Accelerator Vacuum 101, Made Easy ???

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Goals

- Present a condensed and simplified discussion of the principles, procedures, and operating parameters of accelerator vacuum systems as practiced at Fermilab.

- Provide a basis for designers, builders, and operators of accelerator systems to communicate with each other about the needs and impact of the vacuum system.

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Words of Wisdom

For People Who Design, Build, or Operate Our Vacuum Systems:

- A) Keep it simple.
- B) Keep it clean.
- C) Establish guidelines and standard practices; then follow them.
- D) Always stop and think about what the outcome will be before you do something to the system.
- E) Test and certify everything you can before it goes in the system.
- F) Despite the abundance of “hot air” around physics laboratories, air is not the only gas we need to think about.
- G) There is no vacuum gauge on this planet that, in and of itself, gives you the real picture.

Why Vacuum?

In particle accelerators the purpose of the vacuum system is to remove gas molecules from the path of the beam. Pressure is nothing more than a measure of the number of molecules that can interfere or interact with the beam.

$$n = P\,V / R\,T$$

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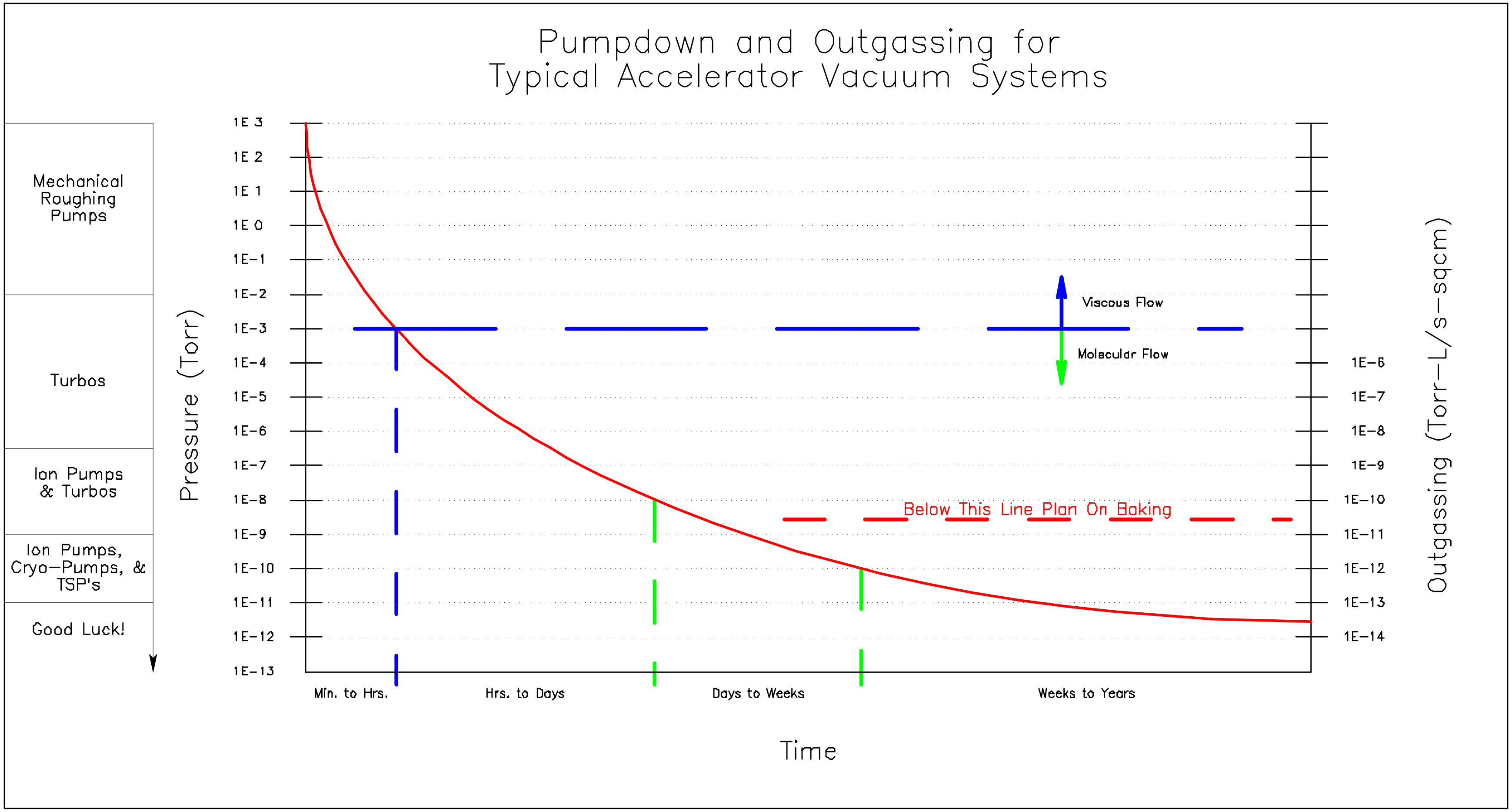
The Vacuum World We Live In



Note: Information depicted is intended for general reference and may or may not be representative of any real system.

Basic Equations for Molecular Flow:

$$Q = S\ P$$

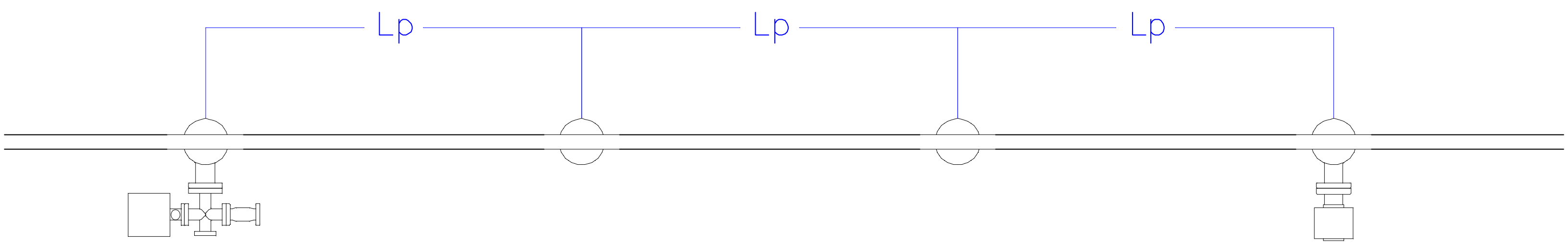
$$Q = C\ \Delta P$$

$$C = k\ A\ \alpha$$

$$1/S_{eff} = 1/S + 1/C$$

Where: Q = Gas Flow (Torr-L/s), S = Pump Speed (L/s), P = Pressure (Torr), C = Conductance (L/s), k = Flow Constant for Specific Gas (L/s-cm^2), A = Cross-Sectional Aperture Area (cm^2), α = Transmission Probability, S_{eff} = Effective Pumping Speed (L/s).

System Design Equations



$$P_m = P_p + \Delta P$$ (Pressure Between Pumps)

$$P_p = q_D \, B \, L_p / S$$ (Pressure at the Pump)

$$\Delta P = q_D \, B \, L_p / (4C)$$ (Pressure Drop in a Beam Tube from Midpoint to Pump)

Where: P_m = Midpoint Pressure (Torr), P_p = Pump Pressure (Torr), q_D = Specific Outgassing Rate (Torr-L/s-cm^2), B = Inside Tube Perimeter (cm), L_p = Pump Spacing (cm), C = Conductance Over Length $L_p/2$ (L/s).

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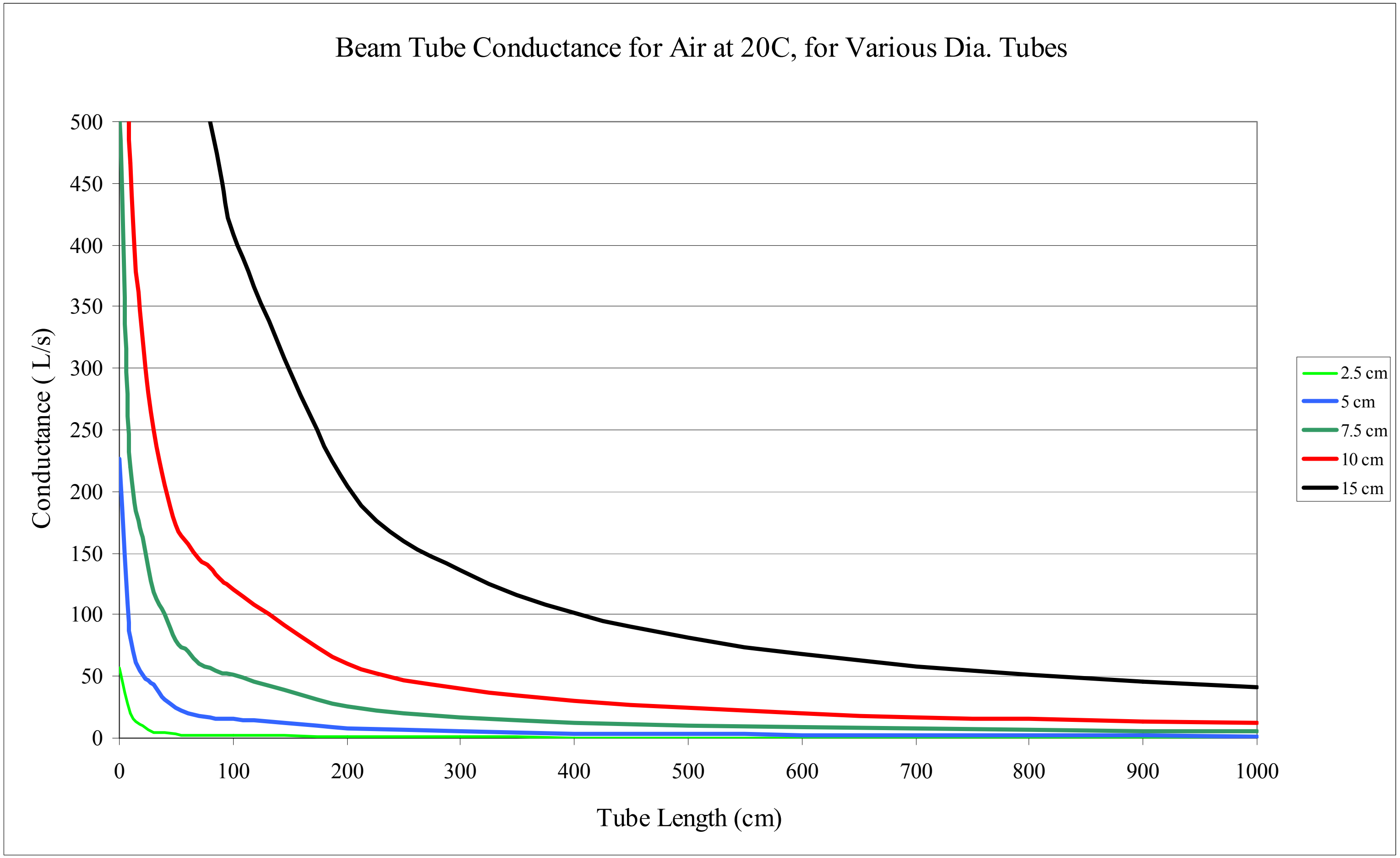

Multiply by $(29/M_m)0.5$ to adjust for other gases. Where: M_m = molar mass (g/mol) of gas.

Component & Devise Design

- Components are any part of the vacuum system that is not the beam tube.
- Devices are components whose primary function is beam related.
- If Q = S P, Then S P / Lp = Gas Load / cm.
- Any component or device to be installed has to have a gas load, per unit length, equal to or less than the above load.
- If the gas load is larger, additional pumping must be supplied or steps need to be taken to reduce the gas load in the component or device.

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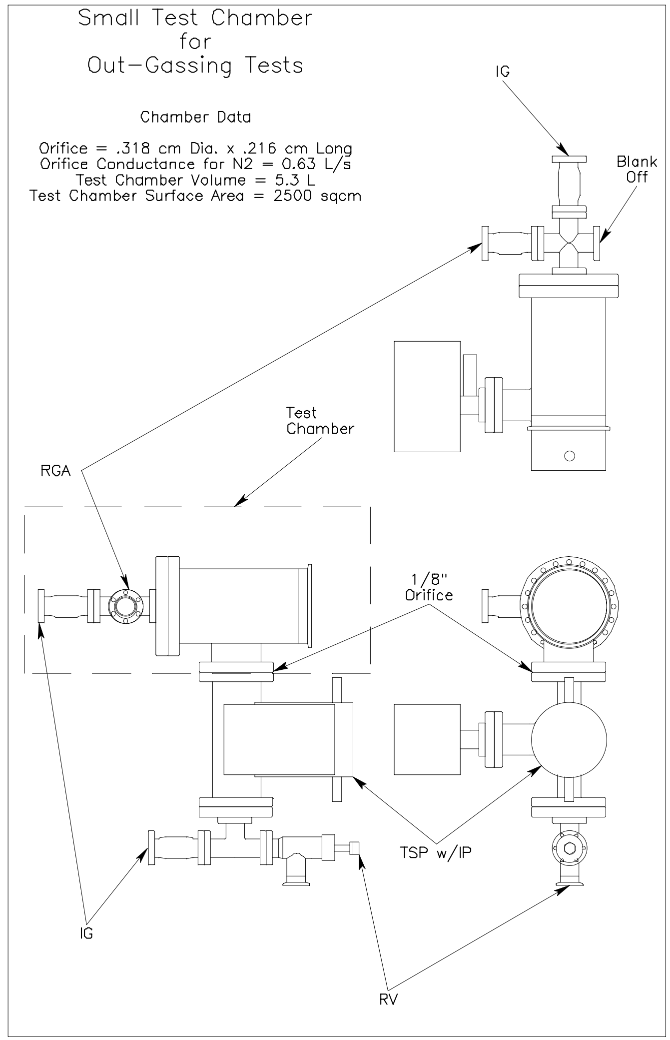
Don’t Guess; Test and Certify



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Outgassing Rates

Outgassing Rates (Torr-L/s-cm2) of Various Materials

Material	Totals (Torr-L/s-cm^2)	H_2	CH_4 Methane	H_2O	CO / N_2	C_2H_6 Ethane	Ethyl Alcohol	O_2	Ar	C_3H_6 Cyclo - propane	CO_2
Stainless Steel (unbaked, no degas)	1.0E-10	5.0E-11	2.0E-13	5.0E-11	1.0E-12	5.1E-14		3.0E-16		1.0E-14	1.0E-13
Stainless Steel (baked, no degas, based on Small Test Chamber)	5.1E-11	5.0E-11	2.0E-13	8.0E-14	2.0E-13	5.1E-14		3.0E-16		1.0E-14	8.0E-14
Stainless Steel (baked & degassed, based on Recycler)	6.7E-13	6.2E-13	1.0E-14	1.3E-14	1.3E-14	5.4E-15		1.7E-16	4.8E-16		5.7E-15
Torlon (baked)	3.1E-08	4.2E-09	6.2E-11	2.5E-08	6.7E-10	9.6E-11		8.2E-11	2.6E-12	7.5E-12	9.1E-10
Armalon (baked) (Glass filled Teflon)	3.1E-10	3.0E-10	2.0E-12	6.0E-12	4.0E-12	3.0E-13	3.0E-14	2.0E-15	1.0E-14	4.0E-13	2.0E-12
Rulon (baked) (Glass filled Teflon)	6.7E-11	6.1E-11	1.7E-13	4.2E-12	1.4E-12			1.4E-15			1.3E-13
Microwave Absorber Material (MF190) (baked)	6.5E-11	4.0E-11	2.5E-13	1.1E-11	6.0E-12	1.1E-12		3.8E-14	3.3E-15	5.7E-14	6.2E-12

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Outgassing Rates

Outgassing Rates (Torr-L/s) of Various TeV IPM Flex Circuit Materials

Sample Material	Total	H_2	CH_4 Methane	H_2O	CO / N_2	C_2H_6 Ethane	Ethyl Alcohol	O_2	Ar	C_3H_6 Cyclo - propane	CO_2
Test Chamber Baseline	2.3E-08	2.2E-08	1.2E-10	2.2E-11	6.8E-10	1.2E-11			5.3E-13	3.7E-13	3.6E-11
Flex Circuit Sample 1	1.0E-07	8.7E-08	6.9E-11	1.9E-09	1.3E-08	5.0E-10	1.2E-10	4.9E-12	3.1E-11	1.3E-10	6.2E-10
Flex Wires	2.3E-08	2.2E-08	1.7E-10	1.5E-11	9.9E-10	2.5E-12					3.9E-11
Flex Circuit Sample 2	1.7E-08	1.6E-08	7.1E-11	4.0E-11	9.7E-10	2.1E-12	1.2E-11				3.4E-11
Flex Circuit Sample 3	3.9E-08	3.1E-08	4.6E-10	7.0E-10	5.6E-09	5.4E-11		3.9E-11			5.6E-10
Peek Connector, before bake	1.3E-04	3.6E-05	1.1E-07	8.5E-05	2.0E-06	2.2E-07		6.4E-06	6.4E-08	1.1E-09	3.3E-06
Peek Connector, after bake	7.2E-07	4.0E-07	1.4E-09	2.7E-07	2.4E-08			8.1E-09			1.7E-08

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Five Rules for Good Vacuum

Cleanliness is Next to Godliness!

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Keep the !?d Damn Thing Clean!!!!!

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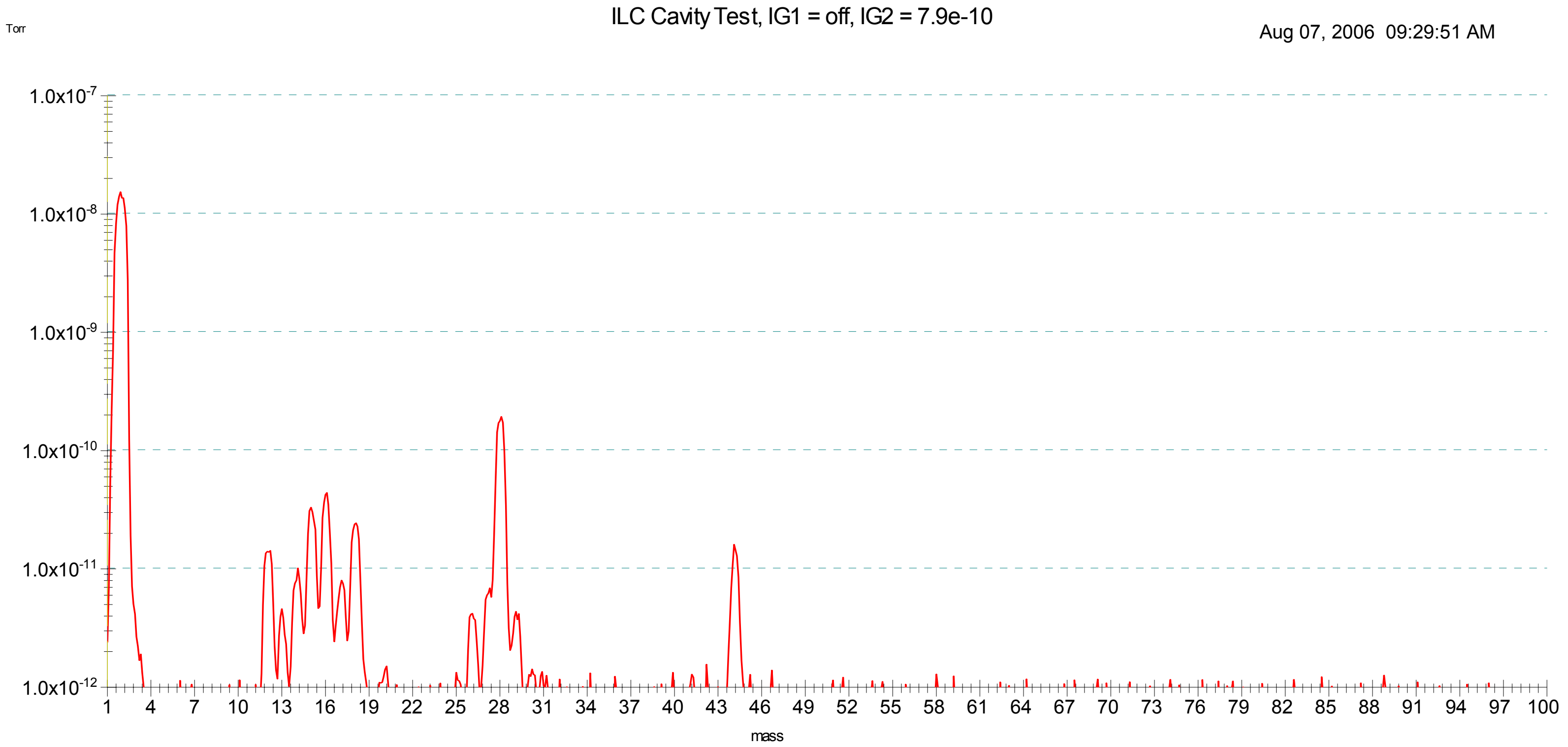
What a Very Clean System Looks Like



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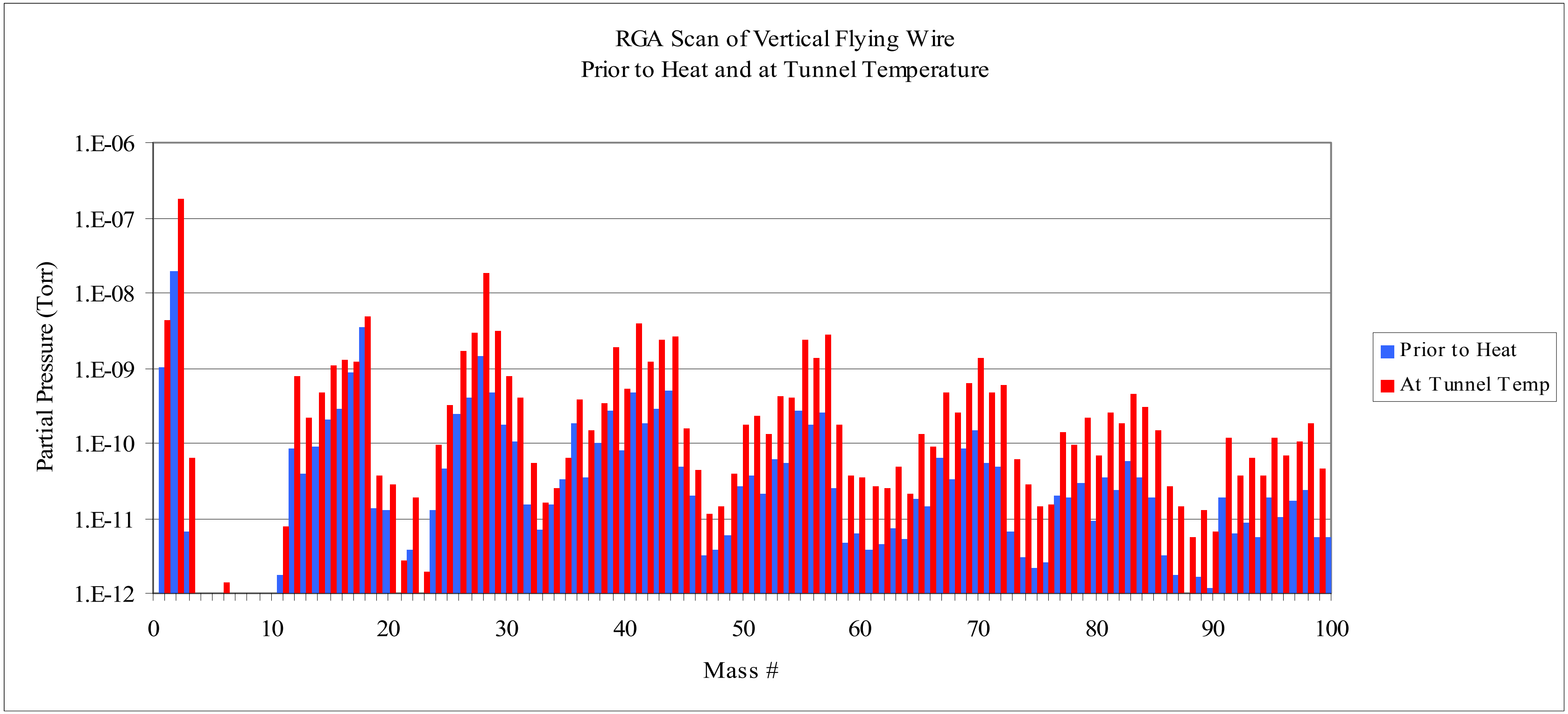
What a Dirty System Looks Like



Cleaning

The best cleaning procedure is the one that works best for your application. There are any number of procedures that work, so be flexible when specifying cleaning procedures. Specify the vacuum performance you want, and then choose the cleaning procedure that works.

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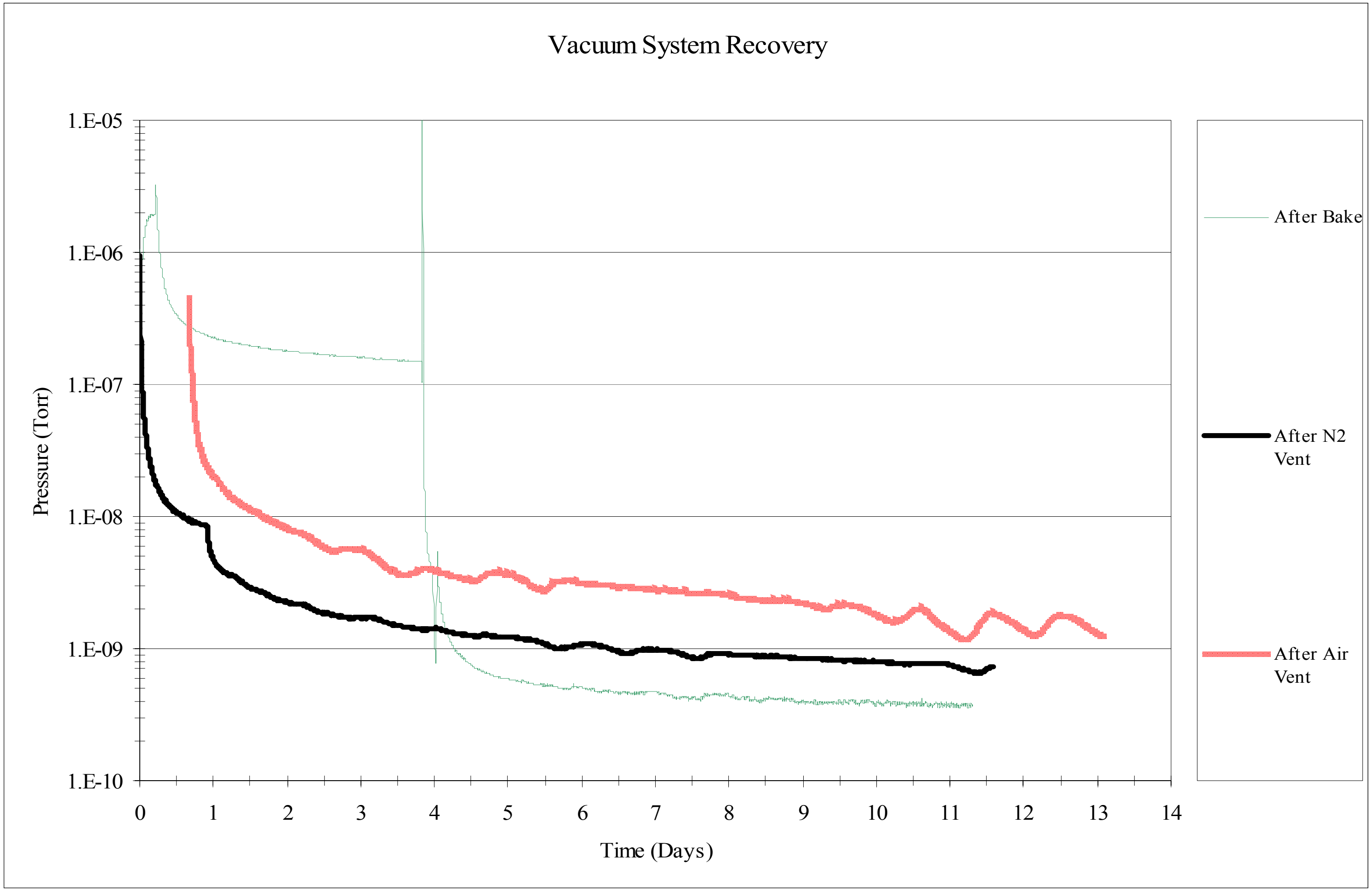
What Happens When We Vent?



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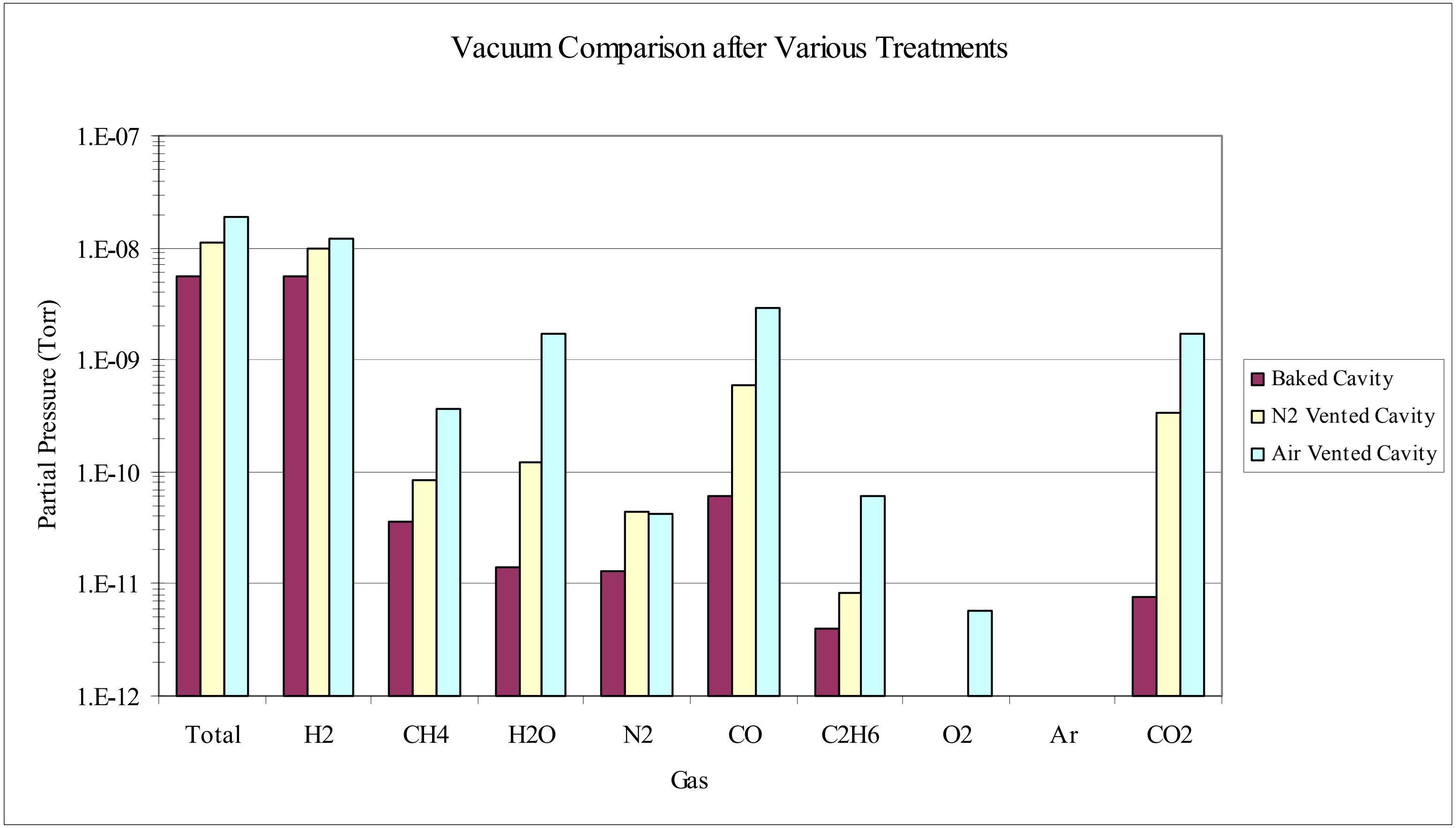
Vacuum Quality



Z for Baked System: 1.1 Z for N2 Vented System: 1.57 Z for Air Vented System: 2.75

Conclusion

The information that has been presented here is very basic in scope and complexity. Even though this is a simplified view of the vacuum systems we use in accelerators, it is important for those of us that design, build, and operate these machines speak the same language and have the same basic understanding of how the different systems interact.

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So, now that you all know everything I know about vacuum, I guess I need a new job. Anybody interested in a new hand built guitar???