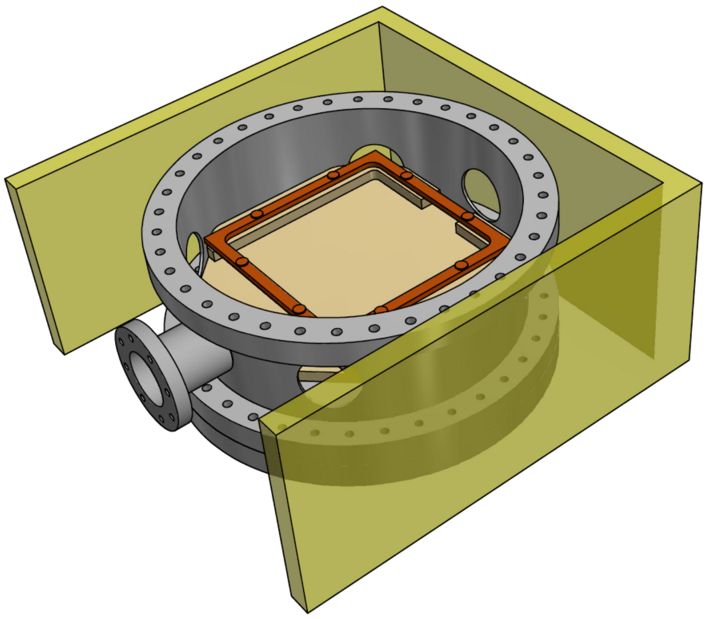
Margherita User's Manual

University of Chicago



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Contents

1 Introduction

1.1 "Who?"

Names can be misleading... the title of this manual may lead one to believe that what follows is a guide to a particularly scrumptious pizza style, or perhaps a discussion about the proper ratio of Cuervo Gold to ice in order to make a tasty concoction.

No, in fact, what follows is a detailed manual to a dual vacuum chamber: the LAPPD tile fabrication station appropriately named "Margherita" after its pizza like nature. This manual will include Margherita's purpose, operational instructions, experimental procedures, and more.

1.2 What is Margherita?

In the summer of 2014, it was proposed that we move quickly onto new ways to fabricate large area pico-second photo detector (LAPPD) tiles. One reason for this is that we saw a common pattern among other fabrication procedures, some of which worked well, others not working well enough. One attitude for approaching photo tube fabrication is that of extreme tidiness and attention to detail. While this is effective in producing a clean, long lasting, even *perfect* product, it can often be expensive and require an excessive amount of organization and infrastructure.

Another attitude is the one that we adopt: make it simple, make it cheap, make it fast, and make it right. In order for LAPPD tiles to be produced in large scales for use in high energy physics experiments or medical imaging equipment, an assembly line process must be designed and tested. Even though we prioritize "getting it done", here at University of Chicago, we always keep the quality of the product in mind, maintaining good practice while designing simple apparatus.

Margherita is our assembly-line fabrication station: she is a sixteen-and-a-half inch pizza-shaped high vacuum chamber with a few ports for diagnostics and pumping—and that's it. All of the components are comparatively cheap. With a bit of further development, Margherita will make tiles in 24 hours or less, start to finish. Furthermore, the size and simplicity will allow future commercial fabricators to make many tiles in parallel, similar to the current practices of photomultiplier tube manufacturers.

In this revision of the paper, what follows is a detailed description of the design, procedure, and maintenance required by the Margherita station. Keep in mind that this document was made with the intention of being rewritten over and over again. ***Please revise as needed***.

2

Assembly and Design

2.1 Vacuum Techniques and Practices

A brief introduction in vacuum practices is necessary to serve as a code of conduct when dealing with Margherita. Building an effective high vacuum chamber or UHV dual chamber takes a somewhat large degree of attention to detail. Familiarizing ones self with the basic concepts that concern the assembly process can help make these details more naturally apparent.

2.1.1 Outgassing

An ideal vacuum is, in essence, the absence of molecules or gas. If you were to have extremely powerful and advanced pumping technology at your disposal, you could remove, one by one, each gas molecule in a chamber until there is only space. This would be an amazing feat! Unfortunately, this technology does not exist today. We truly take for granted how many gas molecules are in a given amount of space at any time.

At atmosphere and room temperature, a cubic meter of ideal gas has about 2.5×10^{25} molecules. In a high vacuum of 10^{-7} Pa, this becomes 2.5×10^{13} molecules. These numbers shed light on how difficult it is to remove every molecule from a volume element. Perfect vacuum is unachievable, but it is worth noting that the first few decades of pressure are the “roughest”. After about 10^{-1}, the job becomes one of picking things out one by one.

The biggest issue in creating high vacuum environments is *outgassing*. Quantifying the outgassing of a material is a way of characterizing the rate of desorption of molecules from a bulk material. In other words, the outgassing rate tells us how many gas molecules leave a surface in a given time interval. It may come to a surprise to many that every material is always emitting gas molecules. However, some materials outgas more than others and need to be avoided in vacuum applications. Sure enough, even with the most advanced pumping technology, one could pump on a material with high outgassing for days and not achieve a desired vacuum.

The saving grace is that some materials have very low vapor pressure, and as a result do not outgas strongly. These are the materials that we choose to use in vacuum chambers like Margherita. Other materials are strictly taboo. A list of acceptable and taboo materials for high vacuum can be found in Appendix C (C.2).

2.1.2 Cleanliness

Humans are the most unclean materials that would be in the vicinity of a vacuum chamber. The oils on our fingers and the gases that fly out of our mouths often embed themselves in stainless steel or other normally vacuum friendly materials. Therefore, we must maintain a convention of cleanliness when handling parts of Margherita.

- Wear nitrile gloves when handling flanges or the insides of clean vacuum parts

- Replace gloves often, they are cheap
- When putting on gloves and removing from the box, *do not* touch the finger tips. Grab by the wrist end of the glove and slip on from there
- When gloves are on, do not touch anything but the part to be cleaned
- While cleaning, wear a face mask. Gases from our mouths (water, CO2, etc.) are hot and have enough energy to embed themselves in stainless steel, increasing the outgassing of the material.
- Use Kimwipes for light alcohol rubs, sterile cloths for more thorough cleanings
- Wipe all gaskets and knife edges with a alcohol immediately before making a connection (if they didn't just come out of a clean plastic sealed bag)

2.1.3 Knife edge and Gaskets

A sealed Conflat (CF) interface is made with either an O-ring or a copper gasket. O-rings are only temperature rated for about 200 °C , thus we have avoided them so far. However, the top CF flange is a difficult beast to bolt on. In this case, we have been using a 16.5" Viton O-ring for quick and easy (and cheap) sealing of Margherita. With respect to the 16.5" CF flanges, the copper gasket can be used up to three times before the leak rate starts to become noticeable. Please reuse the copper gaskets or use an O-ring when available, as gaskets are expensive materials.

The Cu gasket is squeezed by the knife edge of the CF flange when bolts are heavily torqued. The main danger that can lead to a leaky interface is scratching or denting of either the gasket or the knife edge. Thus, *be very careful when placing flanges and gaskets together* and use gloves when handling.

2.1.4 CF Bolting Procedure

1. Prepare all of the necessary items before starting, especially bolts, nuts and washers.
2. If the bolts are fresh from the box, put a very small dab of thread lubricant on the end of the threads. This prevents galling which creates "false torques" and extra strain on the bolt.
3. With gloves on, wipe all flange knife edges carefully with an alcohol dampened Kimwipe (if the flange has been exposed to air) .
4. Carefully place the copper gasket within the grooves of the knife edge on one of the flanges. This can sometimes be tricky, especially when dealing with upright flange interfaces. One solution is to use a sliver of scotch tape to hold the gasket in place while connecting the flanges. In this case, the tape must be outside of the knife edge, ensuring that the tape will not be inside the seal (tape will outgas heavily and/or cause a leak).
5. Without scratching the gasket or the knife edges, press the two flanges together and align the bolt holes (gentle turning).
6. Place lubricated bolts into two of the bolt holes (helpful to do a top and bottom hole so that the flange will not fall). At this point, gloves becomes very hard to work with. Take them off as long as the flange is held onto its mate.

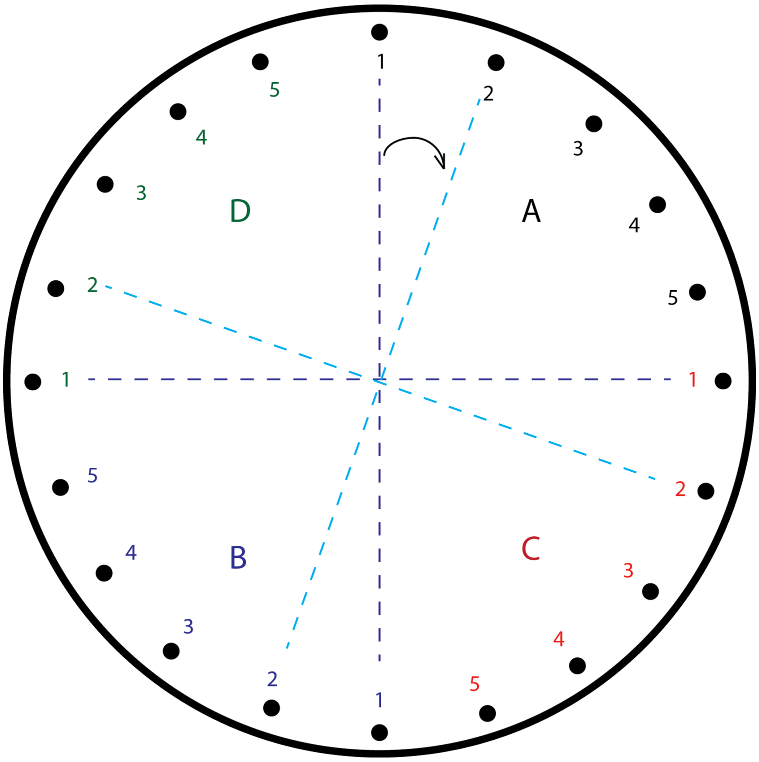


Figure 1: Depending on the size of your flange, label the bolt holes with a permanent marker. For flanges with more than 8 bolts, do the cross pattern shown above. Each iteration of the cross is one bolt away. For flanges less than or equal to 8 bolts, do an "opposites only" pattern, alternating turns on opposite bolts, each iteration is one bolt away.

7. With all bolts in, hand tighten (not tight).

8. With proper wrenches, do what we call "wrench tight" which is little to no torque but tight enough to where the bolts will not spin.

9. To tighten the bolts, turn a quarter turn, following the tightening pattern described by figure 1. This pattern is essential—if a mistake is made, there will be a leak and the gasket must be thrown out. After a few iterations, the bolts will become much harder to turn by a quarter turn. In general, *turn so that each bolt is evenly torqued*. This is the true golden rule. A quarter turn is often a good guide.

   a In the tightening process, there must be a balance between tightening enough to effectively compress the gasket and not over torquing to the point where the bolts break. Over torquing is easy when using a long wrench. You will know if you are over torquing if the bolt makes a loud cracking sound and starts to "skip". If this happens repeatedly, the connection may loosen, ruining the seal and the copper gasket.

10. Everyone will be different, but when the bolts have a significant amount of torque on them and are evenly torqued, you are done. By eye, this looks like a "metal touching metal" connection between the two flanges. If there is a gap between the flanges, continue tightening (evenly).

2.1.5 O-Ring placement

The O-Ring option is used for times when no high temperatures are expected; the o-ring is rated for less than 200°C. It is much more convenient to use the o-ring as it can be used about 50 times and does not require a lot of bolt tightening, whereas a copper gasket has one use (up to three for large flange), costs upward of $60, and requires heavy intense torques on all bolts.

The Viton o-ring becomes circular right outside (almost balancing on) the knife edge of the 16.5" flange. This makes it difficult to lift and place a heavy CF blank on top of it, perfectly centered, without shifting the o-ring. The ring needs to be a uniform circular shape at the time of vacuum, otherwise it may get sucked into the chamber and not hold a seal.

1. Wipe the length of the o-ring down with alcohol

2. Place the o-ring evenly on the flange knife edge

3. Ready the mating CF flange, hoisting it onto the crane hooks as evenly as possible, with the bottom face parallel to the ground. Sometimes, it is not perfectly even. Be aware of this when lowering onto the o-ring.

4. Slowly lower until the flange is directly above the o-ring but not touching. At this point, look all the way around to make sure the o-ring and flange are evenly aligned. Also, try to turn the flange such that the bolt holes are perfectly aligned. This cannot be done once the flange is on top of the o-ring.

5. Lower the CF slowly onto the o-ring, not completely, but now touching.

6. Do one more look-around, this time focusing on bolt hole alignment.

7. Lower completely on, completing the process. Remove crane straps.

For the o-ring, further practice can improve these steps. Place a bolt every three holes and tighten in no particular pattern until metal touches metal (much easier and quicker than copper gasket).

2.1.6 Vacuum pump settings and procedure

If you have not used the Pfieffer HiCube before, *please read all of the manuals associated with the DCU unit, MVP015 diaphragm pump, TC100, HiPace 80 turbo-molecular pump, and the HiCube 80 Eco main manual.* These manuals are short and provide a necessary understanding of the usage of the pump station. `http://en.wikipedia.org/wiki/RTFM`

Here are a few noteworthy points about setup before operation:

- The turbopump is a delicate and expensive pumping apparatus. The pump side flange should almost never be exposed openly to air or dirt. Try to keep covered or sealed off at all times other than transferring to different ports.

- You must turn a small dial on the backing pump, setting the input voltage to either "115V" or "230V" depending on your operation environment.

This particular pumping station is very reliable and user safe. Some may say that it is the "McDonald's of pumping stations" and thus is expected to be fool proof (user proof). There are, however, a few factory settings that should be changed before operating.

- **Manual Operation:** The factory settings are such that the turbopump turns on after 8 minutes of pumping from the backing pump. You can disable this if you would rather operate the turbopump manually by accessing parameter 023 (see 1). About 5 mbar is a reasonable backing pressure for effective use of the turbopump.

- **Default Operation:** The pump comes out with factory settings that allow for simple "on/off" button operation. The program will start the turbopump immediately, but it will not reach full speed due to the high backing pressure. Eventually, when the vacuum becomes low enough, the turbopump will have an effect. But until then, it acts like a fan. Most turbopumps become damaged when operated at high backing pressures, but again... user proof

See the table below for factory settings and parameters that are noteworthy, and should be set before initial operation.

#	Display	Description	Factory setting	Should be set
023	MotorPump	Turns the turbopump on and off	ON	OFF
027	Gas Mode	0=heavy inert gases (Ar) 1=other gases	0	0
326	TmpElec	Electronics temperature °C	–	–
330	TmpPmpBot	Pump temperature $\circ$C	–	–
340	Pressure	Reads pressure from connected gauge	–	–
398	ActualSpd	Reads actual runtime RPMs of the turbopump	–	–
700	RUTimeSVal	Time after turning on for activation of turbopump	8min	$\tilde{1}$5min
794	ParamSet	Allows you to change parameter values	1	1

Table 1: Noteworthy parameters on the HiPace control box. For operating the turbopump, changing parameter 023 will be a manual on/off switch.

A full list of parameters and descriptions (as well as dangers and cautions of operation) can be found in the manuals.

For pumping...

1. Make sure all connections are vacuum sealed
2. Make sure turbopump venting screw is fully tightened
3. Double-check that the roughing pump voltage input switch is at the correct position
4. Double-check all necessary parameters
5. Monitor pressure (340) and press the rightmost circular button with the 'power' icon, turning the roughing pump on
6. Check the max RPMs for the turbopump (397) and make sure it is at nominal speed. Also double check that the actual RPMs (398) are ramping up

7. Monitor 340 until desired pressure is reached

For venting...

1. Turn off the turbopump and monitor the actual rotation counts of the turbo at parameter **398** until it drops to 0.
2. Turn off the roughing pump with the DCU on/off button and wait at least 10 seconds
3. Turn off the pumping station with the large green switch
4. Open the turbopump manual vent screw (large black screw in the side) about one turn to vent and wait until hissing stops (may be quite a few minutes)
5. Re-tighten the screw, you have vented

Other venting procedures are built into the station and described in the manuals, but require separate accessories.

2.2 Margherita Assembly

Here we discuss the actual assembly procedure for Margherita. This section will undoubtedly change over time. Please edit in the future. At the end of the section, we list the steps explicitly in terms of the section and chapter names of this manual, as it is not practical to describe each step in detail in chronological order.

2.2.1 Port Layout and Design

Margherita lends herself to many configurations. Therefore, the configuration stated here can be changed and reformed based on the needs of the setup.

On Margherita, there are five 2.75" CF ports, as well as one $4\frac{5}{8}$" port (see 3). This allows for the (necessary) use of electrical feedthroughs, thermocouple feedthroughs, pumping station attachment, gas inlet connections, tile outlet connections and pumps, and more.

Notes about each port:

- **A::Main Chamber:** This is a 16.5" CF flange main chamber. For explicit dimensions see Appendix A.
- **B::Turbopump:** The turbopump (along with the attached diaphragm pump and pumping station) supplies vacuum pumping for both the Margherita main chamber and the small tube tile chamber. Valves are used to control direction of the pumping. At all times, the tile pressure must be lower than the main chamber pressure. *Be sure to allow for proper ventilation of all parts in the pumping station.* Monitor temperatures with parameters 326, 330, 342, and 346. Refer to section 2.1.6 for instructions on how to operate the pumping station.
- **C::Pressure Gauge:** The pressure gauge can be plugged directly into the Pfieffer HiCube box or used with the PiDAQ system (section 2.2.4 for instructions).

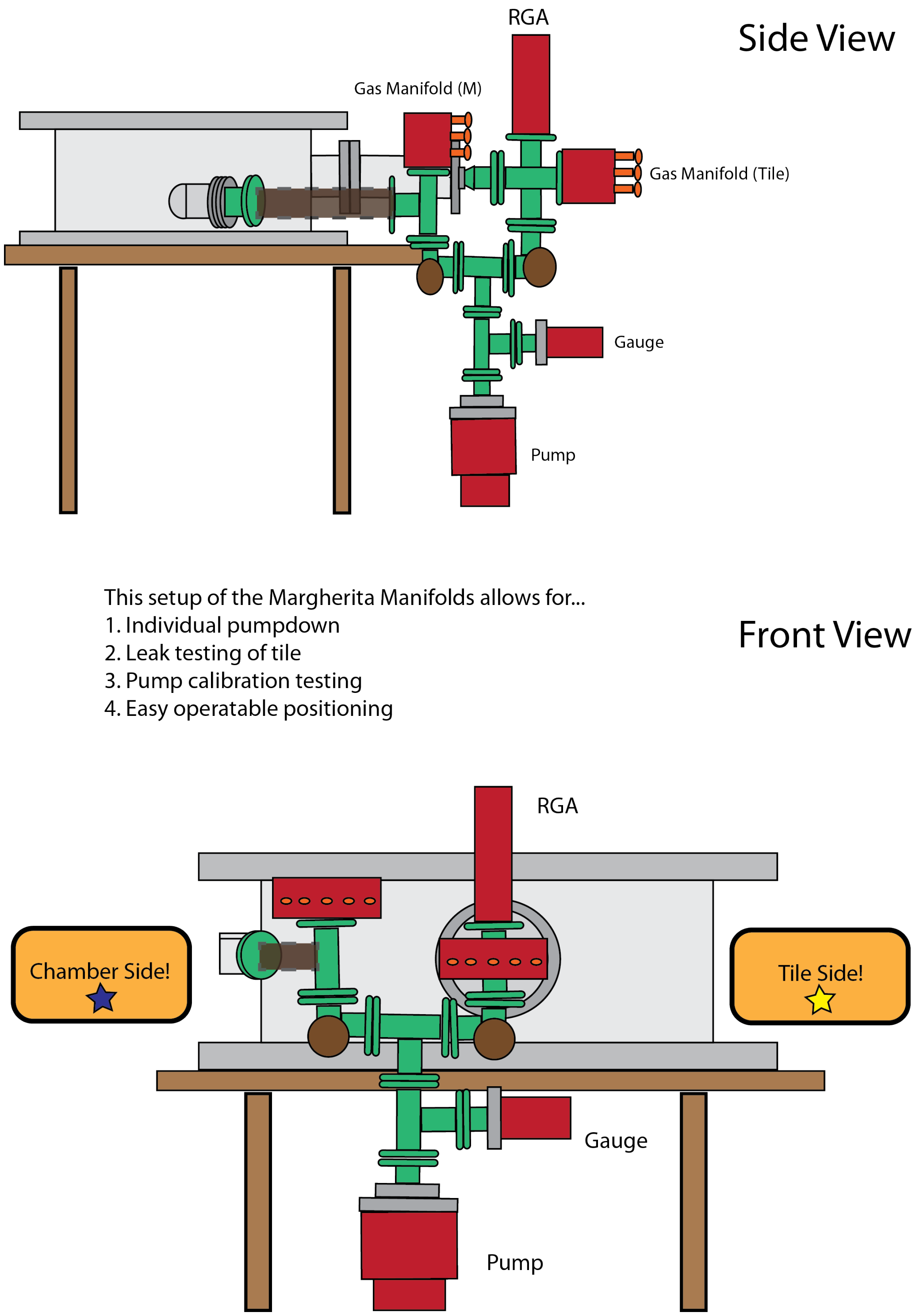


Figure 2: This design maximizes the operational ease of the setup. In figure 3, the components and valves are incredibly spread out and hard to manage. This makes things easy for one operator to know what is going on and not forget to turn valves, while still maintaining each feature needed for tile fabrication. At some point, one may want to put the setup in a rack for easy moving on wheels!

- **D::Alkali Gas Input:** This can be implemented as a gas manifold, standard item with many tubes and small valves, pictorially represented in figure 2
- **E::Leak Gas Inlet:** For leak testing a tile, we also need a gas inlet for the main chamber. The leak

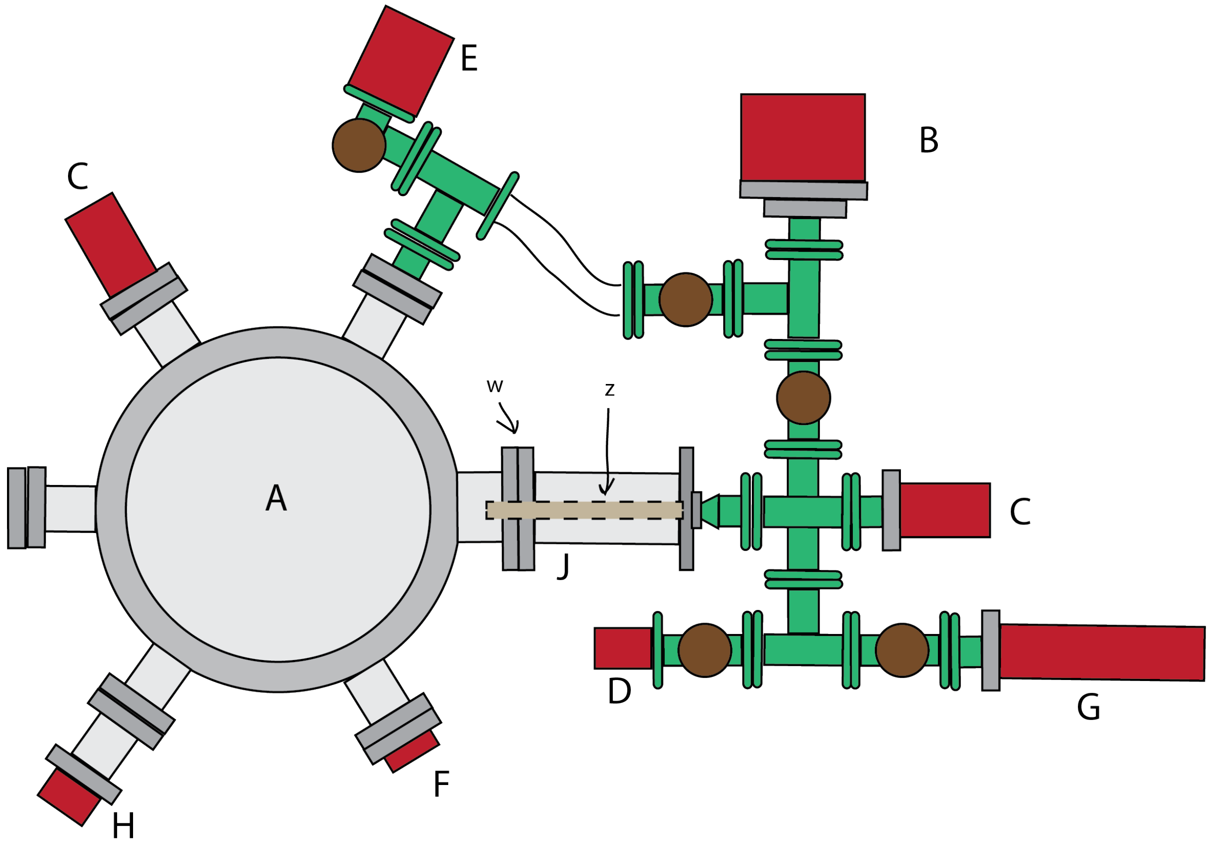


Figure 3: Green means KF, gray means CF. **A**: Main Chamber, **B**: Turbopump, **C**: Pressure gauge, **D**:Alkali Gas Input, **E**: Leak gas inlet, **F**: Electrical FT, **G**: RGA, **H**: Thermocouple FT, **J**: Tile pump extension outer tube, **w**: Pump extension flange, **z**: Tile pump extension inner tube

would then be indicated by a readout from the RGA (::G)

- **F::Electrical Feedthrough:** This allows us to feed current to the heating elements inside of the main chamber. Inside the chamber are uninsulated copper wires which are connected to the electrical feedthrough. ****Caution:* The air-side leads of this part are extremely delicate. Bend a few times and they break off in a way that is irreparable. See section 2.2.2 for more information.

- **G::Residual Gas Analyzer (RGA):** This will be used to measure the fractions of gases coming from the inner tile. It is tantamount to our understanding of the outgasing properties of the tile components, as well as the photo cathode procedure. It will also indicate a leak in the tile seal. The uses are endless, very good tool.

- **H::Thermocouple Feedthrough:** The Lesker thermocouple feedthrough will stick into a full nipple extension 2.75" CF, thus allowing it to properly fit into the main chamber without bumping into the tile fixture. The thermocouple hot junctions stick into the tile fixture via two drilled holes and a bottom-center clamp. *Caution:* Stainless Steel is conductive. Thus, any touching of the thermocouple leads to the side walls will result in an inaccurate reading.

- **J::Tile pump extension, outer tube:** This piece is refered to a few times in the fabrication procedure (chapter 3) and thus is labeled "J". This houses a complex system of tubes and small flanges, allowing for pumpdown of the tile.

- **w::Pump extension flange:** This item is labeled purely for reference in chapter 3.

- **z::Tile pump extension, inner tube:** This is the complex system of small parts that allow for pumpdown of the tile. It is designed with bellows and glass to metal fittings such that the dual chamber fabrication system can be realized. The order of assembly and connections to this piece is important for proper fabrication of a tile.

The descriptions of these items apply to all setups. There have been a few manifold setups in design — one highly suggested "final" manifold design is suggested in figure 2.

2.2.2 Electrical Setup

One of the main components of the fabrication process is internal baking. To do this we use special heating elements that will ideally bring the tile fixture to a uniform temperature of $400°C$ max. The current setup is with a set of three high vacuum quartz lamp infrared heaters, originally designed for substrate heating in substrate evaporation chambers. One can find various calibration data on these heating elements in Appendix B (B.1).

- **Note:** We currently have another option for the heating element that has yet to be bought and tested. It is a heating coil made by *Nexthermal* that can be embedded into the tile fixture, or a plate in which the tile fixture sits. This will require a similar electrical setup. The main contact for this item is Ray Jeske (`r.jeske@nexthermal.com`), with another scientific contact being Mearl Noviskey (`m.noviskey@nexthermal.com`)

An electrical setup is needed for any heating element used (see figure 4). Because the chamber is in vacuum, we use 16AWG bare copper wire to complete the circuit. The lamps are rated to have a max current of 5A (**power rating of the lamps are 500W at 120VAC**). Choose a wiring configuration with this in mind (either series or parallel).

In either configuration, a the electrical feedthrough is a delicate item. One should make a spot welded connection between the vacuum side of the feedthrough to a copper wire. This wire can then wrap around one of the Macor standoffs, providing a stable point where the wires and feedthrough do not need to be touched. From there, one can alligator clip or use crimp connectors to connect the circuit to the feedthrough.

Order of electrical assembly:

1. Attach all quartz filaments to the lamp holders. Make sure that the pin leads go directly in the center of the filament terminals, they are known to jostle and become misaligned. Tighten the inner nuts to the point where the filament is stable and will not shift.

2. Configure the wires of the parallel circuit while still outside of Margherita

3. Attach the electrical feedthough so that an anchor is made between the inner leads and a Macor leg for easy connecting and disconnecting of the lamp circuit

4. Screw in the three lamps to the base of Margherita

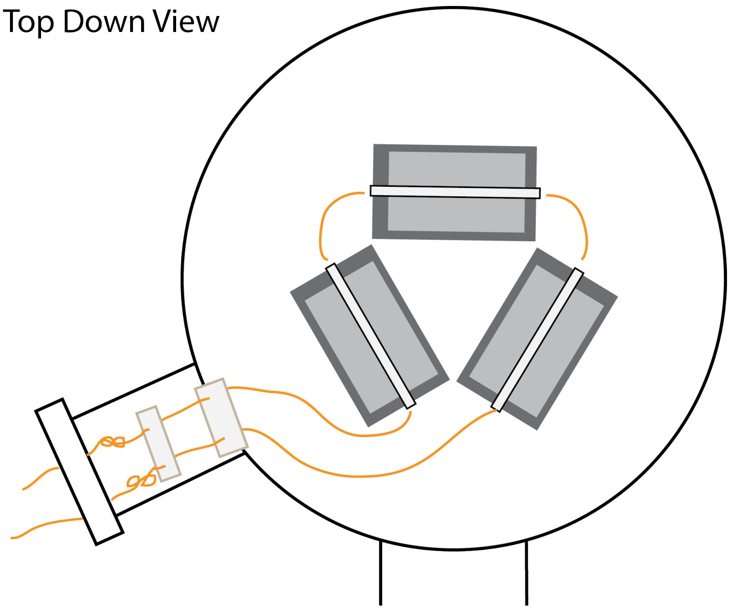


Figure 4: An example of an electrical setup used early on. This has proven to be not the best setup, we are currently trying a parallel circuit setup with Macor legs as structural points for the wires.

5. Attach the lamp circuit to the anchor wires

Test this circuit before any further assembly. It is common for there to be a small short. Refer to electrical data gathered on the lamps to make sure that the current, power, and resistances match up.

On the air-side of the electrical FT, the leads are very delicate. If any pulling occurs or bending to a right angle with respect to the flange face, they are likely to break in such a way that renders them irreparable by soldering techniques. For this reason, when attaching wires for 120VAC input, use zip ties to clamp the wires in a strain relieving position.

2.2.3 Total Assembly Order

1. **Attach bottom** 16.5" **CF (see section 2.1.4)**

   a For both of the large flanges, there are special bolts made short, as they ran into the tile pump port side walls. These special bolts are labeled with either a red mark or a blue mark. The red marked bolts should also have a shaved off nut with them. These two bolts should be used on the top flange for Margherita and not the bottom flange (on one side, the bolts and nuts will absolutely not fit, on the other they will). There are extra short bolts that can be placed anywhere around the flange.

2. **Bathe the partially assembled Margherita chamber in a large tub of cleaning solution**

   a Possible available solutions are Micro90, Alcanox, and Barkeeper's Friend. All work, we should test and find a consistent solvent. Alcanox is especially good for pieces with glass.

   b Place other stainless steel parts into the bath as well. This saves time cleaning all pieces individually with rags.

c *Before connecting each vacuum piece to Margherita, make sure to follow appropriate cleaning procedures (see section 2.1.2)*

d Rinse with water (deionized if possible) and dry with clean sterile towels, using alcohol wipes intermittently as an evaporative solvent

3. **Connect all auxiliary ports and accessories**

a Firstly, follow the electrical assembly outlined in section 2.2.2, placing lamps and wiring correctly to ensure uniform heating and preventing any chance of electrical shorting

b Attach thermocouple feedthroughs, gas manifold fittings, and gauges.

c Thermocouples should be placed such that the leads do not touch the walls of the chamber. Use Kapton tape if necessary.

d *Thoroughly test the polarity and high temperature characteristics of the thermocouples before tightening the flange. Use a heat shrink gun if needed*

e Connect the bellows staged tile port extension **z** to the inside of the outer tile port CF flange. Keep the outer tube **J** extension unattached to Margherita. This is bolted in after attaching the inner tube extension to the pre-flame sealed glass to metal CF flange. (see section 3.2)

f Attach the port extension **z** to the outer tube **J** extension, still unattached to Margherita.

g Carefully and cleanly attach the RGA tube.

h Lastly, attach the pumping station. This is tricky and delicate, be sure to treat the turbopump carefully. When attached, immediately wall off any inlet into the main face of the turbopump with aluminum foil. Make sure that the tube on the HiCube is not kinked and that the electrical input to the turbopump is not strained.

4. **Begin tile fabrication procedure detailed in chapter 3**

2.2.4 Raspberry PiDAQ

Margherita should be able to fabricate tiles with ease, whether operated at University of Chicago or at some company over seas. Any sophisticated system needs to be able to tabulate, record, and monitor various parameters that may or may not be changing often. For this, we designed a data acquisition system centered around a small microelectronic computer called the “Raspberry Pi”.

The Raspberry Pi, R-Pi for short, is lightweight, small, but has enough processor capability to run a few python programs and take data from direct analog or digital inputs. As of when this revision of the manual was released, the R-Pi system is still heavily under development. We have made a few successful systems for measuring temperature from multiple thermocouples, cameras, and pressure gauges, but have yet to implement RGA interfacing and ambient sound monitoring.

This section should be revised when more progress has been made. What follows is meant for documenting work already made so that no progress is lost.

Git Code Repository: `https://github.com/PionDegenerate/MargheritaCode`

In the repository above, you will find various scratch code workings for allowing the R-Pi to interface with the outside world. These should eventually become developed enough to be put into one single continuously running program on one R-Pi that talks to a circuit with all of the digital to analog connections. Unfortunately, we do not have a circuit schematic for that mapping at this time.

Another goal of the R-Pi system was to have an easy display of the data. A web server has been developed, currently hosted on **hostname:** 'Dirac' that is lightweight and updates real-time data pulled from a MySQL database (also located on 'Dirac'). This means that all data processed by the master R-Pi should be sent to the database at a fixed time interval, which is then easily read onto the web-server. For implementing the data sending functions into the PiDAQ system, see the file **datasend.py**. To view the webpage, open up a browser on the R-Pi named 'Dirac' and type the url *localhost*.

Path	Description
dirac:/var/www	Apache server home directory
MargheritaCode/src	Finished source files

Table 2: Please add more directories as they become relevant

Noteworthy Commands:

```
###mysql server
mysql -u root -p
  >pass: lappd

###git repository
git pull
git add
git commit -m `` message''
git push origin master
```

3

Fabrication Procedure

We now plan to outline the fabrication procedure for an LAPPD tile. This chapter assumes that you have followed the instructions in the previous chapter for assembly, including cleaning, electrical setup, and attaching of all ports and vacuum flanges (keeping the top open).

3.1 Insertion

The fabrication story starts with one philosophy we hold here at University of Chicago called the *NSA*, or *Never See Air*. The tile should never see air during the entire fabrication process, from receiving a micro-channel plate to removing the tile from the vacuum chamber.

By the time the tile has reached the Margherita fabrication station, it has been through most of its assembly. This includes packing together of inside materials (plates, spacers, *getter*) and sealing off the top with a liquid indium seal. Ideally, the tile will come straight out of a nitrogen environment glove box and go right into the Margherita chamber. This means that at this stage of the fabrication, the tile has been inserted into the aluminum tile fixture and is being pressed by eight spring clamps. In addition, a flame seal has been made to the glass to metal CF flange, which is blanked off so that no air can enter the tile.

In the following steps, because Margherita is open and you are inserting parts, wear a mask and follow the guidelines outlined in section 2.1.2 on cleanliness.

1. Take the four macor standoff legs and place them in the four grooves in the base of Margherita.

2. Bringing the tile fixture closer, connect the center, corner, and edge thermocouples

   a The side and corner thermocouples should be inserted into the holes drilled into the fixture.

   b Firmly screw tighten the center fixture washer to hold the center thermocouple in place. The tip of the thermocouple should be underneath the small rectangular aluminum plate so that radiation does not directly hit the thermocouple hot junction.

3. Carefully bring the tile fixture close, angling into Margherita for a smooth landing onto the macor legs

   a This is the key movement. It is quite tricky. Use an angled "plane landing" motion with others around to guide the fixture slide for alignment with the tile pump port extension

4. With the tile fixture inserted, the slide should stick out the open $4\frac{5}{8}$" flange. Now, connect the glass to metal adapter to the tile pump port extension **z** (see figure 5).

5. Make a final check for stability of the lamps, electrical wiring, thermocouple wiring, etc.

Tile pump port assembly procedure:

1. Stretch bellows while the extension is inside the tube

2. Connect the z junction

3. Bolt the "w" flange

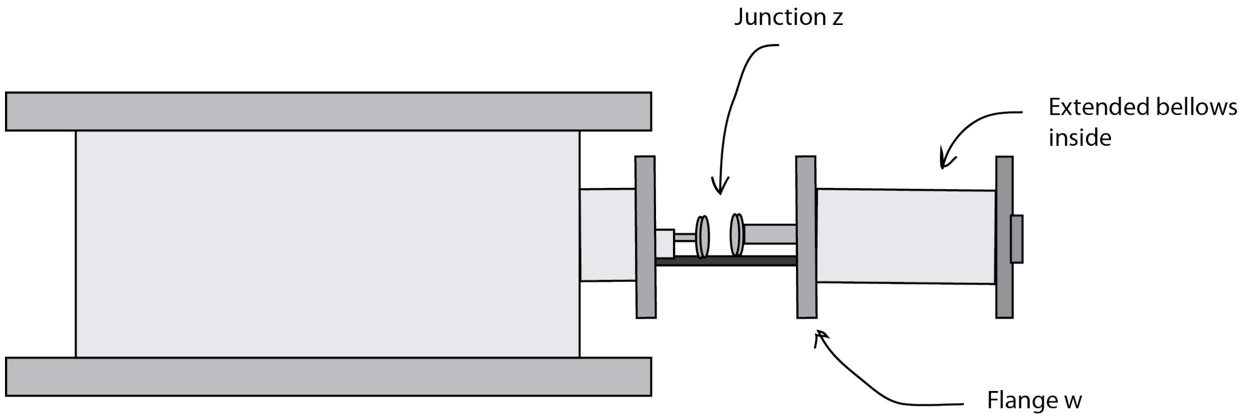


Figure 5: This is a tricky bolting procedure. With the tile fixture inserted and the slide stage extruding from Margherita, make sure that the glass to metal adapter is firmly held by the clamp. Hold the pump port extension tube closely and stretch the internal bellows to give room for bolting. Connect the glass to metal adapter flange to the extension. Finally, close up Margherita, bolting on the outer tube.

3.2 Flame Seal and Closing

This section will hopefully describe a lesson from Joe Gregor on performing the tricky *flame seal of the glass trident*. Joe will take a small and powerful flame torch and point it directly at the interface between the glass to metal CF adapter and the tile glass trident outlet. The effect of this is to bond together the trident with the glass to metal CF flange, allowing us to attach an extension for tile pumpdown.

The flame sealing procedure is now planned to occur even before a top seal is made in the glove box. This allows the inside of the tile to never see air through the opening of the glass tube. The only time in which this rule will potentially be violated is when attaching the glass to metal CF flange to the tile to pump extension. This should be done as quickly and cleanly as possible. (see figure 5)

After everything is connected, close Margherita up with the top 16.5" flange either with the O-ring procedure (section 2.1.5) or a copper gasket.

3.3 Tile Pumpdown

At this point everything should be attached and ready for sealing. Adjust the operation valves to set for tile pump control. Follow the instructions in section 2.1.6 and pump down the tile.

3.4 Leak Check

Leak check the tile using a gas manifold connected to the main Margherita chamber. Introduce small amounts of helium into the main chamber (now at atmospheric pressure). On the RGA, monitor the gases present. If a leak has occurred in the Indium seal, then helium will saturate on the readout.

In the case that there is a leak, the tile is to be removed and scrapped. Helium on its own will damage the internal components of a tile, and a faulty indium seal is irreparable and not acceptable.

3.5 Margherita Pumpdown

With the tile under high vacuum (C.1), change the operation valves to control main chamber pumpdown. Bring the main chamber down in pressure while carefully monitoring the tile pressure.

Keep the main chamber pressure well above the internal tile pressure at all times. The tile seal will pop off and all precious internal components will be garbage.

3.6 Photo cathode chemistry

This is the point in the fabrication where the magic happens. We will begin to use the tile side gas manifold to introduce various alkali metal mixtures to fabricate a high quantum efficiency photo cathode. Currently the procedure is quite uncertain and should be documented in detail at a later point.

For now, we will assume that a few alkali gases such as Cs and K are introduced via the tile gas manifold in specific proportions. When the chemical reaction process of the antimony layer is completed, try to evacuate all residual gases from the tile and manifold tubing using the pump. This can be monitored via the RGA, however, one may want to check if certain concentrations of alkali gases can destroy the RGA.

The chemistry and research on this procedure is currently being done mostly by people at Cornell. They have a highly sophisticated setup with good equipment.

3.7 Getter Activation

In many ways, the getter activation step was the main motivation for creating a dual chamber vacuum system. In photo tube production, the getter is essential. It acts as the final kick, pumping a volume down a few decades lower in pressure than one would think to be possible. For us, the getter will be the long term cleaner of the tile internals, holding a vacuum for years with the ability to be reactivated.

A detailed report of the getter characteristics has been written within the group and a few details are mentioned here. For a few of the plots describing the getter characteristics at different activation times, see section B.2 or visit `http://psec.uchicago.edu/library/evapmath.php`.

We use the SAES St707 non-evaporable getter material, which absorbs any molecules that strike its surface. This means that any unknown nasty outgassing materials inside the tile will be pumped on internally, even after making a flame seal. In fact, after pumping the tile down with the Pfieffer box, the final step to achieving reasonable photo tube vacuum is to activate the getter.

To activate the getter, we need to bake it. The brochure [5] advises that for best results, activation should be at 450 °C for 10 minutes, or 400 °C for 30 minutes. Further studies and modeling tells us that there is no need for us to reach these temperatures. In fact, we can tune the time of the getter activation and temperature of activation based on experimental results. Many sources quote close to full getter activation at temperatures of 300 °C or even 250 °C for longer periods of time. See section B.2 for a set of curves representing pumping speeds at different activation times and temperatures.

1. Turn on the quartz lamps via the control box or other power supply
2. Bake for a predetermined activation time and temperature (for example, 300 °C for 3 hours)
3. Turn off the quartz lamps and gauge the tile pressure to confirm proper getter activation

3.8 Main chamber vent

At this time, we want to continue pumping on the tile while venting the main chamber. Control the valves to ensure no venting of the tile. Follow the venting procedure outlined in section 2.1.6. Once the chamber is at atmosphere, remove all bolts from the top CF flange and crane it off, exposing the inner Margherita chamber.

3.9 Final flame seal

This section will eventually describe a second lesson from Joe, which is to perform the flame sealing procedure that closes off the tile. This procedure may very well be the trickiest part of the entire experiment. From what we have seen, the process is like such:

1. Valve off the tile pump port extension
2. Unbolt the pump port outer wall CF flange **w** and hold carefully, making sure not to break the glass to metal junction
3. Hold the tile fixture slider in one hand while holding a small flame torch in the other. Point the flame torch at the glass to metal junction, ***evenly*** heating the tube all the way around with a rapid rotational movement.
4. As the glass begins to soften, slowly pull the tile fixture slide out, stretching the glass down to a fiber-optic width, finally flaming off the connection and separating the pieces.
5. A small hole still exists in the tile glass trident. Use the other end of the melted glass to lightly mush a piece of glass on the hole of the trident, sealing it off.

3.10 Removal of the tile

At this point the tile should be completely disconnected from any vacuum hardware. Use the same "airplane" like motion to remove the tile base from Margherita. Vent the tile port end and clean up. Send the tile over to the photo cathode testing station for confirmation of a successful tile fabrication.

3.11 Celebrate: you made a tile!

At this point you should celebrate. Congratulations, a tile has been successfully made. Make sure to have multiple frozen Margherita style pizzas ready for the oven; common manufacturers are Digiorno, Palermo's, California Pizza Kitchen, etc.

Margarita proportions:

Ingredient	Amount
Ice	determine based on taste
Tequila (%100 agave)	1.5 fl oz
Triple sec or Cointeau	1.5 fl oz
Lime juice	1 fl oz

Table 3: Proportions are for one drink. Multiply by n for n tile fabricators. Alternative recipes can replace both triple sec and lime juice with a pre-made margarita mix (Jose Cuervo)

4 Things to do

This chapter is a reference for figuring out what to do next. It should list all the action items needed for Margherita before fabricating a tile can be possible. I also include edits to sections in this manual, such that information is well documented as it comes along.

4.1 Action items

1. Finalize an electrical configuration that is both reliable, safe, and consistent
2. Experiment with the transient properties of the baking procedure. We need to understand how uniform the temperature is across the tile fixture, as well as how long it takes for equilibration, and the maximum achievable temperature. Add all information to both the appendix and sections involving the quartz lamps (B.1, 2.2.2)
3. Perform a full test with a mock (or real) tile. The purpose for this test will be to straighten out the procedure with Joe Gregor, making the flame seal, and then checking that the conductance on the tile is pumpable.
   - A second step to this is to look at the outgassing of all real internal tile components. On the RGA.
   - Get a lower limit on the vacuum of a tile before baking or getter activation
4. Test the getter material pumping speed at various activation times and temperatures
   - One way to do this is to use the unfinished getter testing apparatus called the “Personal Pizza”. The issue with the personal pizza is that it uses conductance heating, there are no internal lamps. However, the chamber is small and the getter will be completely surrounded by stainless steel. Thus, baking in an oven may be enough to activate the getter. Either way, the personal pizza may need modifications before any real experiment can be done.
   - The other way to do it is to use a mock tile with the getter material inside, complete with glass bead housings etc. This method may be preferred and less complicated.
5. Determine the procedure for the photo cathode production. This will involve partial pressures of various alkali metals to introduce into the tile, time for reaction, heat for reaction, and any other of numerous problems that could arise. Test this procedure using the Margherita setup and the small tile port tube conductance. Use the photo cathode testing station to test the quantum efficiency.

6. Do tests with both a getter and photo cathode production procedure in place. Make sure that the getter material does not inhibit the photo cathode fabrication. Ensure that the getter is still active and not "saturated" after photo cathode fabrication.

7. Try making a tile with a clean and thorough, independent "start from 0" procedure

4.2 Looming items

- Finalize the raspberry pi data acquisition system. Create a single circuit to house all connections within a small area
- Finish creating a clean room lab.

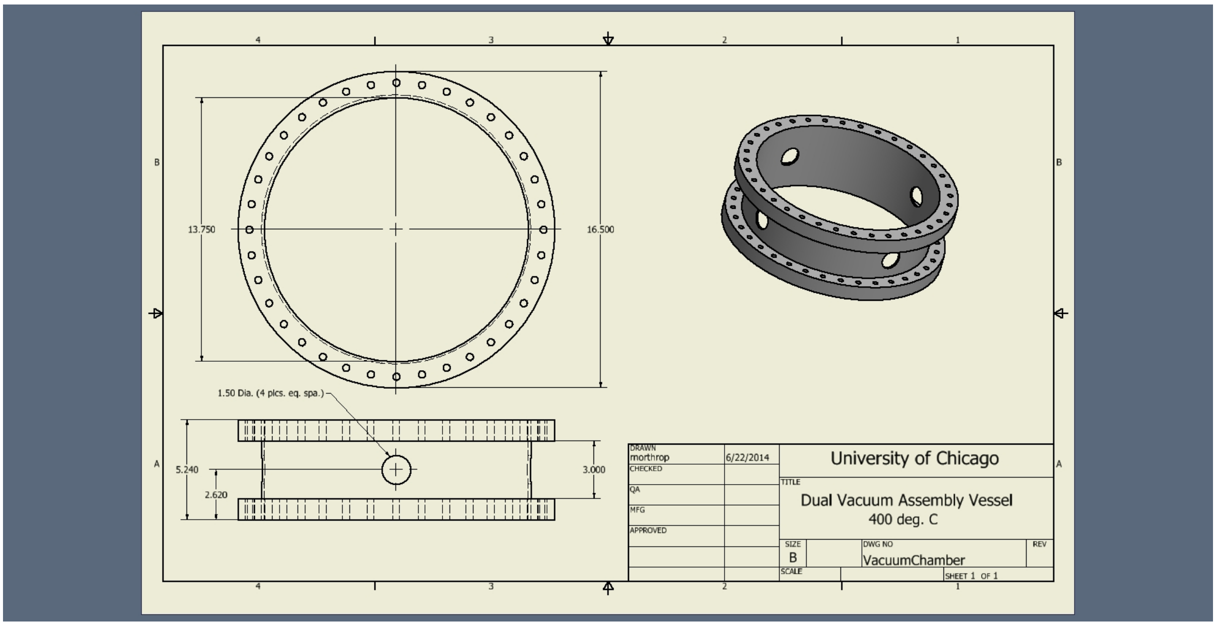
4.3 Manual Edits

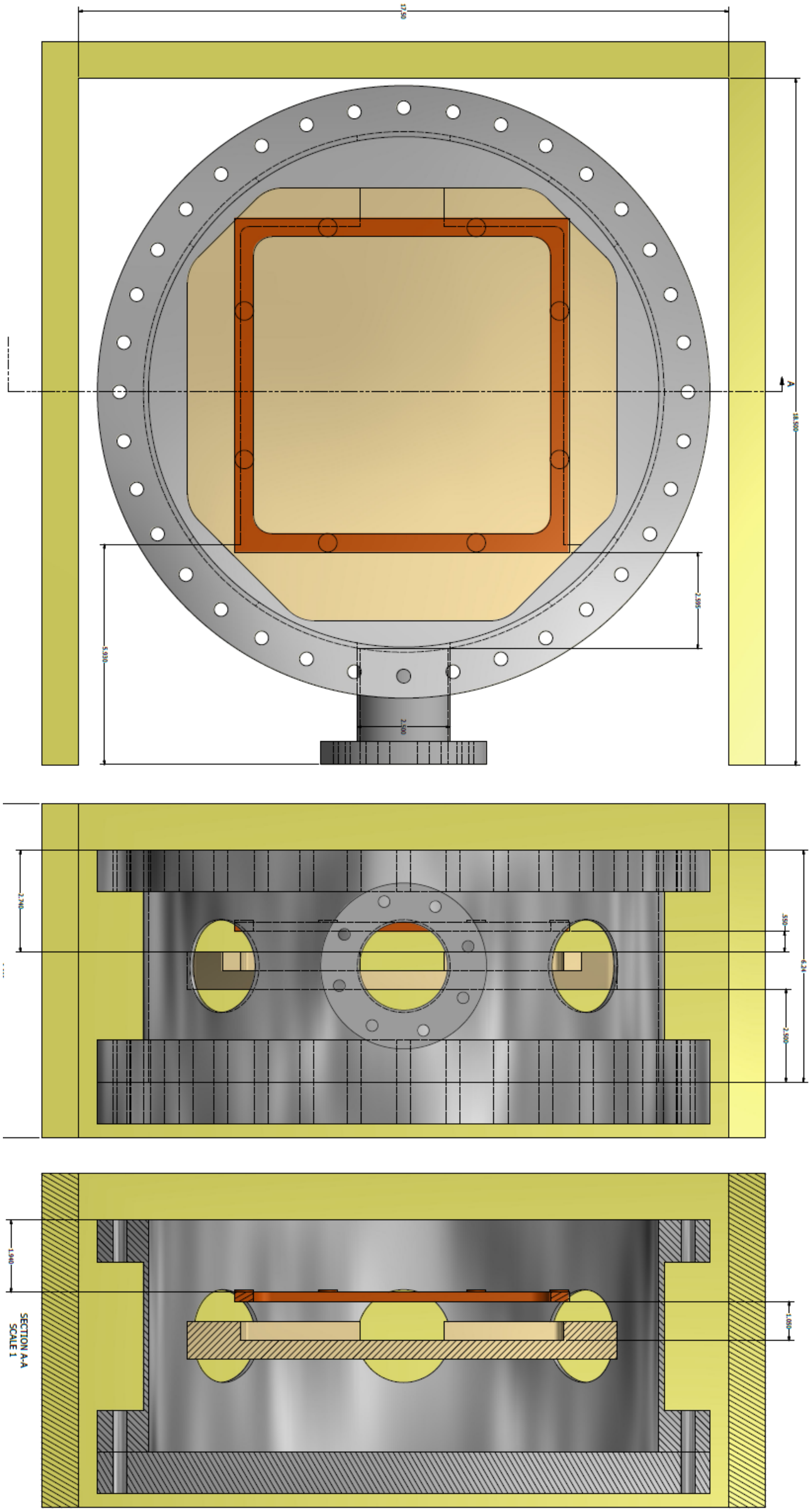
These edits in no way exclude other sections from being updated. For example, the R-Pi DAQ section will have continuous development throughout the lifetime of Margherita, but is not explicitly mentioned here.

- Edit the section 3.2, adding in a description of Joe Gregor's flame sealing techniques.
- Edit section B.2 with a detailed procedure of baking (add parameters)
- Reform section 2.2.2 with a finalized electrical setup
- Replace plots in appendix B.1 with more accurately calibrated temperature data
- Insert further information on finalized programs and circuit configuration in section 2.2.4
- Add all procedures and details about chemistry to section 3.6

A

Appendix A: Design Schematics




SECTION A-A
SCALE 1

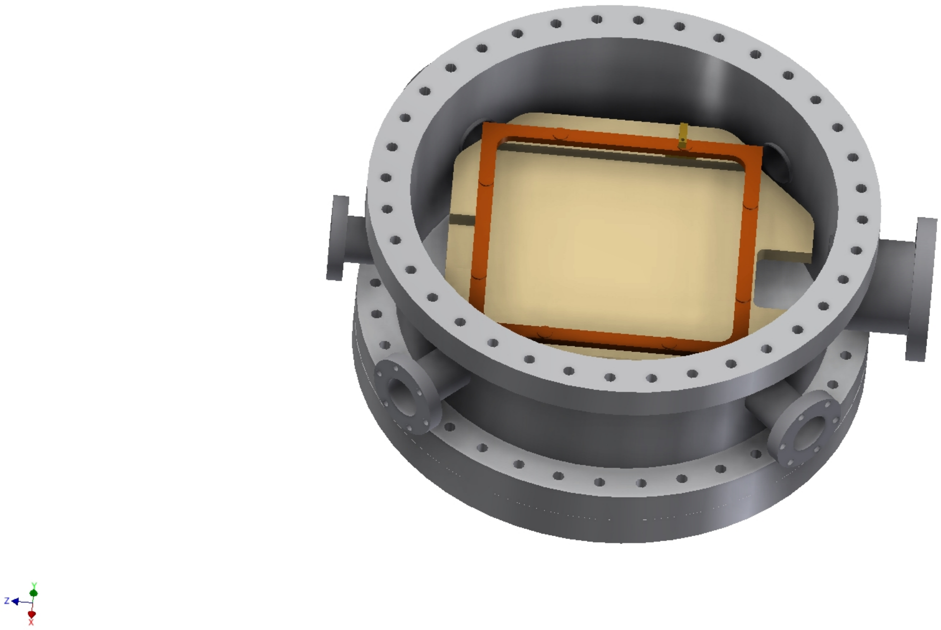


Figure 6: Margherita with a tile fixture

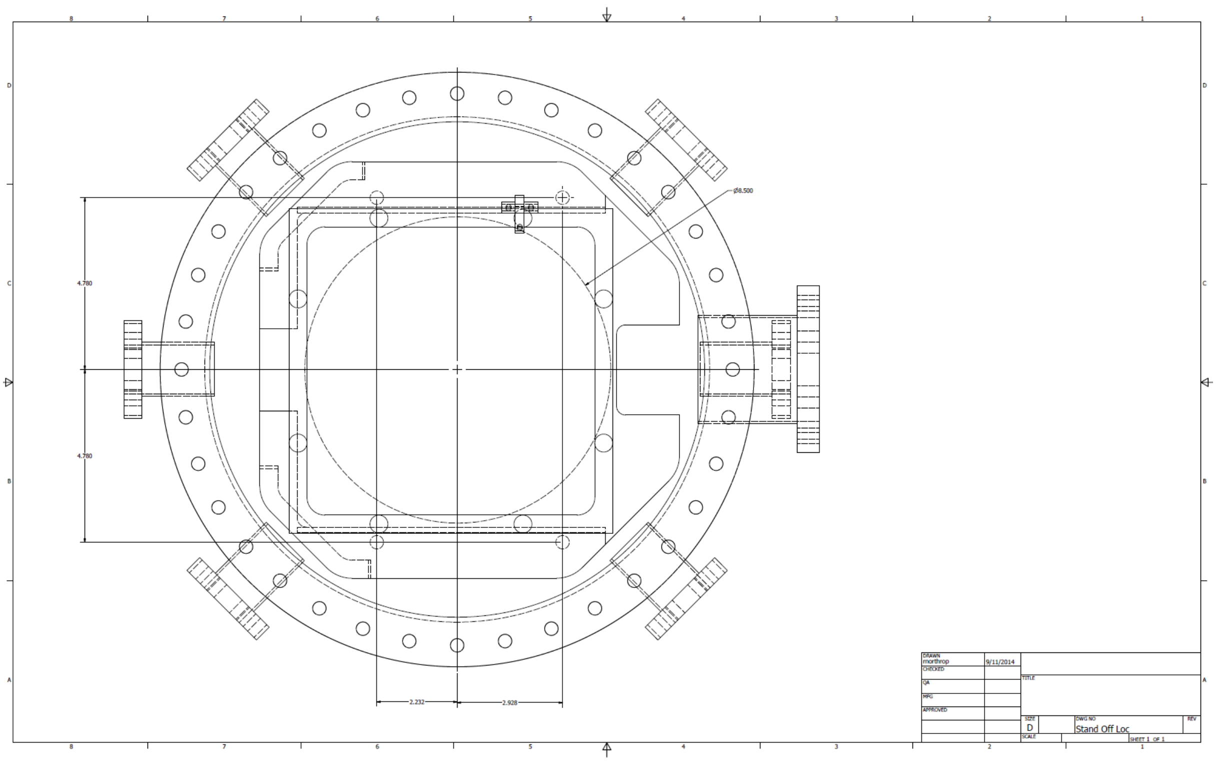


Figure 7: Fixture and standoffs locations

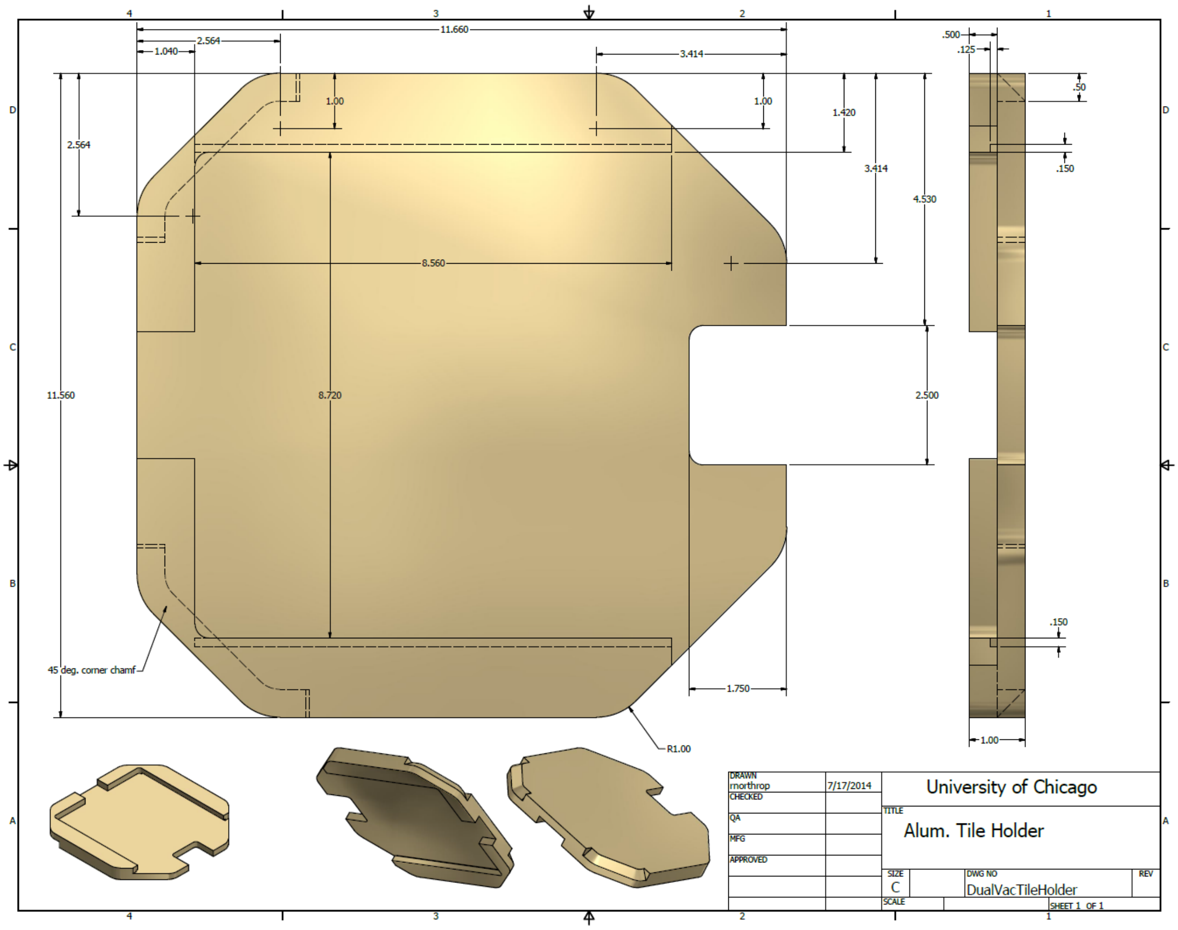


Figure 8: Detail of the tile fixture

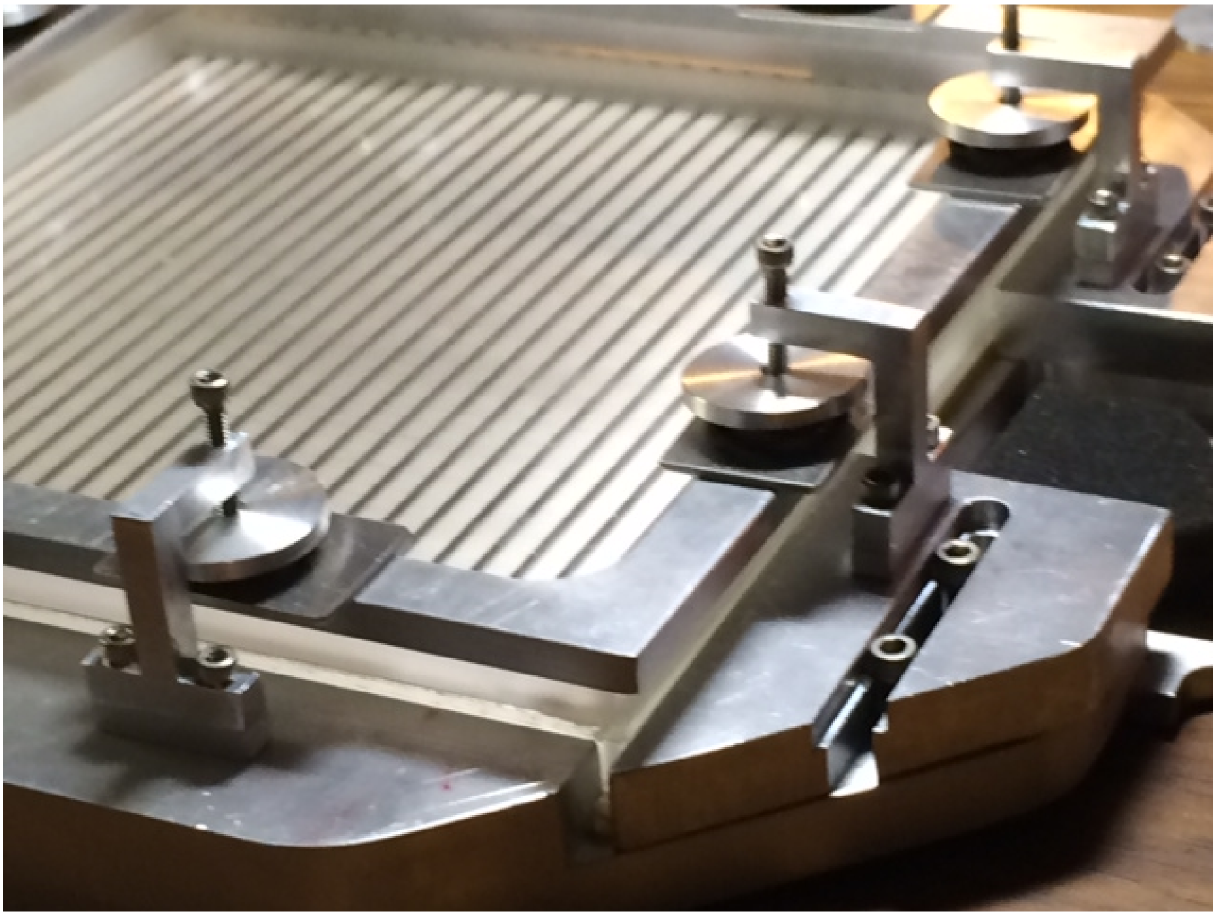


Figure 9: Displaying the special spring clamps for holding down the indium seal

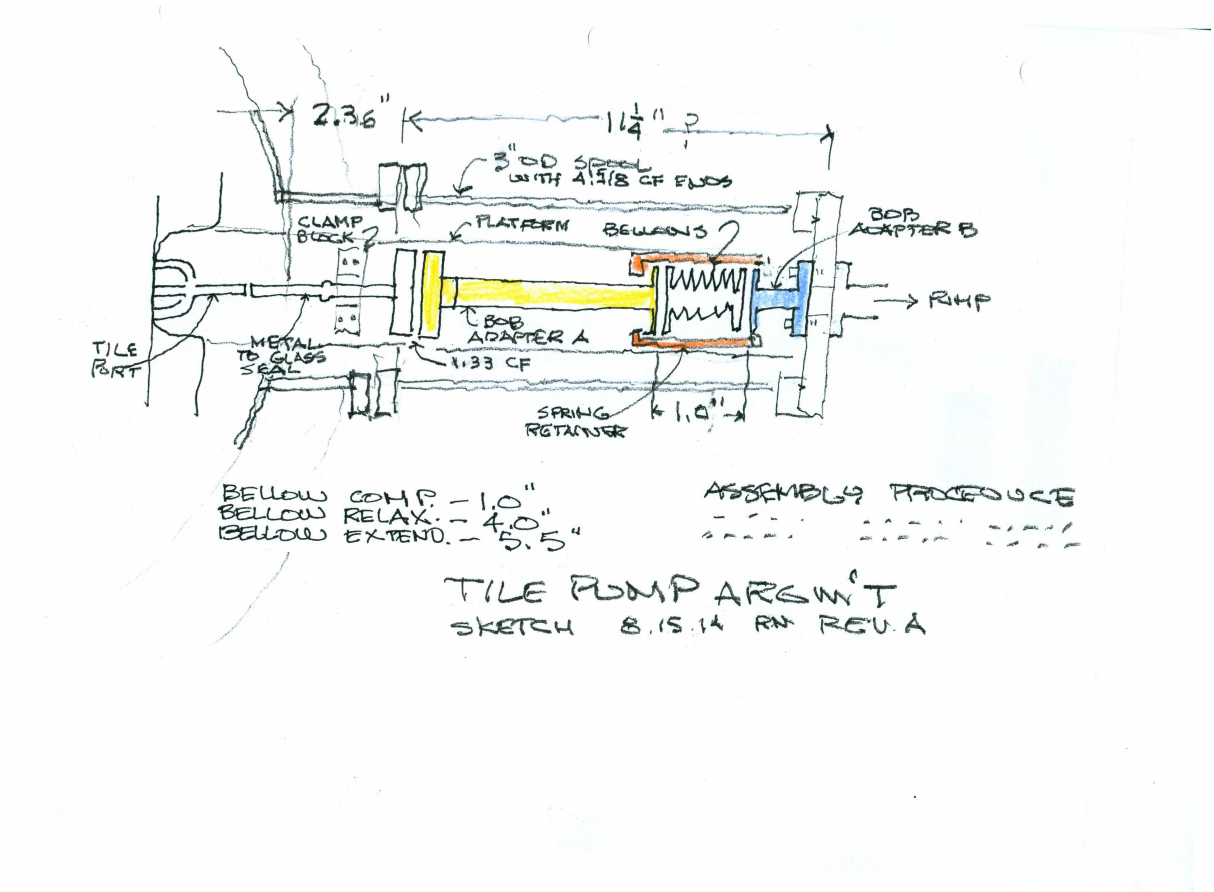


Figure 10: Sketch of the tile pump port extension. Some measurements have been modified

B

Appendix B: Plots and Calibrations

B.1 Quartz Lamps

The quartz lamps went under a small bit of calibration and characterization. Please delete these data plots with the next run, replacing them with higher resolution and more accurate data.

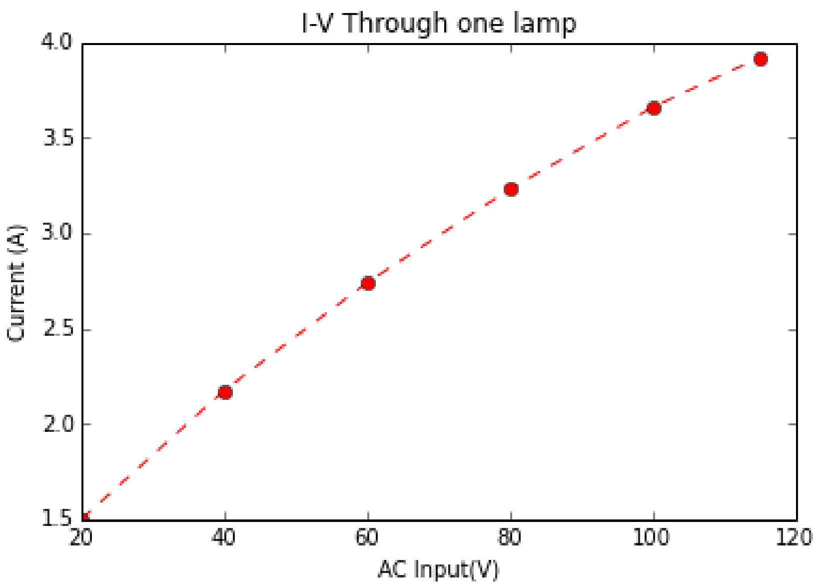


Figure 11: Current vs AC Voltage curve for the one lamp. Curvature indicates that the resistance changes through the power spectrum

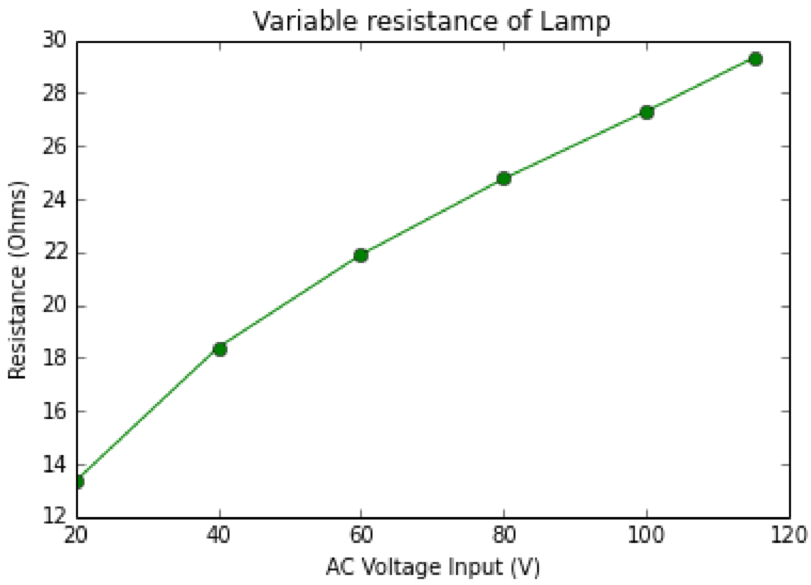


Figure 12: Shows the ballpark resistance of a quartz lamp

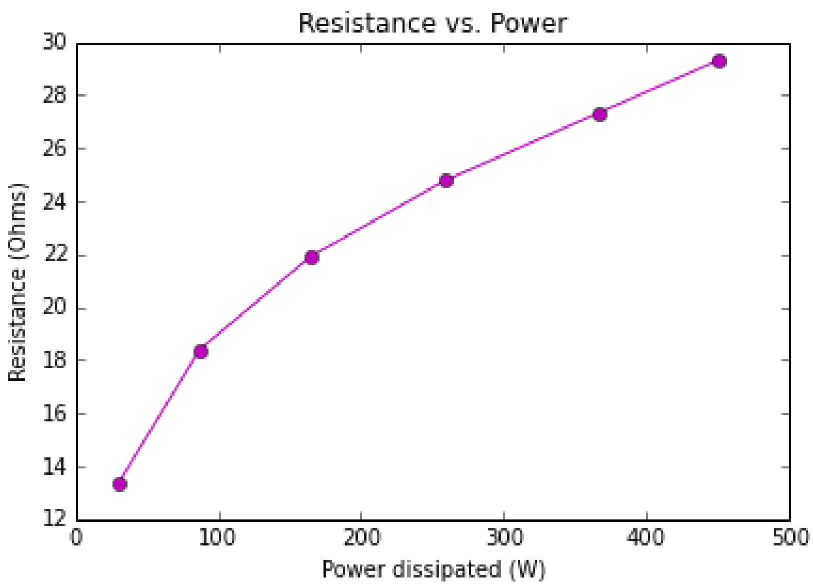


Figure 13: Shows the change in resistance with increased power. Power is nearly directly proportional to temperature as would be expected. Lamps are rated for 120V, 500W

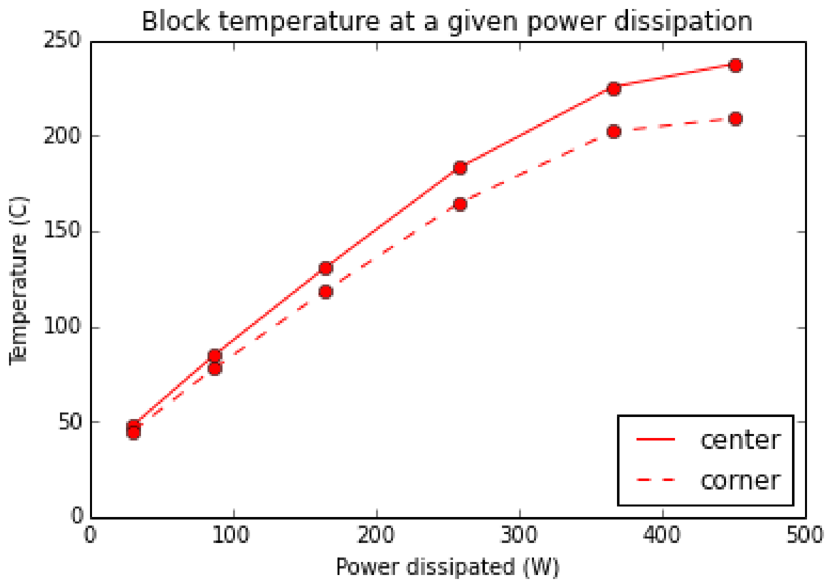


Figure 14: Temperature distribution of the thin aluminum plate as a function of power dissipated in one lamp. This data averages both the 15 minute eq. time and the 45 minute eq. time procedures for the single lamp setup. Center and corner thermocouples are separated by about 4 inches

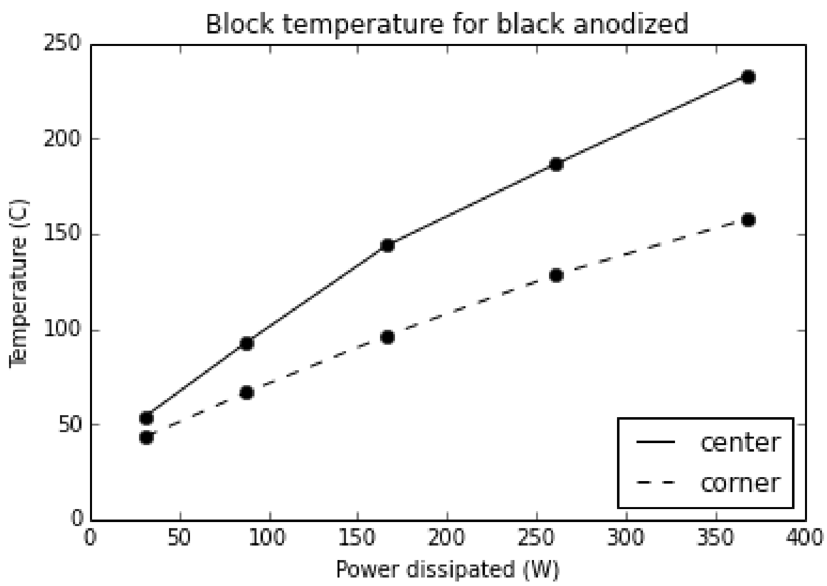


Figure 15: Temperature distribution of the black anodized plate experiment. As is mentioned in the one lamp section, these values are so similar to the regular aluminum plate due to the difference in emissivity and surface area. The spacing between the corner and center thermocouples was also greater by about a factor of 1.5

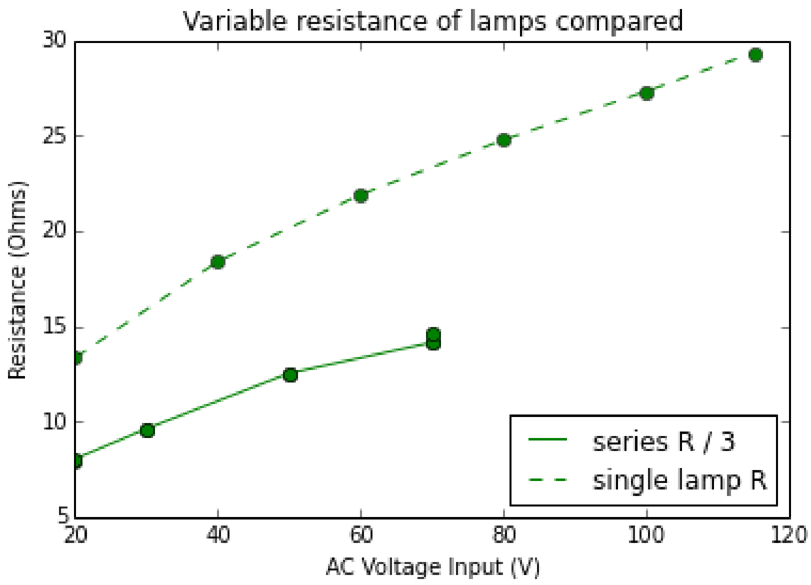


Figure 16: Ohms law dictates that for three identical resistors in series, the resistance of one resistor (lamp) will be $V/3I$. This compares the resistance of one lamp in each configuration. The disagreement indicates that something electrically is different (possible short) with the series configuration, but not enough to worry about it.

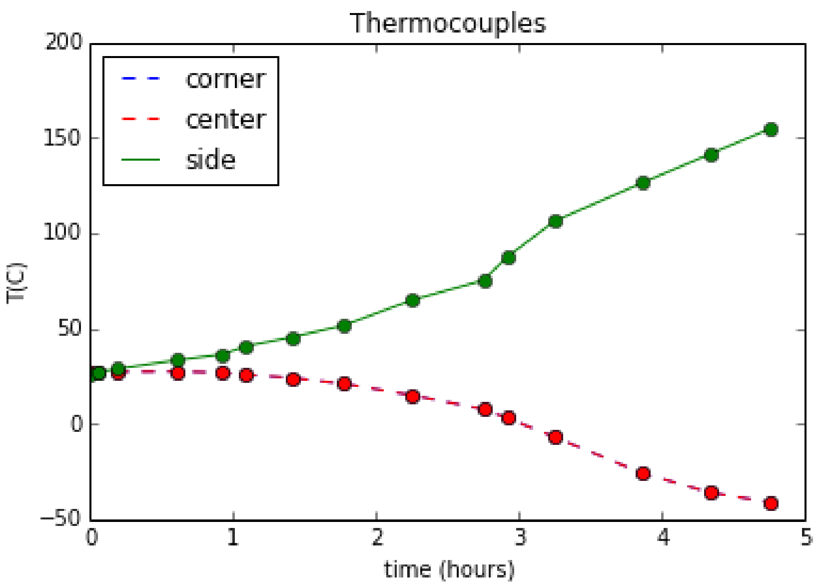


Figure 17: Temperature from three thermocouples on the real tile fixture plate while under vacuum. Kinks in the curve represent a change in input voltage (0-1h: 45W, 1-1.75h: 84W, 2.25-2.75h: 136W, 3-5h: 300W. Two of the three thermocouples (believed to be the corner and side area) had a malfunction. Because the lines lie directly on top of each other, we assume that they shorted and thus don't represent good data.

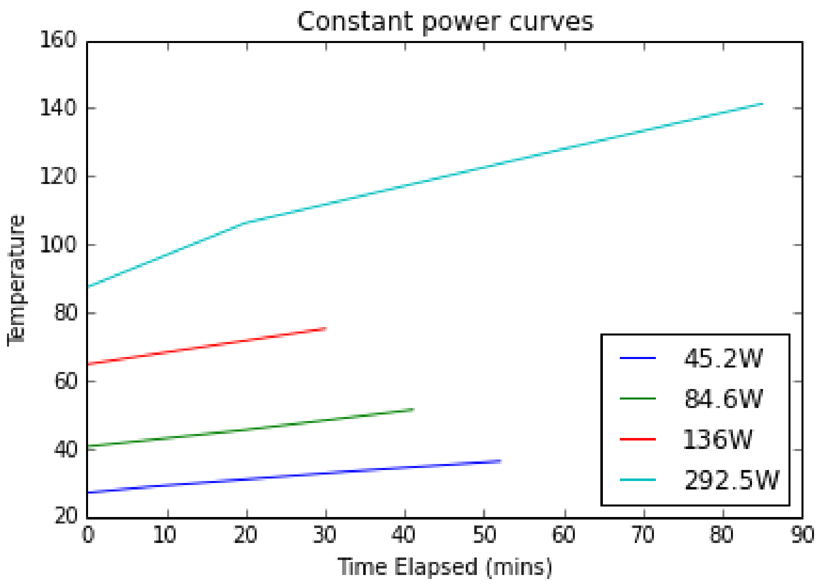


Figure 18: Using only the well defined temperature data, these are the constant power temperature curves with respect to the amount of time elapsed after a voltage change. The slope of these curves then indicates something about how fast it takes for the aluminum plate to equilibrate.

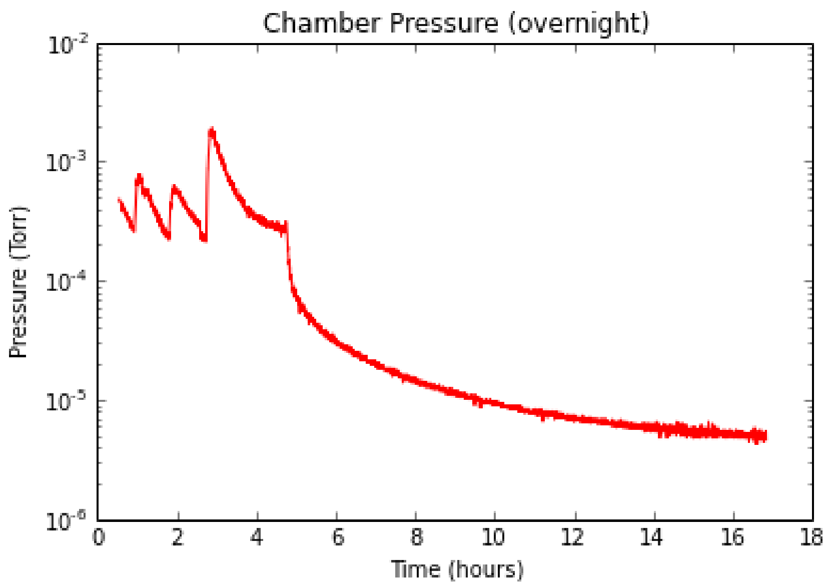


Figure 19: Chamber pressure as a function of time. After an overnight pumpdown, the maximum achieved pressure was 6.6×10^{-6} mbar.

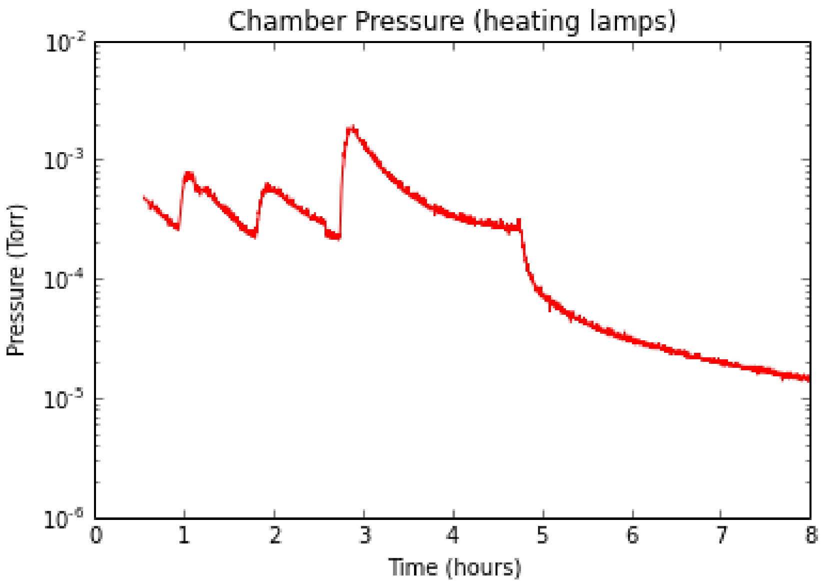


Figure 20: Chamber pressure zoomed in. Discrete jumps in pressure indicate an increase in temperature (power dissipation) of the quartz lamps. This induces outgassing of the internal materials, thus increasing the pressure of the chamber until those gases are fully pumped away.

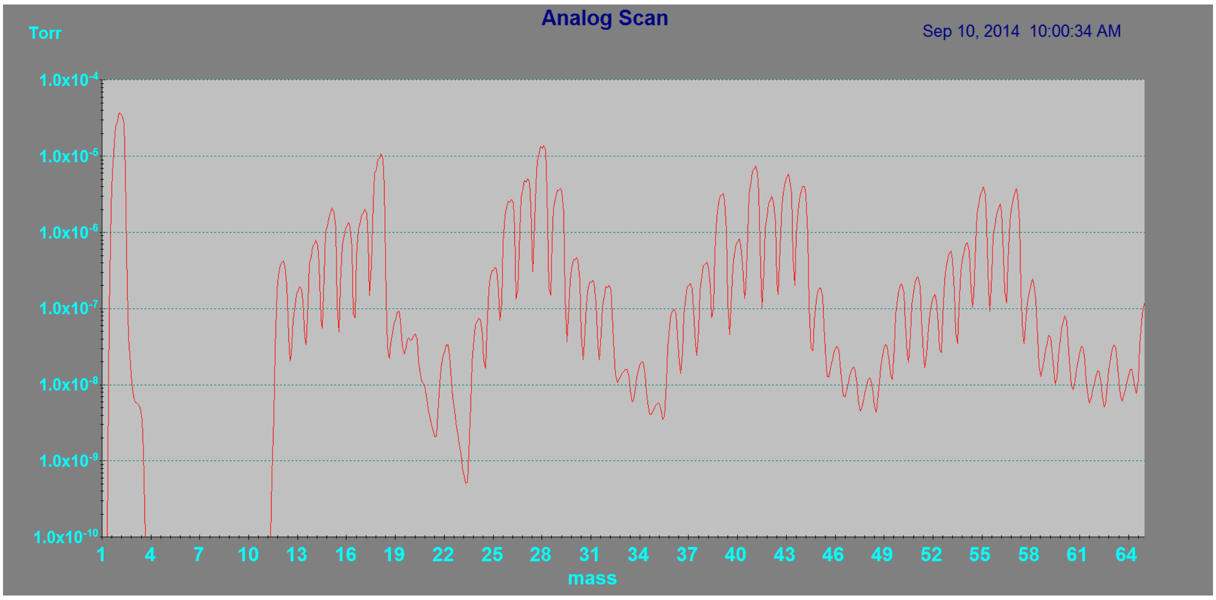


Figure 21: Final RGA reading taken after a day of pumping. Peaks on 1-4amu indicate hydrogen outgassing from the stainless steel chamber. Other peaks indicate water as well as oily residue, probably from machined parts

B.2 Getter and Antimony

This section shows plots taken from the theoretical study of the getter characteristics, as well as how they effect the evaporation and recombination of Antimony. A full note was produced and can be found through

Henry or Evan Angelico. For interactive plots, see `http://psec.uchicago.edu/library/evapmath.php`

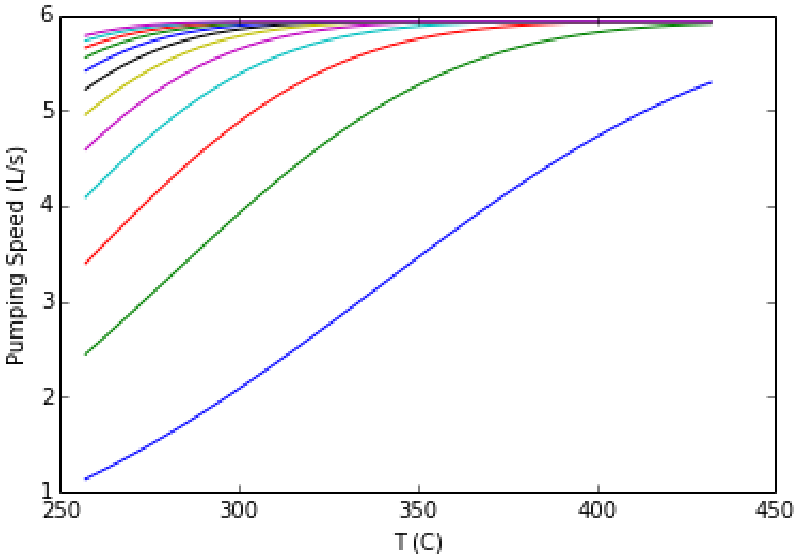


Figure 22: Pumping speed of the getter as a function of activation temperature. Colors blue up to violet represent different activation times from 10 minutes (blue) to 3 hours (violet) in increments of 15 minutes. See *http://psec.uchicago.edu/library/evapmath.php* for an interactive plot.

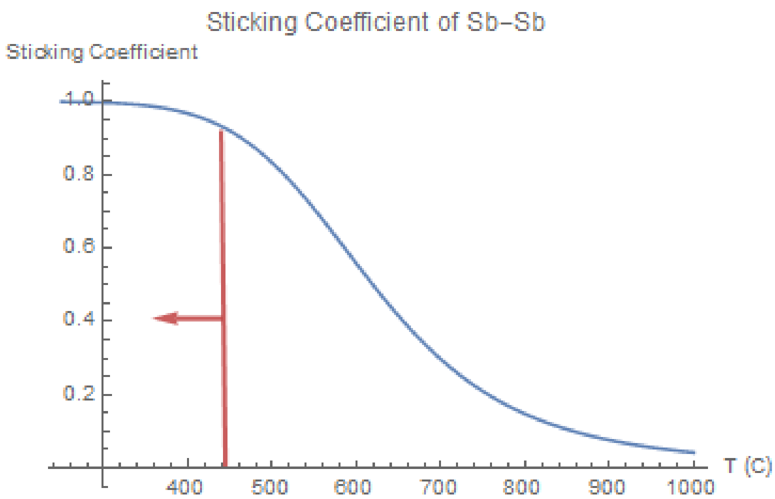


Figure 23: Sticking coefficient of Sb to Sb as formulated by Bennett [4]. The red vertical bar indicates our temperature range of interest

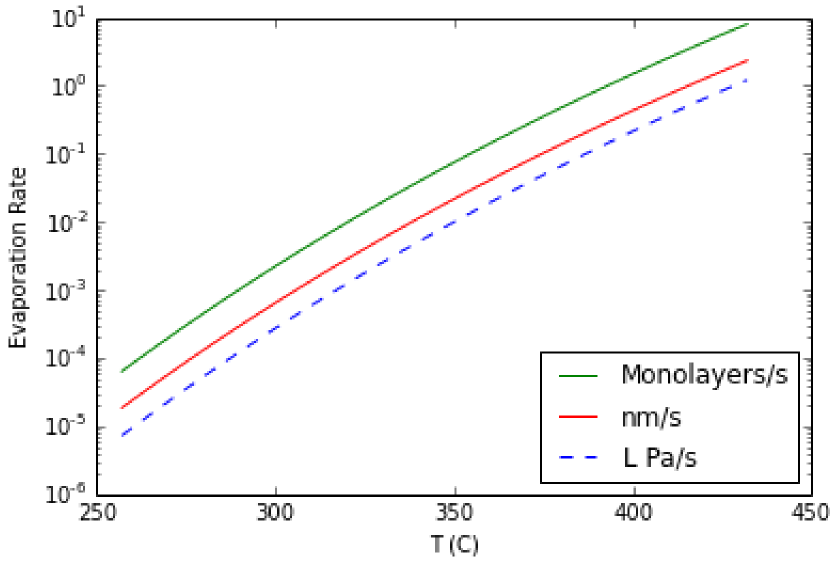


Figure 24: Evaporation rate, or $P\dot{V}$, for Antimony as a function of temperature (blue). The green and red curves represent Monolayers/s and nm/s rates respectively for an 8×8 inch film.

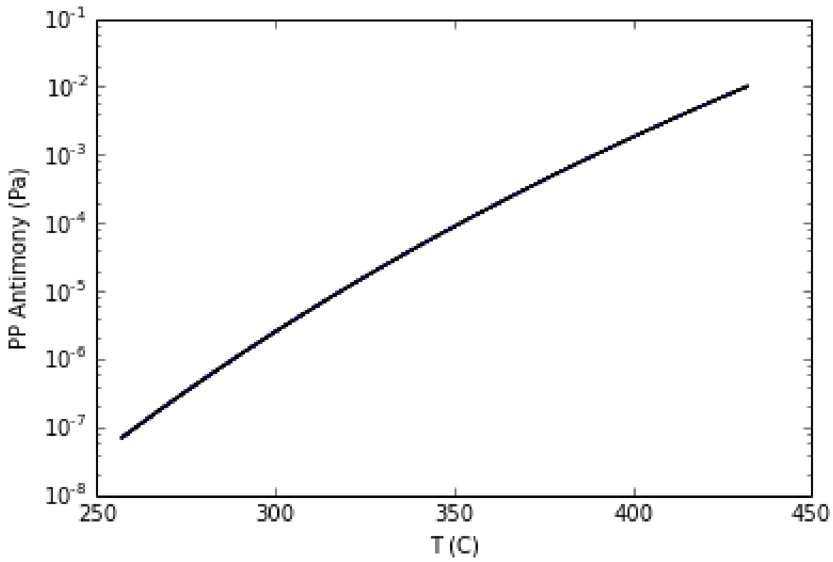


Figure 25: The partial pressure of Antimony in the tile as a function of temperature. The single line distribution shows that the getter material contributes a negligible amount of pumping speed to the system. The recombination of the Antimony atoms to the film dominates the partial pressure.

C

Appendix C: Outgassing and Vacuum Standards

C.1 Vacuum Levels

Quoted from Wikipedia http://en.wikipedia.org/wiki/Vacuum

Vacuum Quality	Torr	Pa
Atmospheric Pressure	760	1.013×10^{5}
Low vacuum	760 to 25	1×10^{5} to 3×10^{3}
Medium vacuum	25 to 1×10^{-3}	3×10^{3} to 1×10^{-1}
High vacuum	1×10^{-3} to 1×10^{-9}	1×10^{-1} to 1×10^{-7}
Ultra high vacuum	1×10^{-9} to 1×10^{-12}	1×10^{-7} to 1×10^{-10}

C.2 Materials

This information is almost directly copied from http://en.wikipedia.org/wiki/Materials_for_use_in_vacuum. The page does not specify levels of vacuum for materials but sometimes implies that "materials to be avoided" can sometimes be used in medium to high vacuum applications.

Use ctrl+F for quick lookup.

C.2.1 Avoid

- **Cadmium**, often present in the form of cadmium plating, or in some soldering and brazing alloys
- **Zinc**, problematic for high vacuum and higher temperatures, present in some construction alloys, e.g. brass and some brazing alloys. Tends to poison hot cathodes and form conductive deposits on surfaces.
- **Magnesium**
- **PVC**, usually in the form of wire insulation (source of virtual leaks too)
- **Paints**, absolutely not
- **Lead** and **Antimony**, used in some soft solders and outgassing at higher temperatures
- **Plastics**, namely many plastic tapes (beware especially of the adhesives). Fiberglass composites, e.g. Micarta (G-10) and G-30, should be avoided. Even kapton and teflon are sometimes advised against.

- **Flux and lubricants**, from soldering and brazing and machining. Thorough cleaning of the parts is important. Getting the outgassable residues from tight crevices can be challenging; a good mechanical design that avoids such features can simplify one's life.

C.2.2 Acceptable

Metals

- **Austenitic stainless steels** are the most common choice for high vacuum and ultra-high vacuum systems. Not all alloys are suitable; e.g. the free-machining 303 steel contains sulfur, which tends to outgas. Alloys with good weldability under argon arc welding are usually chosen.
  - 304 stainless steel is a common choice of a stainless steel.
  - 304L stainless steel, a low-carbon variant of 304 steel, is used for ultra-high vacuum systems.
  - 347 stainless steel does not accept high polish.
  - 321 stainless steel is chosen when low magnetic permeability is needed.
- **Mild steel** can be used for moderate vacuums above 10^{-6} torr. Outgassing can be lowered with suitable (e.g. nickel) plating. It has high permeability to hydrogen and tendency to rust. For use it should be thoroughly outgassed in vacuum.
- **Aluminium and aluminium alloys** are another class of frequently used materials. They are well-machinable and have low outgassing, unless the alloys contain higher proportion of zinc. The parts must not be anodized, as the oxide layer traps (and outgases) water vapor. Aluminium and its alloys have low strength at high temperatures, distort when being welded, and the copper-containing ones are poorly weldable. Aluminium wire rings can be used as cheap gaskets in demountable seals. Aluminium has high thermal conductivity, good corrosion resistance, and low solubility of hydrogen. Loss of strength at high temperatures limits its use in bakeable applications, but aluminium is advantageous for large-size systems due to its lower weight and lower cost than stainless steel. Use of aluminium is limited by difficulties in its welding and brazing. It can be used for x-ray windows.
- **Aluminium bronze** is a material looking and machining similar to brass. It is not susceptible to galling, which makes it suitable for sliding fits against stainless steel.
- **Nickel** is widely used in vacuum technology, e.g. as mechanical parts in vacuum tubes. It is relatively low-cost, can be spot welded, can be easily machined, has high melting point and is resistant to many corrosive fluids and atmospheres. Its potential drawback is its ferromagnetism, which restricts applications that would be influenced by magnetic fields.
- **Nickel alloys**, e.g. cupronickel
- **Beryllium** is used primarily for x-ray windows.
- **Oxygen-free copper** is widely used. It is easily machined and has good corrosion resistance. It is unsuitable for bakeable vacuum envelopes due to its tendency to oxidize and create scales. Copper rings are used in demountable seals. Normal copper is unsuitable for high vacuum as it is difficult to outgas completely. Copper is insensitive to hydrogen and impermeable to hydrogen and helium,

has low sensitivity to water vapor, but is attacked by mercury. Its strength falls sharply above 200 °C . Its vapor pressure becomes significant at above 500 °C .

- **Brass** is suitable for some applications. It has good corrosion resistance. Its zinc content may cause problems; zinc outgassing can be reduced by nickel-plating.
- **Indium** wire is used as a gasket in demountable seals.
- **Gold wire** is used as a gasket in demountable seals for ultra-high vacuum.
- **Platinum** is a highly chemically inert material with high cost and low outgassing.
- **Zirconium** is corrosion-resistant. It has low production of secondary electrons, so it is used as a coating of areas where reducing their production is important. It is used for neutron windows. It is costly and scarce, its uses are therefore limited. Zirconium and zirconium hydride are used for gettering.
- **Tungsten** is often used is high temperature applications as well as for filaments in electron/ion optics. It becomes brittle from work hardening when mechanically deformed, or subjected to very high temperatures.
- **Molybdenum** and tantalum are useful for high temperature applications. Titanium and niobium are good materials.
- **Solders** are sometimes unavoidable for soft-soldered joints. Tin-lead solders (Sn50Pb50, Sn60Pb40, Sn63Pb37) can be conditionally used when the apparatus is not to be baked and operating temperatures aren't elevated (lead tends to outgas). A better choice for vacuum systems is the tin-silver eutectic, Sn95Ag5; its melting point of 230 °C allows bakeout up to 200 °C . A similar 95-5 alloy, Sn95Sb5, is unsuitable as antimony has similar vapor pressure as lead. Take care to remove flux residues.
- **Brazing alloys** are used for joining materials by brazing. Care has to be taken while choosing the alloys, as some elements tend to outgas. Cadmium and zinc are the worst common offenders. Silver, a common component of brazing alloys, can be problematic at higher temperatures and lower pressures. A silver-copper eutectic, named e.g. Cusil, is recommended. A superior alternative is a copper-silver-tin alloy called Cusiltin. Copper-silver-phosphorus alloys, e.g. Sil-Fos, are also suitable.

Plastics

- **Some fluoropolymers**, e.g. polyvinylidene fluoride, are suitable for use in vacuum. They have low outgassing and are tolerant to higher temperatures.
- **Polytetrafluoroethylene** is commonly used inside of vacuum systems. It is self-lubricating, a good electrical insulator, tolerant to fairly high temperatures, and has low outgassing. It is not suitable for barrier between vacuum and atmosphere, as it is somewhat permeable for gases. Ceramics is a superior choice, however.

- **Polyethylene** is usable but requires thorough outgassing. Nalgene can be used as a cheaper alternative for Bell jars. Vespel polyimide is very expensive, but machines well, has good electrical insulator properties and is compatible with ultra-high vacuum.
- **PVC**, despite its high outgassing rate, can be used in limited applications for rough vacuum lines.
- **Nylon** is self-lubricating but has high outgassing rate and high affinity to water.
- **Acrylics** have high outgassing rate and high affinity to water.
- **Polycarbonates and polystyrene** are good electrical insulators with moderate outgassing.
- **Kapton** is a type of polymide film, has very low outgassing. Kapton is discouraged if a ceramic alternative can be used.
- **Some elastomers** have sufficient vacuum properties:
- **Nitrile** rubber is used for demountable vacuum seals.
- **Viton** is used for demountable vacuum seals. It is better for lower pressures than nitrile rubber. It is bakeable to 200 °C .

Glasses and ceramics

- **Borosilicate glass** is often used for smaller assemblies and for viewports. It can be machined and joined well. Glasses can be joined with metals.
- **Porcelain and alumina ceramics**, when fully vitrified and therefore non-porous, are excellent insulators usable up to 1500 °C . Some ceramics can be machined. Ceramics can be joined with metals.
- **Macor** is a machinable ceramic that is an excellent alternative to alumina, as the firing process of alumina can change the dimensions and tolerances.

Lubricants

Lubrication of moving parts is a problem for vacuum. Many lubricants have inacceptable outgassing rates, others (e.g. graphite) lose lubricating properties.

- **Vacuum greases** are greases with low outgassing.
- **Krytox** is a fluorether-based vacuum grease, useful from -75 to over 350 °C , not flammable even in liquid oxygen, and highly resistant to ionizing radiation.
- **Polyphenyl** ether greases
- **Torrlube**, a brand encompassing a range of lubricating oils based on perfluoropolyethers.
- **Dry lubricants**, can be incorporated in plastics as fillers, as a component of sintered metals, or deposited on metal, ceramic and plastic surfaces.

- **Molybdenum disulfide** is a dry lubricant usable in vacuum.
- **Tungsten disulfide** is another dry lubricant usable in vacuum. It can be used at higher temperatures than MoS_2. Tungsten disulfide used to be significantly more expensive, but rise of prices of molybdenum disulfide brought them to a comparable range.[4] Usable from -188 to +1316 °C in vacuum, from -273 to +650 °C in normal atmosphere.
- **Hexagonal boron nitride** is a graphite-like dry lubricant used in space vehicles.

Adhesives

Torr-Seal is an epoxy with resin and hardener for use in vacuum environments. It will begin to degrade at high temperatures but otherwise is very stable with very little outgassing. Other vacuum-rated epoxies are also available.

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