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RHIC Detector Beam-Pipe Pressure in Time

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RHIC PROJECT

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RHIC DETECTOR BEAM-PIPE

PRESSURES IN TIME

Kimo M. Welch
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ABSTRACT

The pressures in baked an unbaked experimental beam-pipes are calculated as a function of time. These results exclude gas impact desorption effects stemming from, for example, species created by the colliding beams. Three general cases have been calculated: Case #1: an unbaked system cryopumped by the 4.2° K apertures of the D0 magnets; Case #4: an unbaked system pumped by the 4.2° K apertures of the D0 magnets, and with a 10,000 $\mathcal{L}$/sec LHe cryopump located proximate to the DX magnets in the DX to D0 beam pipes; Case #6: baked beam pipes pumped by the 4.2° K apertures of the D0 magnets and sputter-ion pumps (*i.e.*, SIPs), with non-evaporable getters (*i.e.*, NEGs), bracketing the experimental beam-pipes. The infinite combinations of non-simultaneous system pumpdowns have been excluded as they are impossible to enforce or predict in *the heat* of operation.

INTRODUCTION

System dimensions from the D0 magnets to the Star Detector center are given in Fig. 1. It is assumed that the dimensions of all detector beam pipes will be similar. It can be shown that Fig. 2 has an exact vacuum correspondence with Fig. 1. This circuit analogy simplifies calculations. The locations of hardware in Fig. 2 are defined by *circle-n*, where *n* is some integer.

Several pumping and baking possibilities were explored. These are summarized in Table 1. In all cases, it is assumed that Pipes 3 and 4, including associated bellows, are vacuum fired at ~950° C prior to installation. This serves to reduce problems associated with high H_2 outgassing into the cold-bores.(1)

Cases involving the *in situ* baking of, for example, pipes 4 & 5, without the baking of Pipes 1 & 2, are discarded (*i.e.*, a *half-baked* system is an unbaked system). Also, the use of SIPs and NEGs in unbaked systems at Locations 9, will cause problems as, once these pumps are contaminated by the unbaked system gases, their base pressures will become prohibitively high.

Dimensions of Pipes 1 & 2 of Fig. 2., are much smaller than those of Pipes 3 & 4. Because of this, pumping at the detector pipe is somewhat conductance limited. To facilitate interested readers (*e.g.*, detector technologists) making similar calculations, the mathematical procedure will first be discussed. Then, the results noted in the abstract will be given.

THE ARITHMETIC

The pressure in any long outgassing tube is given by:(2,3)

$$P_x = P_p \frac{\pi\, q(t)}{2kD^2}(2\ell^2 - x^2) \qquad (1)$$

where,
- P_x = the pressure in Torr, at location x,
- P_p = the pump pressure, in Torr.
- ℓ = the length of the pipe from the pump, cm,
- x = distance along the pipe from the pump, cm,
- $q(t)$ = the outgassing rate in time, Torr-$\mathcal{L}$/sec-cm^2,
- D = the diameter of the pipe, cm,
- k = a constant of proportionality; 12.3 $\mathcal{L}$/sec for CO; 45.9 $\mathcal{L}$/sec for H_2; 15.3 $\mathcal{L}$/sec for H_2O.

Outgassing from a smooth, unbaked, clean metal surface follows the equation $q(t_n) \sim q_1 \times (t_1/t_n)$, where n is the number of hours into pumpdown, and q_1 is the outgassing rate at t_1 = 1 hour. The value q(500) ~ 2.5×10^{-11} Torr-$\mathcal{L}$/sec-cm^2.(3) In a long tube having different cross sections along the length, "P_p" must be solved for at different locations along the tube.

For example, in Case #1, the pump comprises the apertures of the D0 magnets. Referring to Fig. 2,

$$P_{p10} = Q_{1-4}/S_{10} \tag{2}$$

where, Q_{1-4} = the outgassing of pipes 1 thru 4, Torr-$\mathcal{L}$/sec,
and, S_{10} = the cryopumping speed of the D0 apertures, $\mathcal{L}$/sec.

The pressure at Location 8 is the superposition of the pressures stemming from (1) relating to Pipe 4 (excluding P_p) and the ΔP along Pipe 4 from the outgassing of Pipes 3 thru 1. With these data, we calculate "P_{p8}", which is the equivalent of a *pump pressure* at Location 8. We thus define the pressure profiles along the pipes of various lengths and cross sections. Solving for the integral of (1) for each pipe, and the average of the ΔP for that pipe, we progress down the pipe until finally reaching P_x of Fig. 2.

When locating pumps at various locations along the pipes, things are a little more complicated. Assume, for example, that a pump is placed at Location 8. In this case, (1) must be applied in both directions from Location 8, and also from the D0-aperture cryopump. This leads to some simultaneous equations describing the system asymmetries. That is:

$$S_8 P_8 = q_4 \pi D_4 y + Q_{1-3} \tag{3}$$

$$P_? = P_8 + \frac{q_4 \pi y^2}{2kD_4{}^2} \tag{4}$$

$$S_{10} P_{10} = q_4 \pi D_4 x \tag{5}$$

$$P_? = P_{10} + \frac{q_4 \pi x^2}{2kD_4{}^2} \tag{6}$$

$$L_4 = x + y \tag{7}$$

Pressure $P_?$ is the location in Pipe 4 where $dP/dx = 0$ (*i.e.*, at location x).

RESULTS OF CALCULATIONS

Case #1 results, are given in Fig. 3. They apply to the STAR detector system. The unbaked system is cryopumped by the 4.2° K apertures of the D0 magnets. Outgassing rates for clean, unbaked stainless steel surfaces are given elsewhere.[(3)] Gas species proportions, after 500 hours of pumping, are given in Fig. 3.[(3)] If <u>all</u> components of the system undergo high temperature vacuum firing prior to installation, the H_2 partial pressure would be at least ×15 lower. However, this will probably not be possible for Pipes 1 & 2.

Case #4 results are also given in Fig. 3. In this case a 10,000 $\mathcal{L}$/sec LHe cryopump is placed at Location 8. At all times the average pressure in the beam pipe from D0 to the center of the detector is improved by ×6.45, and that of the experimental beam pipe by ×3.25 on using the cryopump at Location 8.

For Cases #6a & #6b it was assumed that the H_2 outgassing rates of Pipes 3 & 4 were 2×10^{-13} Torr-$\mathcal{L}$/sec-cm^2. For Case #6a is was assumed that the H_2 outgassing rates of Pipes 1 & 2 were 1×10^{-12} Torr-$\mathcal{L}$/sec-cm^2. For Case #6b, assumed H_2 outgassing rates of Pipes 1 & 2 were 5×10^{-12} Torr-$\mathcal{L}$/sec-cm^2. In both cases, it is assumed that all parts were *in situ* baked at ~250° C for 48 hours. In Cases #6a & #6b, a 300 $\mathcal{L}$/sec, combination SIP and NEG is located on the detector side of Valve 9. A small holding pump, at Location 8, pumps Pipes 3 & 4 when valves 9 & 10 are closed. Results, about 48 hours after an *in situ* bakeout of Pipes 1 thru 4, are as follows:

Average H_2 pressure from D0 magnet entrance to detector center:
Case #6a: 1.9×10^{-10} Torr H_2,
Case #6b: 8.3×10^{-10} Torr H_2.

Average H_2 pressure in the six meters of experimental beam pipe:
Case #6a: 5.4×10^{-10} Torr H_2,
Case #6b: 2.5×10^{-9} Torr H_2.

The gases CH_4, CO and CO_2 in total will comprise $\lesssim 10\%$ that of H_2.

CONCLUSIONS

Pressures many orders in magnitude are quickly gained by vacuum baking systems leading to and including experimental regions. Data for Cases #1 & #4 *are the very best results to be expected* without some sort of glow discharge cleaning. In all cases, the presence of organic contaminants in any of Pipes 1 thru 4 will be most detrimental to the average pressures in these regions. The *Blears Effect* can often make such contaminants undetectable to all but the beam at room temperature.

REFERENCES

1) Hobson, J.P., Welch, K.M., "Time-Dependent Hydrogen and Helium Pressure Profiles in a Long, Cryogenically Cooled Tube, Pumped at Periodic Intervals", Informal Report BNL-47343, August 1992.
2) Welch, K.M., Capture Pumping Technology, An Introduction, (Pergamon Press, Ltd., Oxford 1992), p 35.
3) Welch, K.M., "The Pressure Profile in a Long Outgassing Vacuum Tube", Vacuum 8, 271(1973).

Table 1. Pumping Requirements From Magnets D0 Through the Experimental Areas

PIPES 3, 4, & 5	PIPES 1 & 2	PUMP AT 9	PUMP AT 8	DETECTOR	CALCULATIONS
NOT BAKED	NOT BAKED	NO	NO	STAR	Case 1
BAKED	NOT BAKED	NO	NO	STAR	Little Value
BAKED	BAKED	NO	NO	PHOENIX, et al	Case 2
NOT BAKED	NOT BAKED	YES	NO	STAR	Pump 9 Problem
BAKED	NOT BAKED	YES	NO	STAR	Pump 9 Problem
BAKED	BAKED	YES	NO	PHOENIX, et al	Case 3
NOT BAKED	NOT BAKED	NO	YES	STAR	Case 4
BAKED	NOT BAKED	NO	YES	STAR	Little Value
BAKED	BAKED	NO	YES	PHOENIX, et al	Case 5
NOT BAKED	NOT BAKED	YES	YES	STAR	Pump 9 Problem
BAKED	NOT BAKED	YES	YES	STAR	Little Value
BAKED	BAKED	YES	HOLDING	PHOENIX, et al	Case 6

Pump No.	H2 Speed L/sec	H2O Speed L/sec
8	300	300
10	2000	10700

"d0toexp"

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Figure 1. Vacuum hardware parameters from D0 magnet to experimental area.

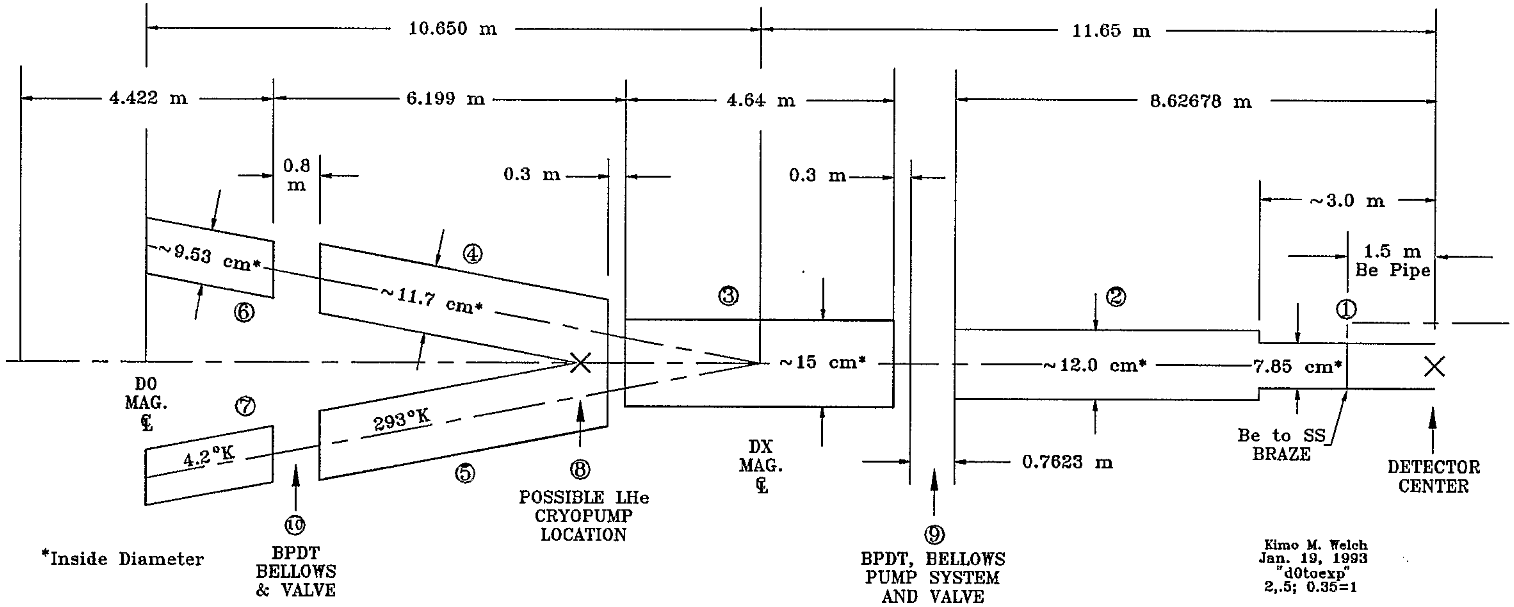
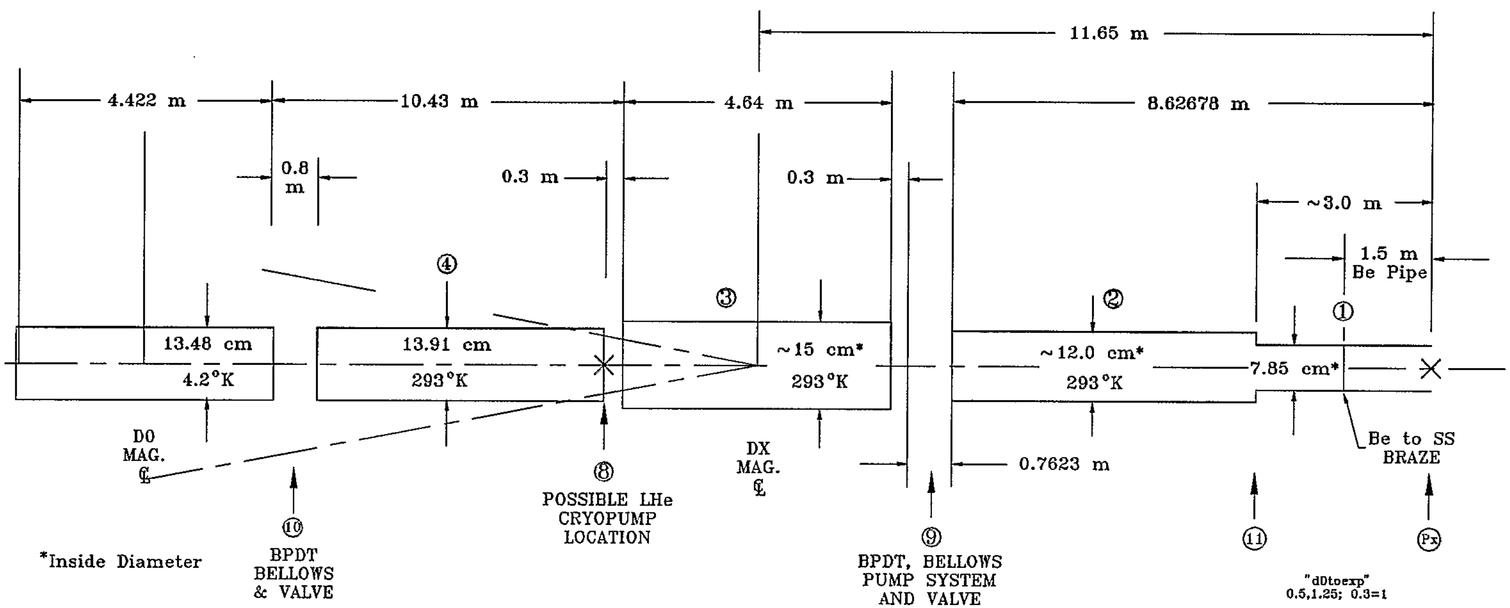


Figure 2. Vacuum equivalent of hardware from D0 magnet to experimental region.



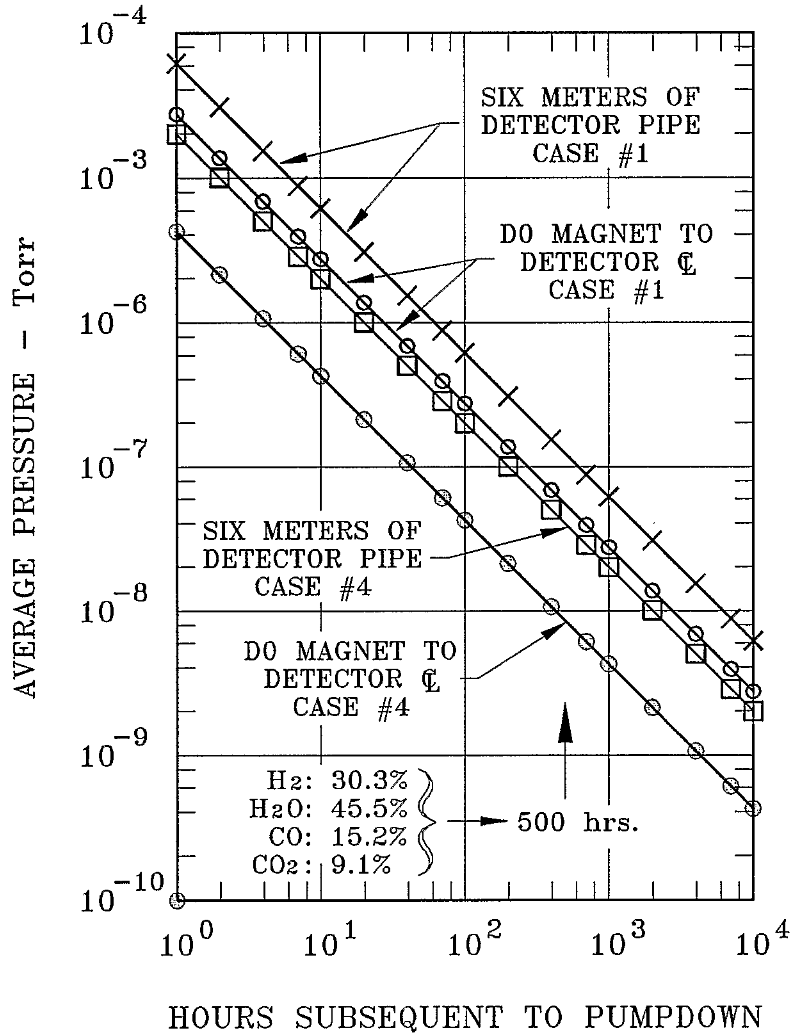


Figure 3. Average pressure in experimental beam pipe, and in accelerator from entrance to D0 magnets to center of experimental beam pipe.

Case #1: Cryopumped only by D0 apertures.

Case #4: Additional pumping of 10,000 L/sec cryopump at DX.

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1,25,1.25; 0.75=1