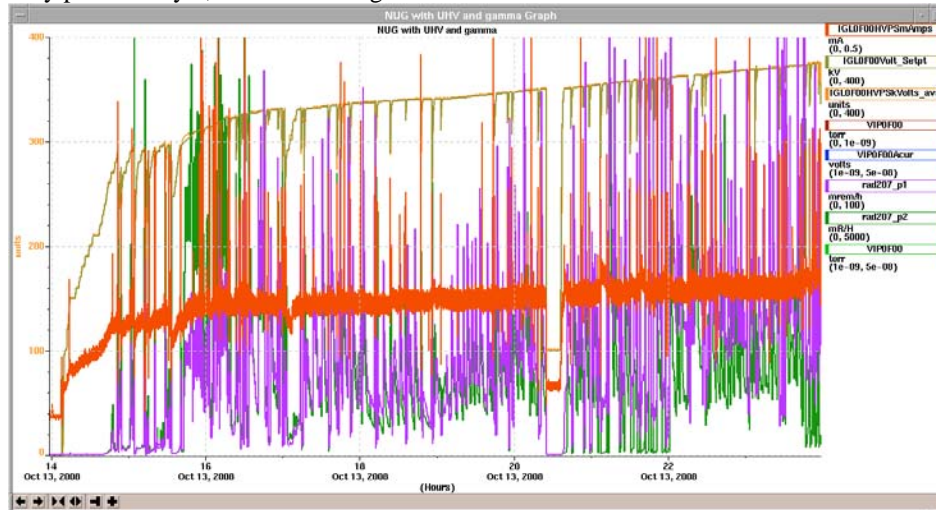


Figure 5. Processing with Krypton up to 375kV, but radiation and current still high at that voltage.

The Krypton was then pumped down and with the gun in nominal vacuum conditions, the voltage was ramped up effortlessly up to 364 kV, where the first indication of gas desorption was observed. For comparison, the first field emitter was encountered at 270kV and could not be processed out under nominal vacuum conditions, then Helium processing shifted the field emission onset to 274kV.

Since the FEL gun operates at 350kV and the cesiated GaAs wafer is high voltage processed to 360kV, it was decided to continue Krypton processing up to 375kV, soaking there for about three hours. During that soaking time, a few current spikes were observed and some slow processing took place, as shown in Figure 6, then the Krypton was pumped out again.

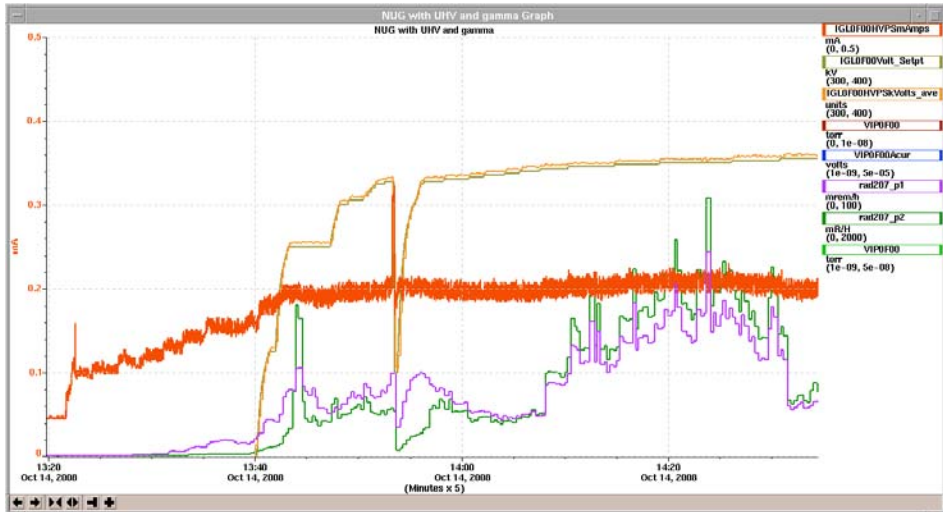


Figure 6. Some slow processing took place while ramping in 0.5kV steps between 370 and 375kV. Notice the rise and decline of both current and radiation as one of the emitter slowly processed out (between 14:00 and 15:00 hours).

Finally, under nominal vacuum conditions, the voltage was ramped from 0 to 360kV without problems (Figure 7).

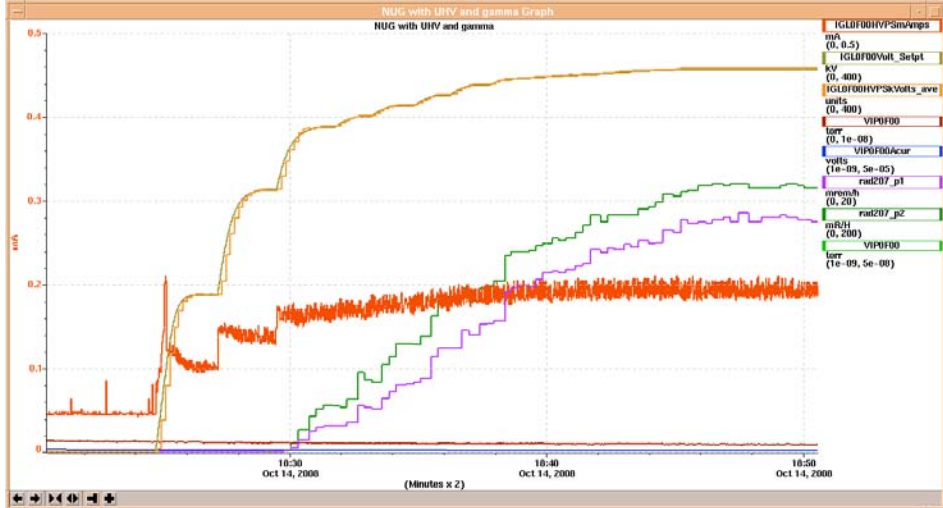


Figure 7. Voltage ramp up under nominal vacuum conditions. Notice radiation tracking the voltage, but not the current. The current spike at the beginning of the ramp is intrinsic to the high voltage power supply.

The voltage was then increased to 365kV and soaked for three hours. A few current spikes associated with very quick pressure spikes were observed (Figure 8). Most likely

associated with gas desorption events. At that point, the gun was declared to be conditioned up to 365 kV.

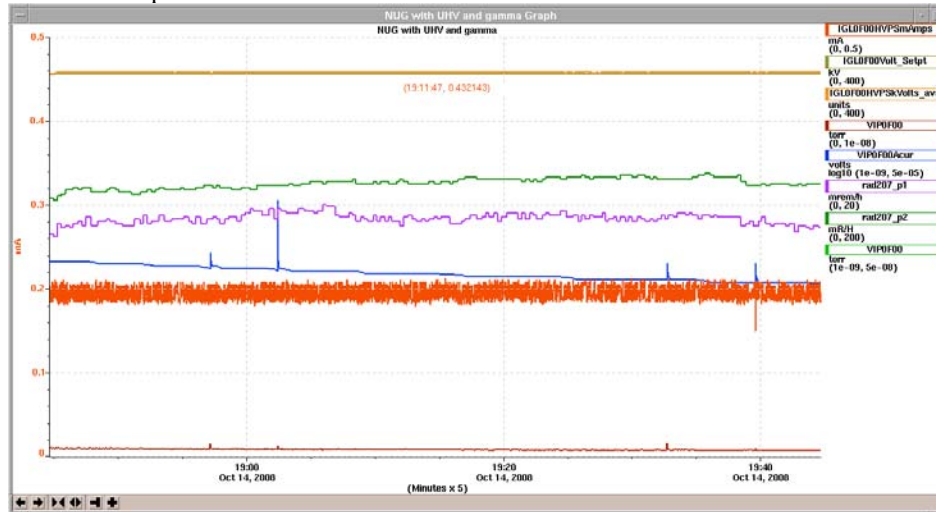


Figure 8. Gun soaking at 365kV under vacuum.

### Some thoughts about Helium and Krypton processing

- It is not clear yet why the Helium processing did not help desorbing gas, as Krypton processing did.
- One speculation is that if the emitter is not processed, most of the available 'energy' is going through the field emission current, limiting the available energy for desorbing gas. Once the emitter was processed with Krypton, the gas desorption phase continued as usual.
- It is not clear if Neon or Argon would have helped processing the emitter in the same way as Krypton did.
- At the pressures used for gas processing ( $1 \times 10^{-5}$  Torr), there is little chance for plasma formation and therefore sputtering on the electrodes surfaces. Besides, the electrodes are biased negatively. In plasma sputtering systems, the pressure is in the  $1 \times 10^{-3}$  Torr range and the electrodes are biased positively.
- The wafer suffered surface damage, most likely due to high voltage conditioning, regardless if gas was used or not. The cesiated GaAs wafer exhibited large amounts of field emission. This effect has been observed previously in the IR-Demo FEL. But heat cleaning the wafer for 5 hours proved to improve the cathode QE lifetime and to minimize field emission from the cesiated surface.
- Radiation monitors proved to be an essential diagnostics during the gun high voltage conditioning.
- Krypton processing works!



**Pre-conditions for Krypton gas processing (refer to Figure 9)**

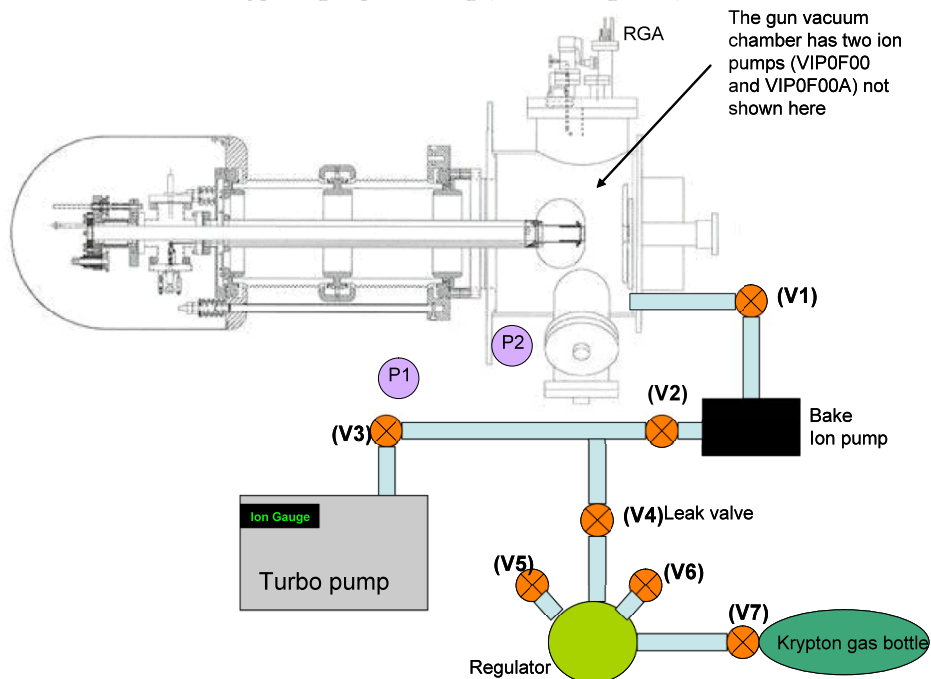


Figure 9. P1 and P2 are radiation detectors (ionization detectors).

1. The gun is under nominal vacuum conditions with (V1) closed. Pumping to the gun is continuously provided by three NEG pumps and two 40 l/s Ion Pumps (VIP0F00 operated with by the regular MPS (Machine Protection System) I/P controller, and VIP0F00A operated with the UHV controller, which is not linked to the MPS).
2. The HVPS is set to operate with one-stack configuration, this means the maximum current the power supply can deliver is 5 mA.
3. The Vacuum Interlock in the back of the Gun HVPS control chassis is “active”. This interlock turns off the gun high voltage if the pressure on VIP0F00 is higher than  $1E-7$  Torr.
4. The gun HVPS is set to “current trip mode” with a switch located in the back of the HVPS control chassis. If the current setpoint in front of the Glassman HVPS control is reached during the gun conditioning, the HVPS will turn off the voltage.
5. The RGA is ON and operating with the Electron Multiplier ON.
6. The Bake I/P is ON and powered by a local controller located under the pump.
7. Valve (V2) is closed isolating the Bake Pump from both the gun and the Turbo pump flexible hose.

8. The turbo pump flexible hose had been baked to 120C and the pump has been running for long time. With (V3) open the ion gauge on the turbo pump should read  $\sim 9E-10$  Torr to  $2E-9$  Torr.
9. The turbo pump flexible hose has been purged three times with the processing gas (Krypton in this case).
10. Valve (V3) is closed.
11. The Gun HVPS is OFF
12. The Gun HVPS is in "current limit mode" with the limit set to 300 uA (dial at 0.6 turns for one-stack configuration, or 0.3 turns for two-stack configuration).
13. Krypton bottle valve (V7) is closed
14. Both regulator valves (V5) and (V6) are closed.
15. Leak valve (V4) is closed.

### **Instructions for Krypton gas processing starting from nominal vacuum conditions**

1. Bay-pass the Gun HVPS Control chassis Vacuum interlock. Contact Dan Sexton, Jim Kortze, or Carlos Hernandez-Garcia to perform this task. **NOTE:** Bypassing the gun vacuum interlock means that the voltage WILL NOT TURN OFF if a leak opens or if the pressure in VIP0F00 goes beyond  $1E-7$  Torr. This is very dangerous to the gun. The operator must shutdown the gun voltage immediately if the RGA indicates pressure higher than that of the gas processing setpoint or if the spectrum shows clear evidence of a leak by the presence of peak 19 (Flourine, the gun ceramic is enclosed in the SF6 tank).
2. Make sure to change the HVPS status from "current trip" mode to "current limit" mode by flipping the switch located in the back of the HVPS Control Chassis.
3. Adjust the current limit setpoint in front of the Glassman HVPS control to 300 uA. With the HVPS in the one-stack configuration, the current dial must be at 0.6 on the dial, since 10 full turns are 5 mA.
4. Go to the Vacuum rack in the RF gallery and disconnect the HV cable in the back of the UHV I/P controller. Use Lock, Tag, and Try (LTT).
5. Turn off VIP0F00 controller, then unplug the controller power cord located in the back of the controller, use LTT for the power plug.
  - a. NOTE: Most of the gun pumping is continuously provided by the NEG's, at the  $5E-11$  Torr range the ion pumps are mostly used as vacuum gauges.
6. Go the vault.
7. Open valve (V2) from the bake pump to the turbo, check bake ion pump readback on its controller.
8. Open Turbo pump valve (V3).
9. Turn off bake ion pump.
10. Throttle turbo pump valve (V3). First fully close the valve (V3), the pressure in the ion gauge on the turbo cart will go to the  $1E-10$  Torr range, then open the valve (V3) half turn.
11. Open gas (Krypton) bottle valve (V7). Verify on the regulator gauge that there is gas in the bottle ( $\sim 500$  psi).
12. Adjust regulator valve (V6) to set the pressure on the other side of the regulator (towards the leak valve) at 20 psi.

13. Open regulator valve (V5).
14. Open gun valve (V1).
15. Return to control room.
16. Adjust the Krypton gas pressure as read by the RGA Total pressure gauge to  $5 \times 10^{-6}$  Torr (the turbo pump ion gauge on Monitor 3 will read about  $5 \times 10^{-8}$  Torr). The Krypton gas pressure is adjusted remotely by operating the leak valve (V4) with the motor connected via a belt to the leak valve, which is seen on monitor number 4. The motor is operated with a toggle switch on the blue box located in the control room. Flip the switch to OPEN, you will see the valve handle turning, the red spot indicates zero (closed) you will have to go about 1.2 turns before you see pressure increasing, be patient, go slowly, it is easy to overshoot and Krypton takes a long time to be pumped by the turbo pump.
17. You can start processing high voltage processing with Krypton.

### **Instructions for returning to nominal vacuum conditions starting from Krypton gas processing conditions**

1. From the control room, close the Krypton leak valve (V4), the red spot will be on top and the indicator almost at the zero position when the valve is fully closed. The pressure in the turbo will go to the low  $1 \times 10^{-9}$  Torr, the pressure in the RGA will continue to drop. Allow about 20 minutes of pumping before proceeding with step 2.
2. Go to the vacuum rack in the Gallery and re-connect the SHV cable to VIP0F00A (the UHV I/P controller) and plug back in VIP0F00, make sure to turn on the VIP0F00 controller in the front of the vacuum rack. VIP0F00 might take some time to turn on. First you will see that the pressure in VIP0F00 will go the  $6 \times 10^{-11}$  Torr, but at that point the I/P is not pumping yet. A few minutes later the pressure will jump to the low  $1 \times 10^{-9}$  Torr, that is when the pump is on.
3. Go to the vault
4. Open fully the turbo pump valve (V3), let the pressure settle down, it will be in the low  $1 \times 10^{-9}$  Torr or maybe in the high  $1 \times 10^{-10}$  Torr. The gun is actually pumping on the turbo, so don't wait too long for the next step.
5. Close the gun valve (V1) (if you turn on the bake pump first, it will spew methane into the gun)
6. Turn on bake pump, let the pressure settled down.
7. Close the valve (V2) on the bake pump to the turbo pump.
8. Close the valve (V5) on the gas regulator.
9. Close the gas bottle valve (V7).
10. Close the turbo pump valve (V3).
11. Make sure the leak valve is closed by removing the belt to the motor. ***Do not overtighten.*** Leave the belt off.
12. Return to control room and make FLOG recording readbacks from VIP0F00 and VIP0F00A, make sure vacuum is recovering by checking VIP0F00 and VIP0F00A traces in the NUG graph, you might have to turn on the traces by going to the graph controls (right click on the graph).

13. Check that vacuum is recovering by observing the RGA spectrum.
14. Re-establish gun HVPS Vacuum interlock. Contact Dan Sexton, Jim Kortze, or Carlos Hernandez-Garcia to perform this task.
15. Change the gun HVPS configuration from “current limit mode” to “current trip mode” The flip switch to perform this task is located in the back of the gun HVPS control chassis. It is clearly labeled.

### **Appendix 1**

#### **Cornell’s instructions for Helium processing, by Bruce Dunham.**

1. Attach a precision leak valve to the pump out port of the gun (or where ever you want)
2. Attach a turbo pump (oil free) to the leak valve
3. Connect a high purity helium bottle to the leak valve, use a filter. Purge the line with helium and pump out several times.
4. pump out the leak valve and hose, then do a short ~120C bake to get rid of the water.
5. Now, you are ready to proceed. I usually process the gun (no helium) until there is a bad field emitter that does not go away.
6. Open the leak valve until the pressure in the turbo pump reads around  $1 \times 10^{-5}$  Torr
7. IMPORTANT: turn off the gun ion pump to avoid saturating it with helium. The NEG pumps do not pump helium. Can also turn off the RGA and any ion gauges, depending on what helium pressure you use. Make sure the gate valve to the beamline is closed and disabled, and also the gate valve to the load lock.
8. Slowly open the valve to the gun (mine is an all-metal rt angle valve), and the gun will fill with helium
9. Now, you can turn up the gun voltage to just below where you had the problem before. Slowly increase the voltage while monitor the current going into the gun. I normally observe an increase in current, a decrease, another increase, and a final increase when the emission site is ‘passivated’. Make sure to keep the current limit low to avoid damage.
10. Once you get thru the ‘bad spot’, turn down the HV, turn off the helium and pump out the chamber and turn the ion pump back on. Proceed processing as usual without helium until you get to another bad spot.

#### NOTES:

1. you might think that this will ruin the bakeout and your good vacuum. In fact, it does not, as long as the turbo does not introduce any contaminants. If the ion pump is off for a long time (hours), it will start releasing methane, and it can take a while to pump it out again
2. What is the helium doing?? Not sure – there are 2 ideas. If the field emitter is a metal, the helium ions may melt the sharp point. More likely, the emitter is a dielectric particle or dust, and the helium somehow changes its surface properties – I have seen this in

several articles. If it is a dielectric particle, the benefits of helium processing may be diminished with heat – so if you do a bake, you may need to He process again.

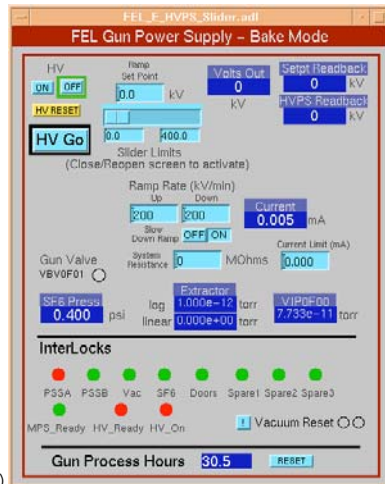
3. **IMPORTANT** This process has worked great for me, actually it works too well. It cleans up bad emitters quickly – this led me to be too aggressive due to being overconfident, and I ended up blowing a hole in the insulator. Since one cannot monitor the RGA spectrum (at least not easily), I could not see SF6 on the spectrum and thus did not know a leak had occurred. The lesson is: be careful, and keep the current limit on the power supply as low as you can.

## Appendix 2

### Baseline currents for gun HVPS operating with one stack (5mA)

#### Measured and extrapolated by S. Benson.

NOTE: The current is as read in EPICS (see Figure A1), which has an offset of about 45 uA above the readback on the Glassman HVPS control.



| kV  | I (uA) |
|-----|--------|
| 20  | 47     |
| 40  | 56     |
| 80  | 72     |
| 100 | 81     |
| 120 | 89     |
| 140 | 97     |
| 160 | 105    |
| 180 | 114    |
| 200 | 122    |
| 210 | 126    |
| 220 | 130    |
| 230 | 135    |
| 240 | 139    |
| 250 | 143    |
| 260 | 147    |
| 270 | 151    |
| 280 | 155    |

|     |     |
|-----|-----|
| 290 | 160 |
| 300 | 164 |
| 310 | 168 |
| 320 | 172 |
| 330 | 176 |
| 340 | 180 |
| 350 | 185 |
| 360 | 189 |
| 370 | 193 |
| 380 | 197 |
| 390 | 201 |
| 400 | 205 |