Introduction:

The prototype MICE RF module under test in the MTA Hall was assembled in Lab-6 at Fermilab and includes a 4 foot diameter 16.5 inch long copper RF cavity inside a 5 foot diameter 3 foot long stainless steel vacuum vessel [1]. It is also referred to as the MICE Single Cavity Module or Single Cavity Test System. Figure 1a shows the system installed in the MTA experimental hall. The vacuum system configuration is similar to other high-vacuum systems in operation around the lab. One notable exception is a pair of large (42 cm diameter), thin (0.38 mm thick) curved windows [2] made of beryllium mounted on the RF cavity [3], figure 1b, inside the vacuum vessel. The vacuum system schematic is shown in figure 2.

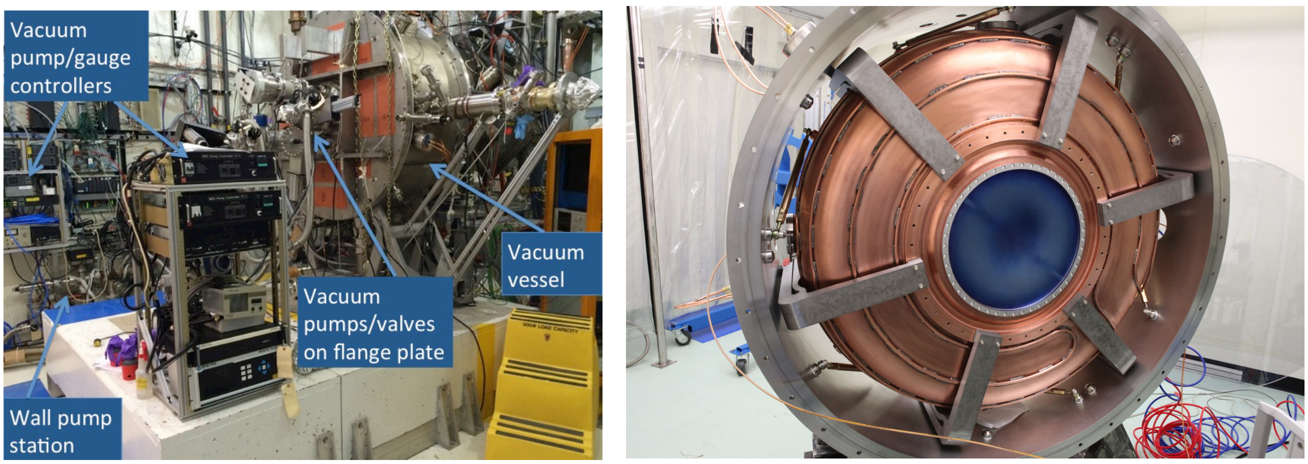


Figure 1. (a) The MICE vessel in the MTA hall. (b) Be window (blue).

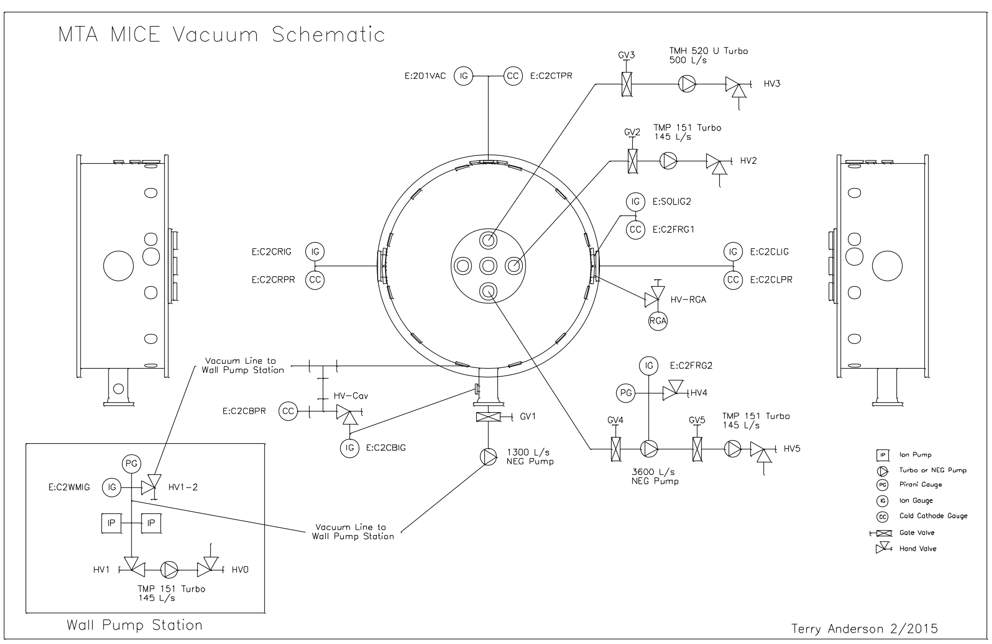


Figure 2. MTA MICE Vacuum Schematic

Vacuum Performance:

During a test pumpdown starting on 1/15/2015 measurements were made to characterize the vacuum system. Figure 4 shows the performance of the system during this pumpdown. The pressure was measured via an ion gauge on the top of the vessel. The gauge is connected to the top of the cavity by 33 centimeters of stainless steel tubing (Figure. 3) with a conductance of 1.6 L/s. The estimated pressure drop along this conductance is $2.0(10)^{-8}$ Torr.

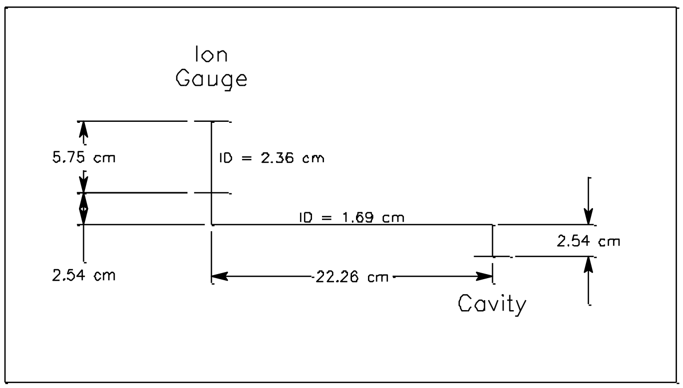


Figure 3. Ion gauge to cavity conductance geometry.

A nitrogen to vacuum leak was discovered in the number 1 actuator during the pumpdown and was mitigated by pulling a rough vacuum on the nitrogen side of the leak. The effect of this can be seen in figure 4 where the pressure changes from $9.0(10)^{-8}$ to $8.0(10)^{-8}$ Torr.

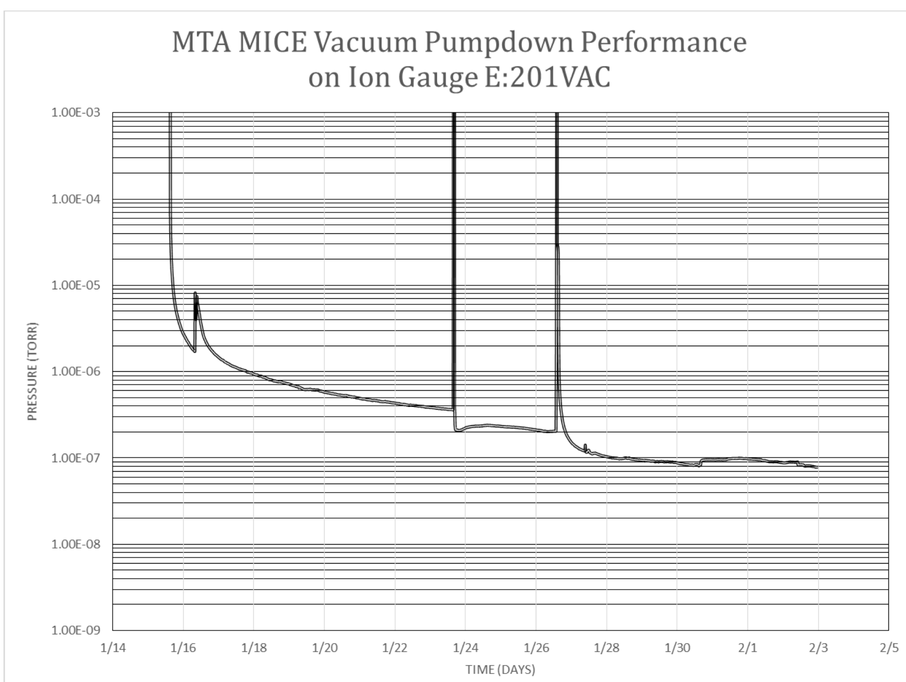


Figure 4. January 2015 pumpdown performance.

Table 1. Significant events during January 2015 pumpdown test.

Date	Event Description
1/15/15	Turbos started about 15:00.
1/16/15	RGA turned on.
1/23/15	Determined source of high 44 peak and found N2 leak in #1 (push) actuator. High 44 peak is due to hot filaments of IG's and RGA. Turned off RGA.
1/26/15	Activated 1300 NEG at bottom of Cavity.
1/27/15	Activated 3600 NEG.
1/28/15	Opened 3600 NEG to system.
1/30/15	System put in final configuration. Only pumping with IP, 1300 NEG, and 3600 NEG.
2/2/15	Pulled vacuum on leaking #1 actuator line.

The vessel is pumped on by three turbo molecular pumps (1 – 500 L/s Balzers TMH 520U and 2 – 145 L/s Leybold TMP 151's). They are connected to the vessel by a manifolding system with various conductances between the pumps and the vessel. All pumps are connected to the vessel by a 3" to 4" reducer and a 4" gate valve. The reducer has a conductance of 118 L/s and the valve has a conductance of 1700 L/s. The 500 L/s pump (attached at GV3) has an additional 4" to 6" reducer, with a conductance of 228 L/s, connecting it to the valve. One of the 145 L/s pumps (attached at GV4) has a getter pump assembly (3600 L/s) and another 4" gate valve in line with the other gate valve. When the conductances and entrance effects are accounted for the effective pump speeds are 63 L/s at GV2, 70 L/s at GV3, and 60 L/s at GV4.

The cavity is pumped at the bottom of the vessel through the wall pump station. The pump station has a 145 L/s turbo and a 30 L/s ion pump. They are connected to the 1300 L/s NEG (non-evaporative getter) pump at the bottom of the vessel. The connections are made through two long flexible stainless steel tubes with a total conductance on the order of 50 L/s. This would give an effective pumping speed on the order of 40 L/s at the NEG assembly (at GV1). The conductance from the NEG assembly to the cavity is 508 L/s, so the effective pumping speed on the cavity is about 35 L/s.

An effort was made to understand what the gas loads are from the vessel, the cavity, and miscellaneous components (cabling, instrumentation, supports, etc.). After eleven days of pumping the total gas load is approximately $4.3(10)^{-5}$ Torr-L/s. The contribution of the nitrogen leak is about $2(10)^{-6}$ Torr-L/s, so the real gas load is about $4.1(10)^{-5}$ Torr-L/s. The surfaces internal to the cavity and coupler arms account for about 24% of the total gas load ($9.84(10)^{-6}$ Torr-L/s) and the remainder ($3.12(10)^{-5}$ Torr-L/s) is accounted for by the components external to the cavity. Assuming a uniform specific outgassing rate these numbers would indicate a rate on the order of $2.2(10)^{-10}$ Torr-L/s-cm^2, this would be consistent with unbaked stainless steel and copper.

When the cavity is in actual operation all the turbos will be valved out and turned off. At that time the only pumping on the system will be from the two NEG pumps and the Wall Pump Station ion pump. The 1300 L/s NEG will pump on the internal cavity volume and the 3600 L/s NEG will pump on the vessel volume. The ion pump is used to pump those gasses not pumped by the NEG's. The 1300 L/s NEG has an effective pumping speed on the cavity of 281 L/s and the 3600 L/s NEG has an effective pumping speed on the vessel of 104 L/s. If the cavity volume was vacuum tight from the vessel volume the stated pumping would be sufficient to provide a pressure of $3.5(10)^{-8}$ Torr in the cavity and $3.0(10)^{-7}$ Torr in the vessel. In the current test configuration this is not the case though.

In the current configuration the cavity volume and vessel volume communicated with each other through an annulus in the bottom cavity pump port and slots in the coupler arms for the coupler cooling tubes. Figure 5 is a schematic of this configuration. The conductance between the vessel and cavity pump port is about 0.42 L/s and the conductance between the cavity and vessel at the couplers is on the order of 46 L/s (assumes a 1 cm^2 orifice area at 4 locations). The coupler conductance is not known specifically, so it can be used as a variable input for a mass balance model using figure 5. Figure 6 is the results of that model using a total gas load of 4E-5 Torr-L/s and the coupler conductance as a variable.

Figure 5.Vacuum Schematic of Operational Pumping

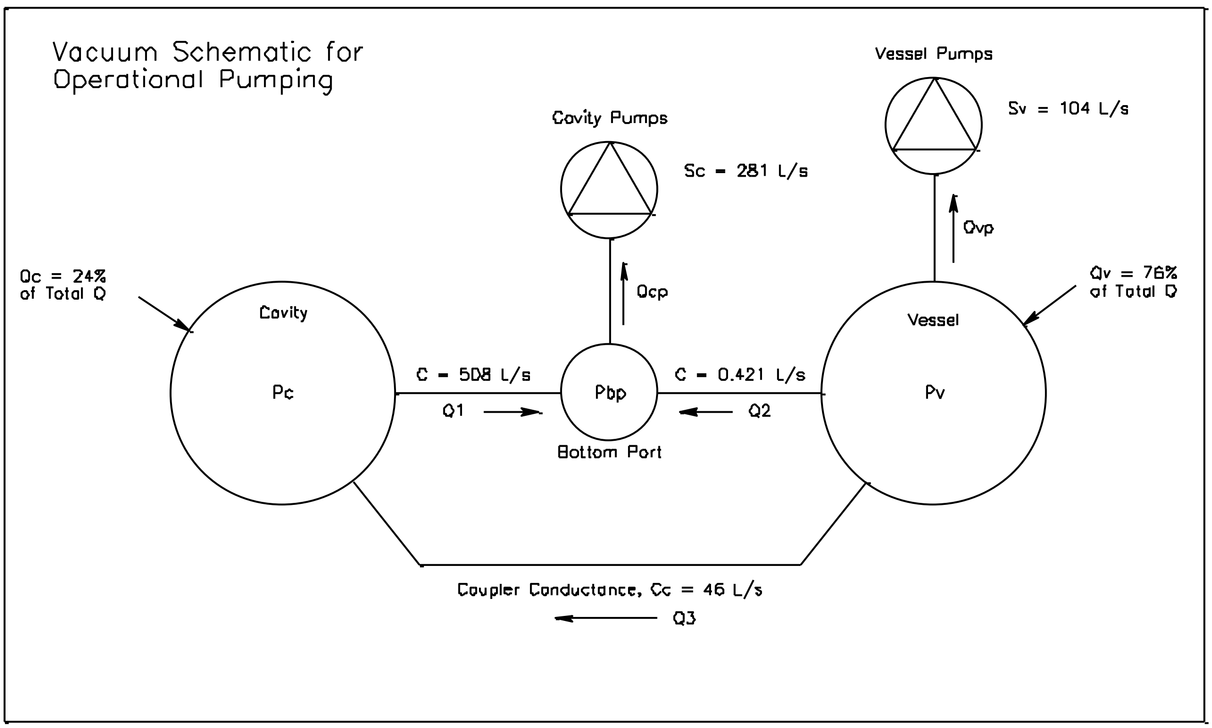
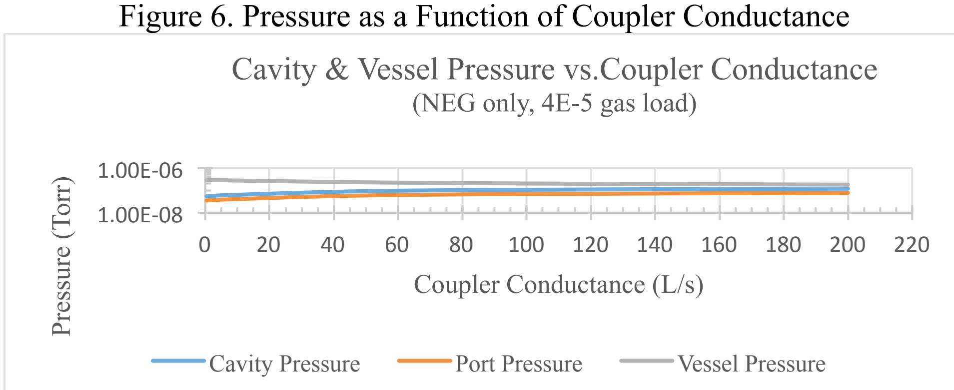
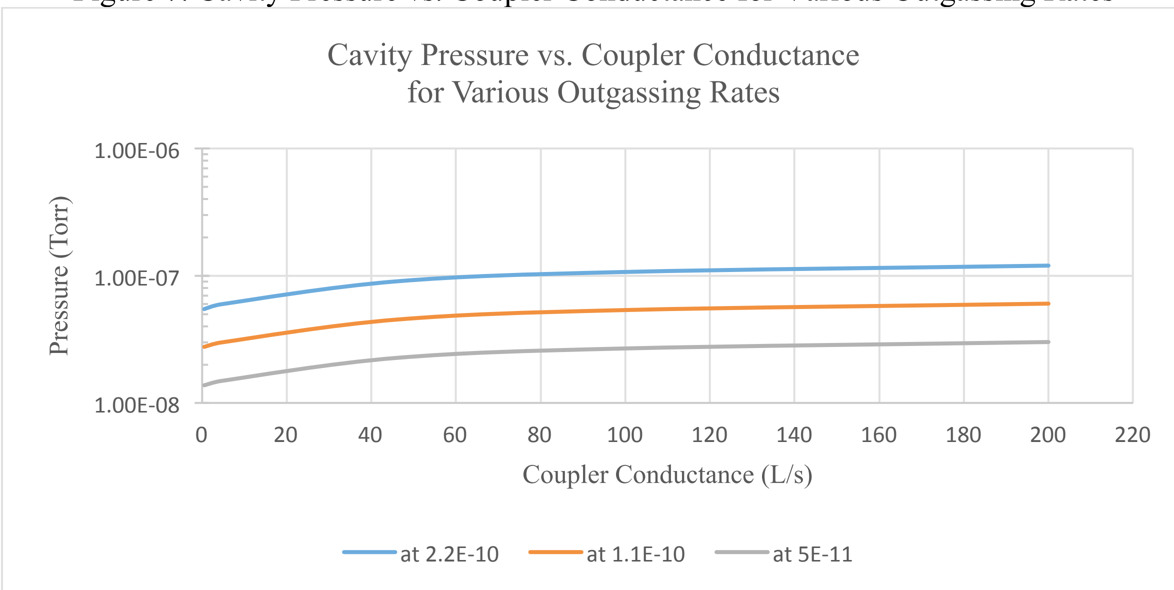


Figure 6. Pressure as a Function of Coupler Conductance



It can be seen that for coupler conductances above 60 L/s there is little change in the vessel or cavity pressures. Even reducing the coupler conductance to zero only gives a factor of two improvement in the cavity pressure (1E-7 to 5E-8 Torr). Larger effects are seen when the gas load is used as an input variable, as can be seen in figure 7. The best estimate for the bulk outgassing rate is 2.2E-10 Torr-L/s-cm^2 after about eleven days of pumping. This will improve with time under vacuum but will probably come back to the base number after subsequent venting.

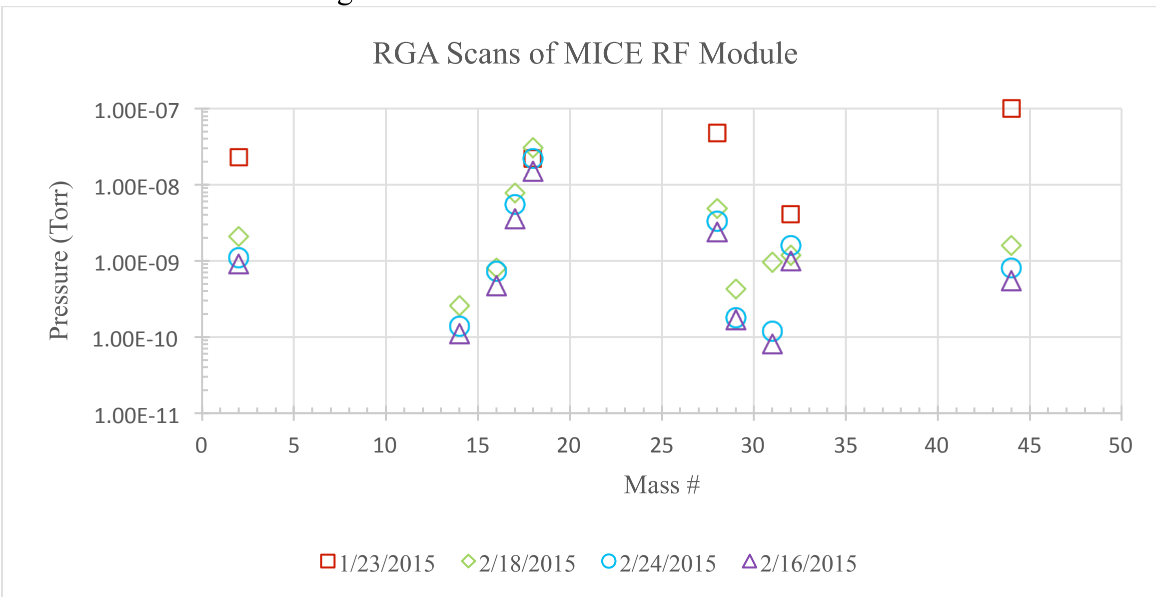
Figure 7. Cavity Pressure vs. Coupler Conductance for Various Outgassing Rates



In addition to looking at the quantity of the vacuum system (gas loads, outgassing rates, and pressures) the quality (gas composition) was also looked at. Figure 8, below, is a plot of various residual gas analysis (RGA) scans taken at various times. The 1/23/2015 scan was taken at the top port of the vessel which samples the cavity through small tubing as shown in figure 3. At the time there was a known nitrogen leak to vacuum from one of the actuator feedthroughs. The scan shows H_2, H_2O, N_2/CO, O_2, and CO_2. The CO_2 was determined to come from the hot filaments on the ion gauges and the RGA, and is therefore of little concern. The high 28 peak is mostly N_2 in this scan and comes from the known leak. It is not clear where the O_2 peak is coming from. It could be from air in the leaking N_2 line or virtual in nature. Discounting the problematic levels of CO_2 and N_2 we are left with H_2, H_2O, N_2/CO, and CO_2. H_2 and H_2O are at equivalent levels (low E-8 Torr) and N_2/CO and CO_2 are at levels a decade or more lower. This is consistent with a clean unbaked stainless steel or copper system.

The three scans in February 2015 were taken during the second pumpdown of the system prior to the test run. The RGA was located on the side of the vessel and therefore directly sampled the gas in the vessel. There was a known air to vacuum leak in the left coupler arm during this pumpdown. The leak was repaired with epoxy but then became a source for a virtual leak. This is evidenced by the 29 and 31 peaks (alcohols). Alcohol was applied to the leak prior to applying the epoxy and remained in the crack as a virtual leak. It is clearly seen decreasing with time. The O_2 that shows up in these scans is also assumed to be virtual in nature. In the vessel scans H_2O is the dominant peak at a couple E-8 Torr followed by N_2/CO at a few E-9 Torr. The remaining gasses are H_2, O_2, and CO_2 1E-9 Torr or less. This would be consistent with a water loaded stainless steel vessel.

Figure 8. RGA Scans of MICE RF Module



Beryllium Window Concerns:

The 201 MHz Muon Cavity Prototype has two 18 inch diameter dished beryllium windows. Beryllium is a hazardous material, so precautions must be taken to insure that if a rupture does occur personnel are not exposed to the debris. The window is 0.015 inches thick and very susceptible to fracturing due to differential pressures between the cavity and the vessel and mechanical shock. For this reason care must be taken when venting the vessel and cavity to atmosphere or working around the window.

When the vessel is open the window is exposed and is subject to normal operational risks associated with working around beryllium. Therefore no exceptional measures need to be taken other than those already in existence at Fermilab (Beryllium Handling Training Course, #FN000196).

While the vessel and cavity are under vacuum there is a risk that a catastrophic event could occur that would cause the vessel or cavity to let up suddenly. If that were to happen there could be a scenario that would cause a large enough pressure differential on opposite sides of a window to cause it to rupture. In the current configuration the cavity and vessel communicate with each other at the bottom pumping port and in the coupler arms. The conductance between the cavity and vessel is estimated to be 46 L/s. Therefore a catastrophic event that does not cause a direct impact (solid material or gas) on a window should not cause a window to rupture.

The other scenario that could cause a pressure differential is during controlled venting to atmospheric pressure when the vessel and cavity are under vacuum. This is done under procedural (Appendix 2) conditions through the bottom pumping port. A 1 to 2 psi pressure relief valve is used on the N_2 gas bottle to prevent over pressuring the system and a bypass line is valved in at the bottom of the vessel so that the vessel and cavity see the same pressure at the entrance to the two vacuum spaces.

If a window were to rupture while under vacuum conditions all debris would remain inside the vessel and cavity because all air flow would be into the vessel. The only possible exposure to personnel would be when the vessel is opened. At that time the hazard can be dealt with under controlled conditions using standard beryllium clean-up procedures. This would be a great loss in time and money to the project, but the exposure to personnel would be mitigated.

The question becomes at what deferential pressure does the integrity of the beryllium become an issue? The window is reinforced at 16.535 inches on the diameter, so the relevant stress location is at the 16.535 inch diameter. For a flat plate the maximum stress would be sigma = $6M/t^2$, where M is equal to the radial moment at the diameter and t is equal to the plate thickness. The moment is equal to $q\ a^2/8$, where a is equal to the radius and q is equal to the pressure differential. The ultimate strength of beryllium is about 65,000 psi, which would give a maximum pressure between the cavity and vessel of 0.2853 psi before failure. This all assumes a flat disk though, and the actual window is dished so the 0.2853 psi (14.75 Torr) is a lower bounds for failure.

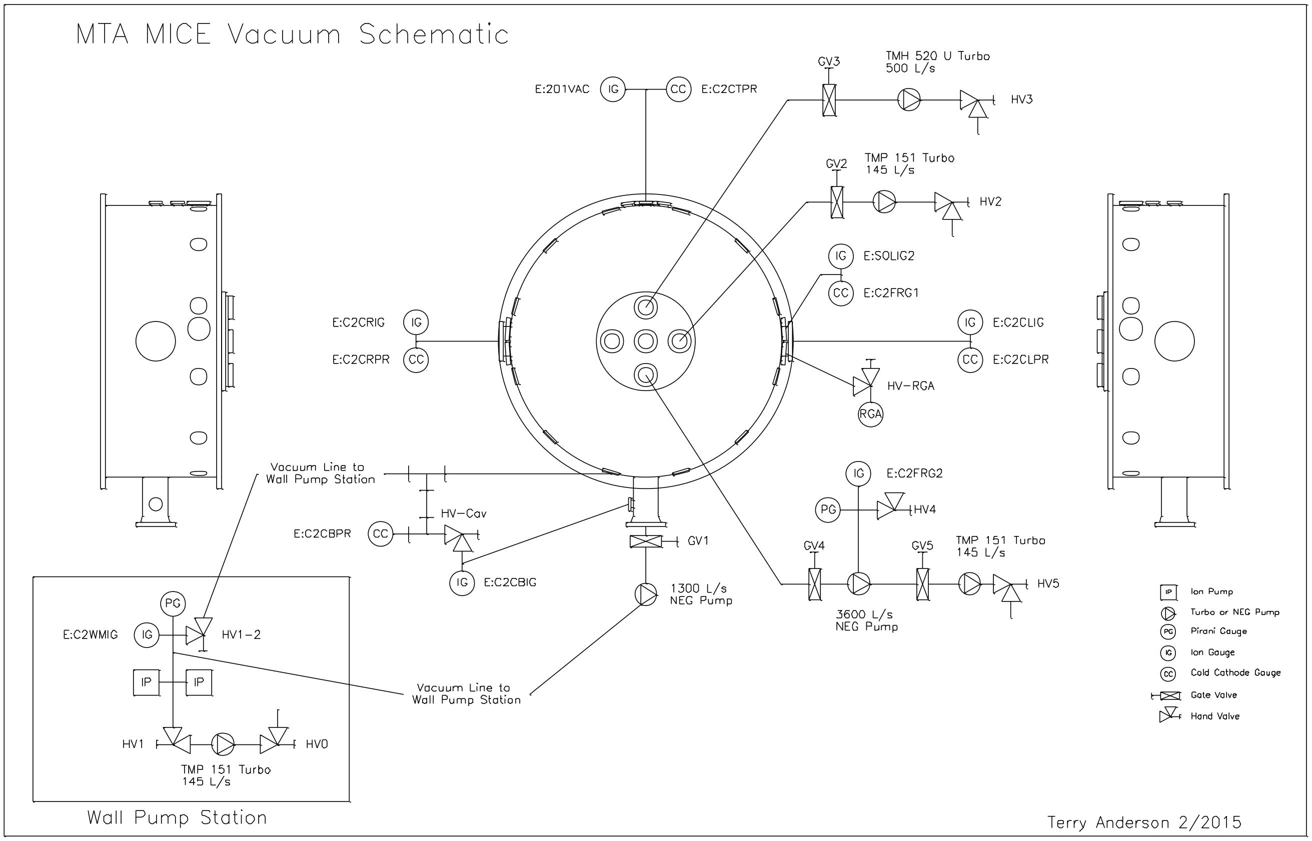
Vacuum Procedures:

See Appendix 1 through 5.

[1] Assembly and Testing of the First 201-MHz MICE Cavity at Fermilab, Y. Torun et al., Proceedings of the 2013 Particle Accelerator Conference.
[2] 201 MHz Muon Cavity Prototype Beryllium Window, drawing 25O640, LBNL.

[3] A 201 MHz Cavity Design with Non-Stressed Pre-Curved Be Windows for Muon Cooling Channels, D. Li et al., Proceedings of the 2003 Particle Accelerator Conference.

Appendix 1
Pumpdown Procedure for MICE Cavity & Vessel



	Check Box
1) Gate valves GV1, GV2, GV3, and GV4 & GV5 in open position.	
2) Hand valves HV0, HV1, HV1-2, HV2, HV3, HV5, HV-Cav, and HV-RGA in open position.	
3) Hand valve HV4 in closed position.	
4) Connect scroll pumps to hand valves HV0, HV2, HV3, and HV5. Scroll pumps must have anti-suck back valves.	
5) Turn on scroll pumps.	
6) When Pirani gauges indicate low pressure (~1E-2 Torr) start turbos.	

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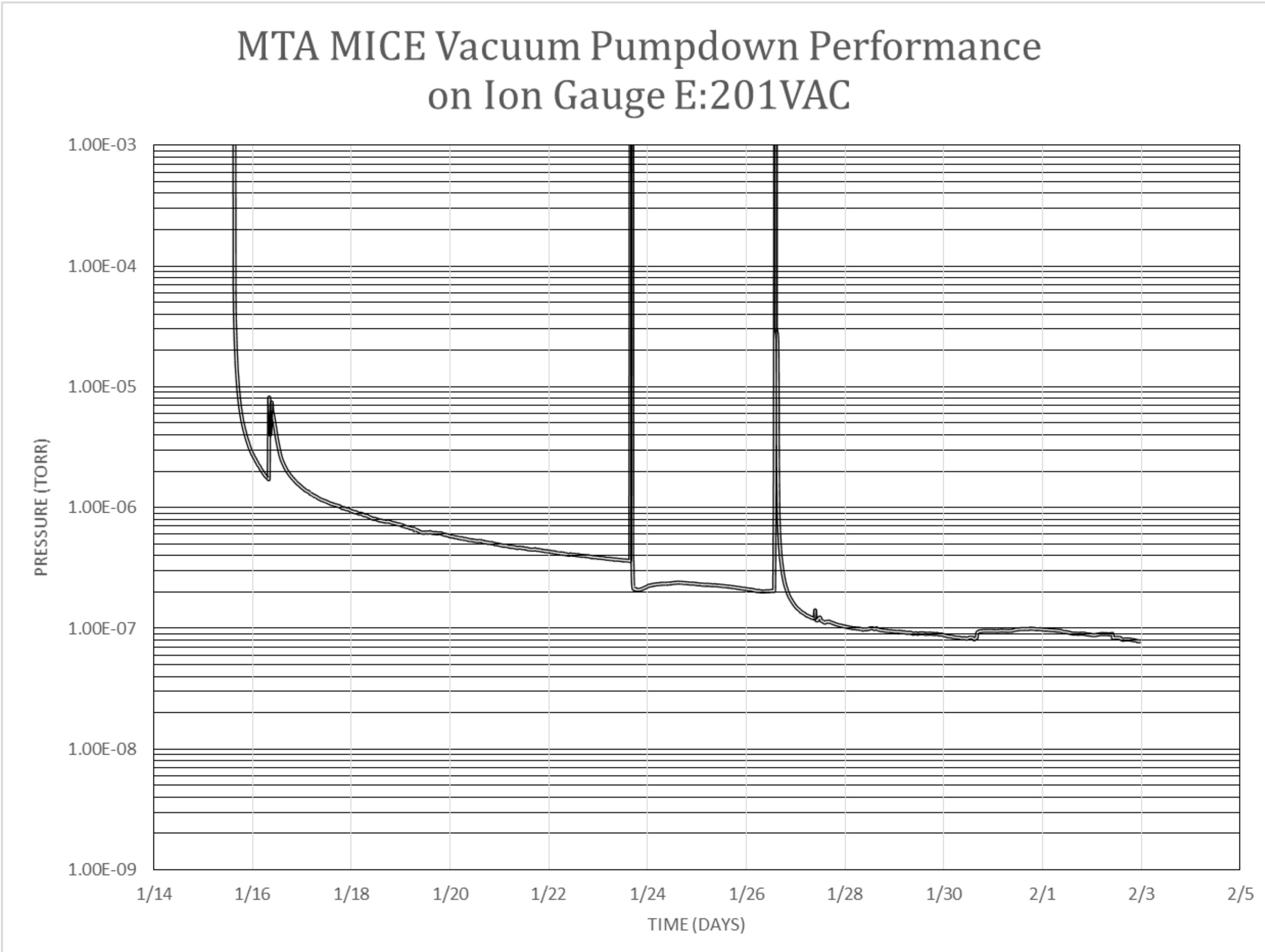
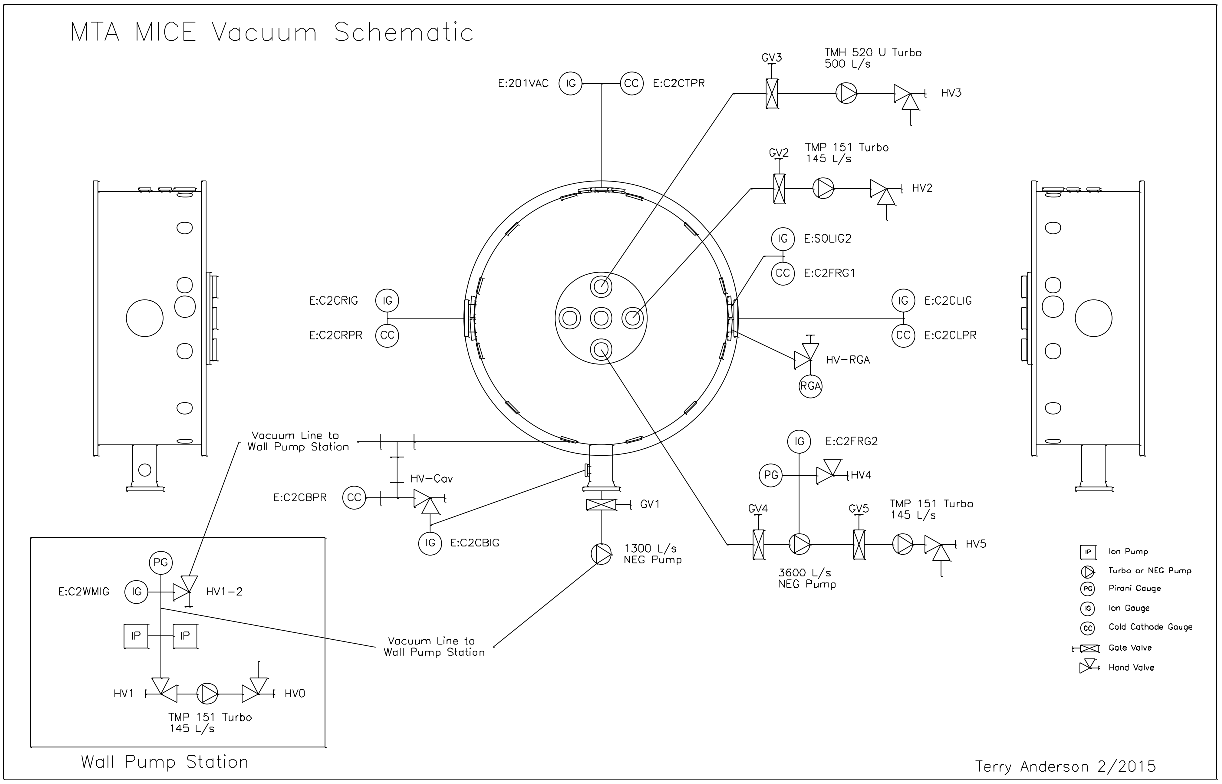
Plot of a previous pumpdown is provided below to help gauge pumpdown progress.



1/15/15 - Turbos started about 15:00.
1/16/15 - RGA turned on.
1/23/15 - Determined source of high 44 peak and found N2 leak in #1 (push) actuator. High 44 peak is due to hot filaments of IG's and RGA. Turned off RGA.
1/26/15 - Activated 1300 NEG at bottom of Cavity.
1/27/15 - Activated 3600 NEG.
1/28/15 - Opened 3600 NEG to system.
1/30/15 - System put in final configuration. Only pumping with IP, 1300 NEG, and 3600 NEG.
2/2/15 - Pulled vacuum on leaking #1 actuator line.

Appendix 2
Venting Procedure for MICE Cavity & Vessel



Step	Check Box
1) Gate valves GV2, GV3, & GV4 in closed position.	
2) Hand valve HV1 in closed position.	
3) Turn off getter (NEG) pump controller and allow getter to cool down.	
4) Turn off Turbos on HV1, GV2, GV3, & GV4.	
5) After Turbos have spooled down turn off scroll pumps.	
6) Disconnect scroll pump from HV0.	
7) Connect dry N2 bottle with pressure relief (1 to 2 psi) to HV0 and open N2 flow slowly until relief valve activates.	
8) Slowly open HV1.	
9) Allow N2 to Flow until vessel and cavity are vented. Pressure relief will pop-off at this point.	
10) Shut off N2 flow and close HV1.	
11) The vessel and cavity will be under slight positive pressure at this point. Disconnecting the vent line from HV0 and cracking HV1 slightly will relieve this pressure. Close HV1 after relieving pressure.	

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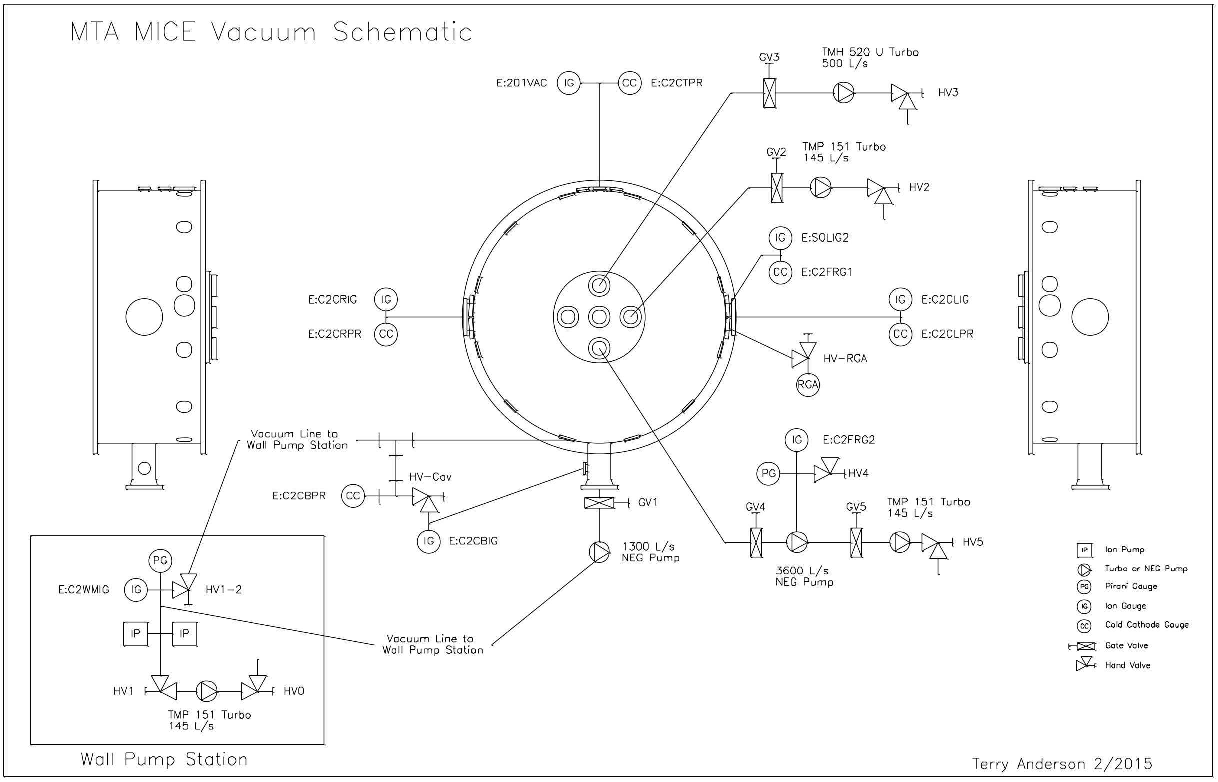
Appendix 3
Activation Procedure for CapaciTorr-B 1300-2/150 MK5 NEG
On MICE Cavity & Vessel



	Check Box
1) With vessel and cavity under vacuum in the 1E-7 Torr range and all turbos operating.	
2) Gate valves GV1, GV2, GV3, & GV5 in open position.	
3) Gate valve GV4 in closed position.	
4) Hand valve HV4 in closed position.	
5) Hand valves HV0, HV1, HV1-2, HV2, HV3, HV5, HV-Cav, and HV-RGA in open position.	
6) Connect the NEG Pump Controller V1.1 cable to the CapaciTorr -B 1300-2/150 MK5 NEG.	
7) Set potentiometer on the NEG Pump Controller V1.1 to the 10 setting.	
8) Set thermoregulation to ON on the NEG Pump Controller V1.1.	
9) Set temperature stop value to 500 C on the NEG Pump Controller V1.1.	
10) Set over temperature alarm value to 510 C on the NEG Pump Controller V1.1.	
11) Start the NEG Pump Controller V1.1.	
12) Allow the NEG Pump Controller V1.1 to ramp up to 500 C and hold at that value for 45 minutes.	

13) Turn off the NEG Pump Controller V1.1 and allow to cool to room temperature. [ ]

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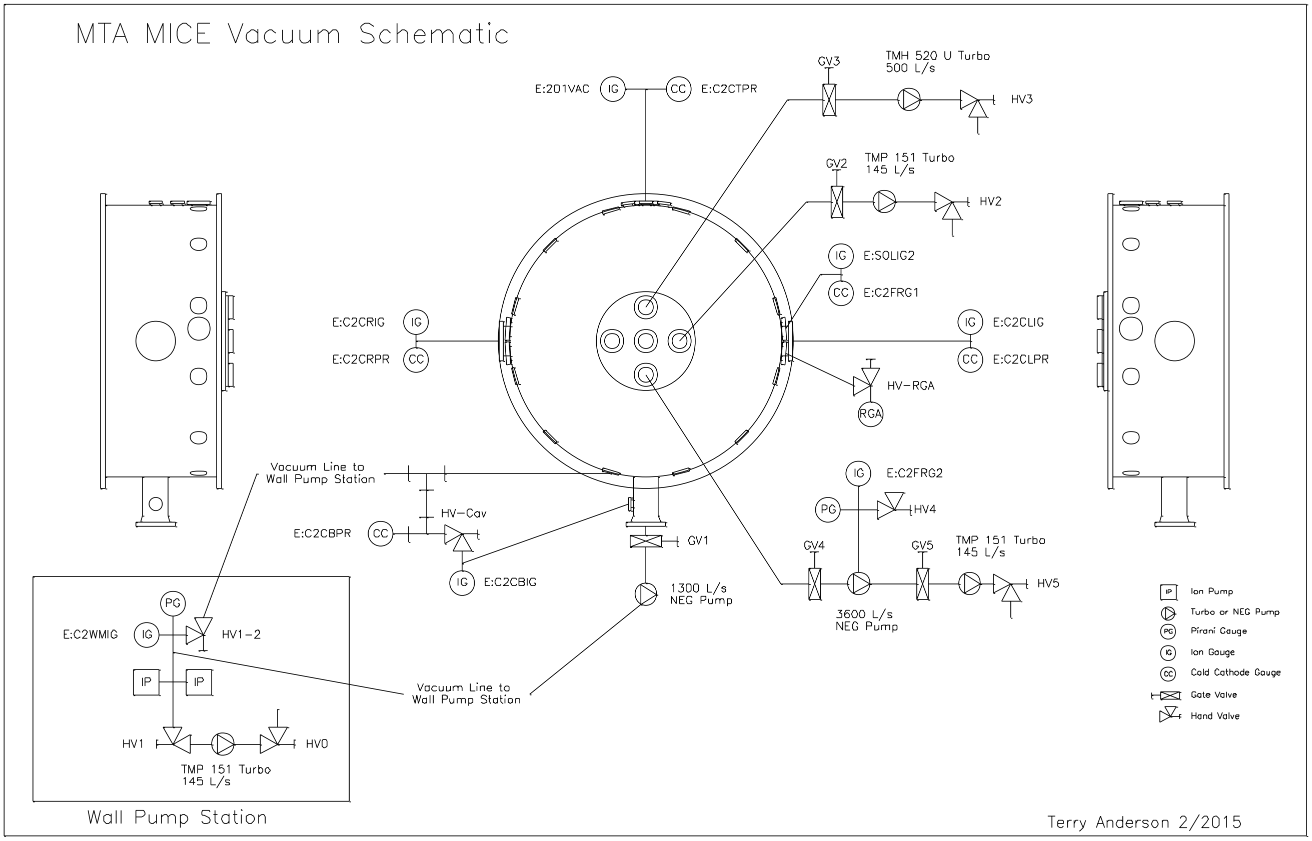
Appendix 4
Activation Procedure for CapaciTorr D3500 NEG
On MICE Cavity & Vessel



	Check Box
1) With vessel and cavity under vacuum in the 1E-7 Torr range and all turbos operating.	
2) Gate valves GV1, GV2, GV3, & GV5 in open position.	
3) Gate valve GV4 in closed position.	
4) Hand valve HV4 in closed position.	
5) Hand valves HV0, HV1, HV1-2, HV2, HV3, HV5, HV-Cav, and HV-RGA in open position.	
6) Connect the NEG Pump Controller V1.1 cable to the CapaciTorr D3500 NEG.	
7) Set potentiometer on the NEG Pump Controller V1.1 to the 8.4 setting.	
8) Set thermoregulation to ON on the NEG Pump Controller V1.1.	
9) Set temperature stop value to 550 C on the NEG Pump Controller V1.1.	
10) Set over temperature alarm value to 560 C on the NEG Pump Controller V1.1.	

11) Start the NEG Pump Controller V1.1.
12) Allow the NEG Pump Controller V1.1 to ramp up to 550 C and hold at that value for 45 minutes.
13) Turn off the NEG Pump Controller V1.1 and allow to cool to below 200 C.
14) Set potentiometer on the NEG Pump Controller V1.1 to the 2.7 setting.
15) Set thermoregulation to ON on the NEG Pump Controller V1.1.
16) Set temperature stop value to 200 C on the NEG Pump Controller V1.1.
17) Set over temperature alarm value to 210 C on the NEG Pump Controller V1.1.
18) Start the NEG Pump Controller V1.1.
19) Open gate valve BV4 when ion gauge E:C2FRG2 reads less than 2E-8 Torr.

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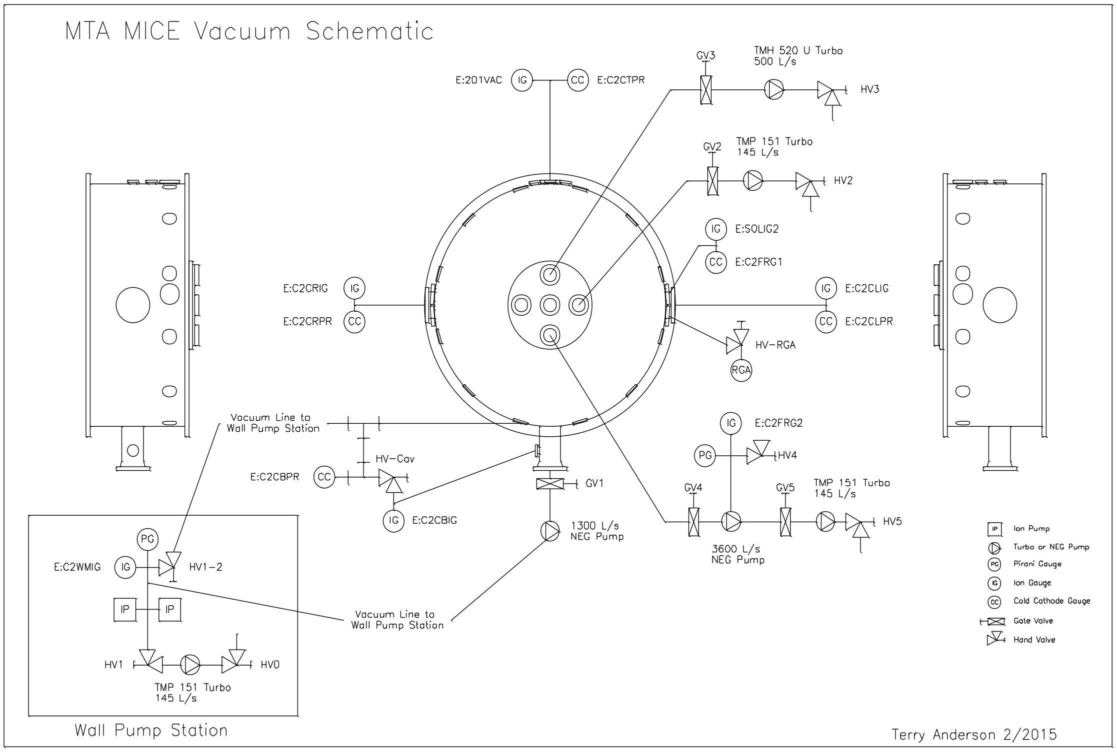
Appendix 5
MICE Cavity & Vessel Vacuum Status for Solenoid Power On

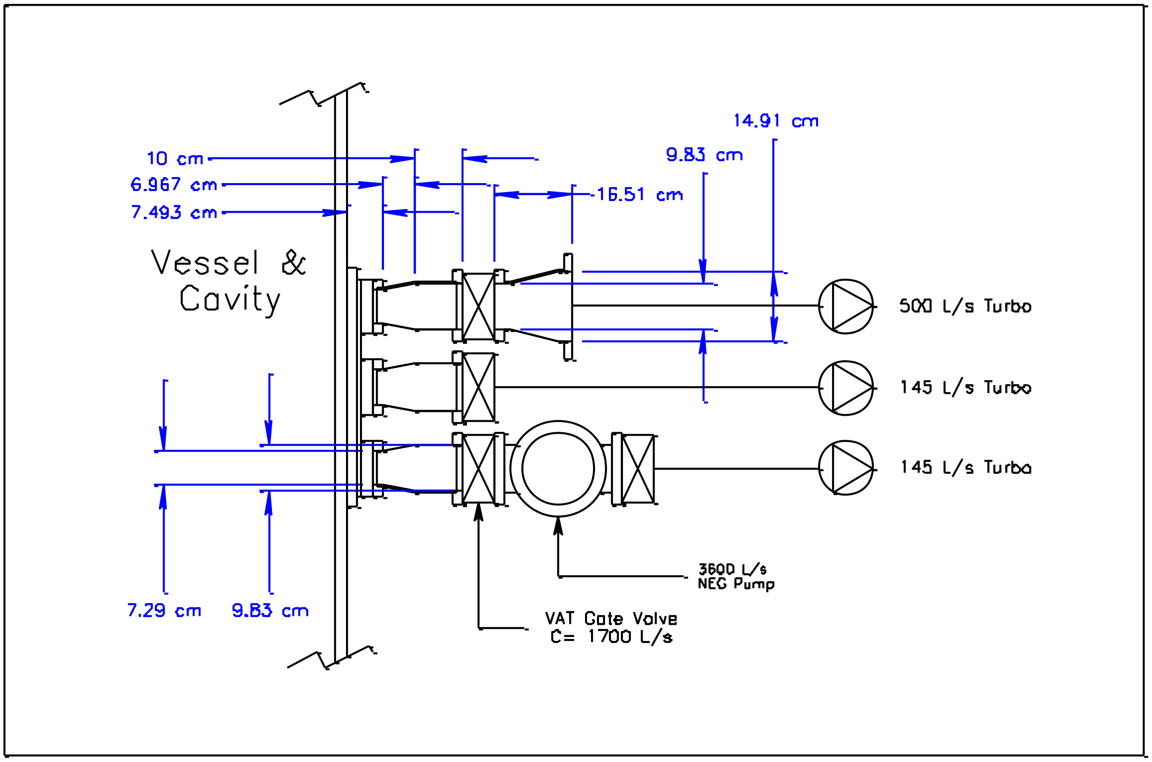


	Check Box
1) Both NEG pumps activated and on.	
2) Ion Gauges E:C2CBIG, E:C2FRG2, E:C2CLIG, E:SOLIG2, E:201VAC, and E:C2CRIG off.	
3) Ion Gauges E:C2CBIG, E:C2FRG2, E:C2CLIG, E:SOLIG2, E:201VAC, and E:C2CRIG disconnected.	
4) Cold cathodes E:C2CBPR, E:C2CLPR, E:C2FRG1, E:C2CTPR, and E:C2CRPR on.	
5) RGA off and head disconnected.	
6) Gate valves GV1 and GV4 in open position.	
7) Gate valves GV5, GV2, and GV3 in closed position.	
8) Hand valves HV1, HV-Cav, and HV4 in closed position.	
9) Hand valves HV1-2 and HV-RGA in open position.	
10) Ion pumps on.	
11) All turbos off and allowed to spool down.	
12) Scroll pumps off.	
13) Remove all unused equipment and material from high magnetic field area.	

Signature Verifying Check List _______________________________________ Date ______________

Appendix 6
Calculations

Conductance Calculations:



3" to 4" Conical Reducer

Small ID (R_1) =	7.290	cm	
Large ID (R_2) =	9.830	cm	
Length (L) =	6.967	cm	
$2_L/R_2$	1.911		
R_2/R_1	1.348		
Transmission Probability (alfa) =	0.380		from "A User's Guide to Vacuum Technology", John F. O'Hanlon, pg. 42
Aperture Conductance (C_{ar}) =	482.261	L/s	11.56 x A
Conductance of 3x4 Reducer (C_r) =	183.259	L/s	C_a x alfa

3" Short Piece

ID (D) =	7.290	cm
Length (L) =	7.493	cm

L/D =	1.028		
Transmission Probability (alfa) =	0.514		from "Foundations of Vacuum Science and Technology", J.M. Lafferty, pg. 89
Aperture Conductance (C_{a3}) =	482.261	L/s	11.56 x A
Conductance of 3x4 Reducer (C_3) =	247.882	L/s	C_{a3} x alfa

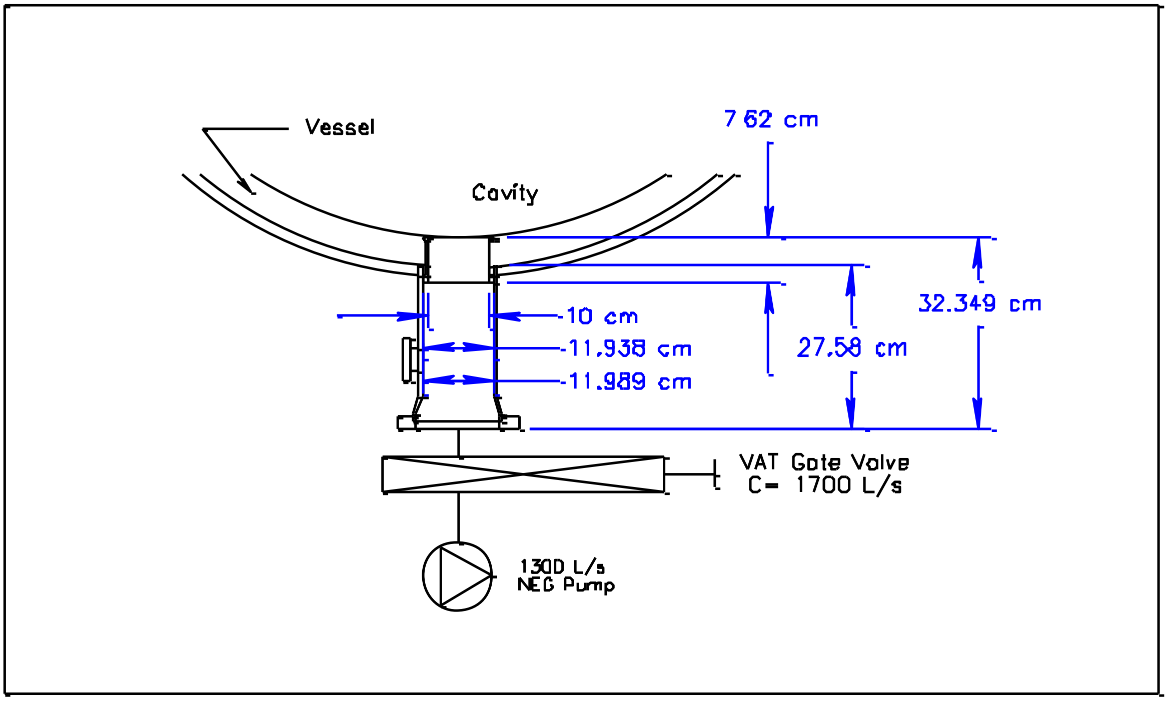
4" Short Piece

ID (D) =	9.830		
Length (L) =	10.000		
L/D =	1.017		
Transmission Probability (alfa) =	0.514		from "Foundations of Vacuum Science and Technology", J.M. Lafferty, pg. 89
Aperture Conductance (C_{a4}) =	876.869	L/s	11.56 x A
Conductance of 3x4 Reducer (C_4) =	450.710	L/s	C_a x alfa
Conductance of Assembly (C) =	117.707	L/s	$1/C = 1/C_3 + (1/C_r - 1/C_{ar}) +(1/C_4 - 1/C_{a4})$

4" to 6" Reducer

Small ID (R_1) =	9.830	cm	
Large ID (R_2) =	14.910	cm	
Length(L) =	16.510	cm	
$2_L/R_2$	3.359		
R_2/R_1	1.517		
Transmission Probability (alfa) =	0.260		from "A User's Guide to Vacuum Technology", John F. O'Hanlon, pg. 42
Aperture Conductance (C_{a4}) =	876.869	L/s	11.56 x A
Conductance of 3x4 Reducer (C_r) =	227.986	L/s	Ca x alfa
Conductance of Assembly (C) =	85.168	L/s	$1/C = 1/C_3 + (1/C_r - 1/C_{ar}) +(1/C4 - 1/C_{a4})+(1/C_r - 1/C_{a4})$

Bottom Pump Port Conductances:



Port to Vessel

Small ID (R_1) =	11.938	cm	
Large ID (R_2) =	11.989	cm	
Length(L) =	2.851	cm	
y =	111.804		$y= L/(R_2-R_1)$
R_1/R_2 =	0.996		
Transmission Probability (alfa) =	0.038		from "Foundations of Vacuum Science and Technology", J.M. Lafferty, pg. 95
Aperture Conductance (C_a) =	11.074	L/s	11.56 x A
Conductance of Bottom Annulus (C_{an}) =	0.421	L/s	C_a x alfa

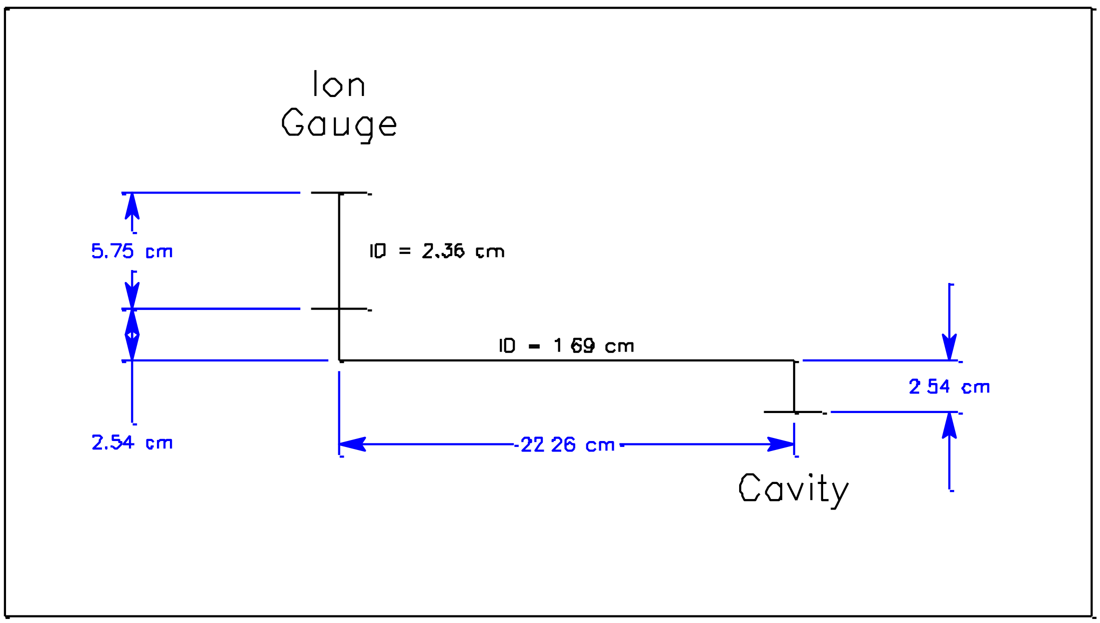
Port to Cavity

ID (D) =	10.000	cm
Length (L) =	7.620	cm
L/D =	0.762	

Transmission Probability (alfa) =	0.560		from "Foundations of Vacuum Science and Technology", J.M. Lafferty, pg. 89
Aperture Conductance (C_a) =	907.460	L/s	11.56 x A
Conductance of Bottom (C_b) =	508.178	L/s	C_a x alfa

Capillary Tube Conductances

Cavity Top



1" Leg

ID (D) =	1.690	cm
Length (L) =	2.540	cm
L/D =	1.503	

Transmission Probability (alfa) =	0.420		from "Foundations of Vacuum Science and Technology", J.M. Lafferty, pg. 89
Aperture Conductance (C_a) =	25.918	L/s	11.56 x A
Conductance of Tube (C_{t1}) =	10.886	L/s	C_a x alfa

22.26 cm Run

ID (D) =	1.690	cm	
Length (L) =	22.260	cm	
L/D =	13.172		
Transmission Probability (alfa) =	0.089		from "Foundations of Vacuum Science and Technology", J.M. Lafferty, pg. 89
Aperture Conductance (C_a) =	25.918	L/s	11.56 x A
Conductance of Tube (C_{t2}) =	2.307	L/s	C_a x alfa
Conductance of Assembly ($C_{3/8}$) =	1.620	L/s	$1/C = (1/C_{t1}) + (1/C_{t2}) + (1/C_1)$

5.75 cm Run

ID (D) =	2.360	cm	
Length(L) =	5.750	cm	
L/D =	2.436		
Transmission Probability (alfa) =	0.310		from "Foundations of Vacuum Science and Technology", J.M. Lafferty, pg. 89
Aperture Conductance (C_a) =	50.542	L/s	11.56 x A
Conductance of Tube (C_1) =	15.668	L/s	C_a x alfa
Conductance from Gauge to Cavity (C) =	1.556	L/s	1/C = (1/C1) + (1/C3/8) - (1/Ca)

Capillary Tube Pressure Drops

Small diameter tubes are used to connect the cold cathode gauges and the one ion gauge at the top of the cavity to the cavity and vessel. As such the pressure readings can be significantly higher than the actual cavity or vessel pressure. The pressure drop is proportional to the length of the tube and the specific outgassing rate of the tube, for a given diameter. There is also some gas load do to the gauge assembly itself.

For the gas load in the gauge assembly: Delta P = Q / C

For a distributed gas load in the tube: Delta P = q_D B L / 2 C From "Vacuum Technology", A. Roth, pg. 133

Where: q_D = Specific outgassing rate (Torr-L/s-cm^2).
B = Perimeter of the tube (cm).

L = Length of the tube (cm).
C = Conductance of the tube (L/s).
$C = 11.56 \times (3.14/4) \times D^2 \times (4/3)\ D/L$
$= 12.11 \times (D^3)/L$
Q = gas load (Torr-l/s)

Cold Cathode Tube Pressure Drop

3/8 " tubing, .035 wall, 0.7747 cm inside dia.

Length =	182.900	cm	Assumes 6 foot length.
Outgassing Rate (q_D) =	1.00E-10	Torr-l/s-cm^2	
Gas Load (Q) =	5.00E-09	Torr-l/s	Assumes 50 square cm of surface.
Sum of the Two Delta P's =	8.85E-07	Torr	Delta P = $(q_D \times (3.14 \times D) \times L / (2 \times (12.11 \times (D^3)/L))) + Q/(12.11 \times (D^3)/L)$

$= (0.1297 \times q_D \times (L/D)^2) + (Q/(12.11 \times (D^3) \times L)$

$= (.2161 \times q_D \times L^2) + (.1776 \times Q \times L)$

Top IG Pressure Drop

Length =	33.000	cm	
Outgassing Rate (q_D) =	2.30E-10	Torr-l/s-cm2	
Gas Load (Q) =	1.15E-08	Torr-l/s	Assumes 50 square cm of surface.
Sum of the Two Delta P's =	2.03E-08	Torr	Delta P = $(q_D \times (3.14 \times D) \times L / (2\ C)) + Q/C$

Effective Pump Speeds and Gas Load:

Pumps	Pump Speed (L/s)	Conductance to Vessel (L/s)	Effective Pumping Speed (L/s)	Pressure During Gas Load Measurement (Torr)	Gas Load (Torr-L/s)
Wall Pump Station #1, 145 L/s	145	45.5	34.6	1.90E-07	6.58E-06
Turbo #2, 145 L/s	145	110.1	62.6	1.89E-07	1.18E-05
Turbo #3, 500 L/s	500	81.1	69.8	1.89E-07	1.32E-05
Turbo #4, 145 L/s	145	103.4	60.4	1.89E-07	1.14E-05
Totals =	935.0	340.1	227.4		4.29E-05

1300 L/s NEG	1000	391.2	281.2	3.35E-08	9.43E-06
3600 L/s NEG	1800	110.1	103.7	3.05E-07	3.16E-05

Gas Loads from Surfaces:

Surfaces	Area (cm^2)	Outgassing Rate (Torr-L/s-cm^2)	Gas Load (Torr-L/s)	Fraction of Total
Cavity				
Interior Cavity	3.28E+04	2.30E-10	7.54E-06	0.186
Interior of Coupler Arms (2 arms)	9.59E+03	2.30E-10	2.21E-06	0.054
Vessel				
Exterior Cavity	3.95E+04	2.30E-10	9.09E-06	0.224
Interior Vessel	5.58E+04	2.30E-10	1.28E-05	0.316
Exterior of Coupler Arms (2 arms)	1.22E+04	2.30E-10	2.81E-06	0.069
Tuner Arms (6 arms)	2.03E+04	2.30E-10	4.67E-06	0.115
Struts (6 struts)	2.48E+03	2.30E-10	5.70E-07	0.014
Miscellaneous (cables, instrumentation, supports, etc.) (calculated at 300 feet of cabling)	3.70E+03	2.30E-10	8.51E-07	0.021
		Total =	4.05E-05	1.00