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Informal Report

MODELING OF RHIC INSULATING VACUUM

FOR

SYSTEM PUMPDOWN CHARACTERISTICS

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ABSTRACT

This paper presents a model for predicting the pumpdown characteristics of a 480 m RHIC (Relativistic Heavy Ion Collider) vacuum cryostat. The longitudinal and transverse conductances of a typical cryostat were calculated. A voltage analogue of these conductances was constructed for room temperature conditions. The total longitudinal conductance of a room temperature cryostat was thereby achieved. This conductance was then used to calculate the diameter of an equivalent long outgassing tube, having more convenient analytical expressions for pressure profiles when pumped. The equivalent of a unit outgassing rate for this tube was obtained using previously published MLI (multi-layer insulation) outgassing data. With this model one is then able to predict a cryostat pumpdown rate as a function of the location and size of roughing pumps.

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I. INTRODUCTION

The RHIC (Relativistic Heavy Ion Collider), is a superconducting particle collider that operates at cryogenic temperatures. The main arc sextants of each of the two rings comprise various types of superconducting magnets which are housed within vacuum cryostats. These twelve cryostats are each 480 meters long (Fig. 1). Each sextant is a complex arrangement of thermal shields, MLI, and cold mass assemblies (Fig. 2). This system may be accurately modeled with a voltage analogue.[1] The main outgassing constituent is H_2O, which comes from the $\approx 4\text{x}10^9$ cm^2 of MLI contained within each cryostat. A simplified model was needed to calculate the expected pumpdown rate through this complex cryostat labyrinth. Insight into probable pumpdown rates facilitates differentiation between MLI outgassing and the existence of possible leaks.

This paper is divided into three sections. The first section deals with modifying an existing voltage analogue,[2] applicable to longitudinal and transverse cryostat conductances at operating temperatures, to a room temperature cryostat system equivalent. The second section deals with modeling the cryostat room temperature equivalent conductances into a single long tube equivalent.[3] The third section uses the published outgassing rates of the MLI,[4] to define an equivalent unit outgassing rate to apply to the equivalent long tube formula. Results of cryostat pumpdown calculations are then given.

II. THE VOLTAGE ANALOGUE (Determining cryostat conductance)

A cross section of the magnet cryostat is shown in Fig. 3. There are three distinct regions which are bounded by the MLI and thermal shield. These regions communicate with one another through transverse conduits, first proposed by Welch in 1990. These conduits, located at every magnet interconnect, create a transverse coupling of the three longitudinal conductances, which facilitates the rapid pumpdown of all interconnecting regions. With the appropriate instrumentation and pumping, they also enable one to locate He leaks into the cryostat with the required longitudinal resolution.

A resistor circuit of a 480 meter long cryostat was created with estimated impedances for room temperature H_2O. Fig. 4 shows the resistor network, which consisted of 24 Half-Cells (one Dipole & one Quadrupole magnet). Table 1 shows the resistor values and their equivalent conductances. These values were obtained by converting the values for He at 4.2°K to those of H_2O at room temperature in the following way,

$$R_{(H_2O,293°K)} = R_{(He,4.2°K)}\sqrt{\left(\frac{18}{4}\right)\left(\frac{4.2°K}{293°K}\right)} \quad . \tag{1}$$

The resistance of the network measured 158 Ω/meter, with a corresponding conductance of,

$$C = (l\text{x}158)^{-1} \text{ x } 1.0\text{x}10^6 \;\; l/\text{sec.} \tag{2}$$

III. THE LONG OUTGASSING TUBE

With the conductance and length of the cryostat known, the diameter of a simple round tube was calculated to give the same conductance as that of the cryostat. This diameter was calculated using the following formula,

$$C = k\frac{D^3}{L} \quad , \qquad (3)$$

where, C = conductance of cryostat (l/sec),
L = length of cryostat (cm),
D = diameter of equivalent tube (cm),
k = constant dependant on molecular weight and temperature.

In this case,

$$k_{water} = 12.1\sqrt{\frac{28.8}{18}} \quad l/\sec\text{-}cm^2 \ . \qquad (4)$$

Solving for D yields a long tube with a diameter of 34.8 cm.

With pumps of equal speed, the pressure profile will be symmetrical between pumps. No net gas flows at a point equidistant between pumps, so the problem is reduced to studying a long tube pumped at one end, as shown in Fig. 4.

The pressure at the pump, P_p, is a function of pump speed, S_p, and can be expressed by,

$$P(t)_p = 2\frac{Q(t)}{S_p} \quad , \qquad (5)$$

where,

$$Q(t) = q_e(t)\pi D l \ . \qquad (6)$$

In this case, Q(t) is the total outgassing rate of the MLI over length l, which gives the equivalent unit outgassing rate, $q_e(t)$, of the imaginary long tube. The pressure profile along the tube is given by,

$$P(t,x) = P_p(t) + \frac{\pi q_e(t)}{2kD^2}(2xl - x^2) \ . \qquad (7)$$

On integrating (7), we obtain the average pressure in the long tube. This is given by,

$$P(t)_{avg.} = P_p(t) + \frac{2}{3}\left[\frac{\pi q_e(t) l^2}{2kD^2}\right] . \tag{8}$$

In one 480 meter cryostat the total area of REEMAY, A_R, is $\approx 2.3\text{x}10^9$ cm^2, and the total area of DAM, A_D, is $\approx 1.9\text{x}10^9$ cm^2. The measured unit outgassing rate of the DAM vs. time, $q_D(t)$ is given in Fig. 6, and that of the REEMAY, $q_R(t)$ is given in Fig. 7. Using these data and (6), we establish the unit outgassing rate to be,

$$q_e(t) = \frac{(q_R(t)A_R + q_D(t)A_D)}{\pi DL} , \tag{9}$$

where, L = The total length of the cryostat.

IV. RATE OF PUMPDOWN

Using (8) and (9), the cryostat pressure as a function of time may be determined based on the speed and number of equidistantly spaced pumps. The speed of the pumps were held constant over the entire pressure range. The time to rough down the cryostat from atmosphere was relatively small, and therefore neglected. Figure 8 gives results for two extreme pumping conditions, along with an intermediate case for comparison. Tables 2-4 give pumpdown durations for a wider variety of pump sizes and for pump quantities ranging from one to four.

V. CONCLUSIONS

This model has characterized the pumpdown of a RHIC insulating vacuum sextant (480 meters) as a function of the number of pumps and their size and speed. We have concluded that four pumps with a speed of $\approx$ 100 *l*/sec will achieve a satisfactory pumpdown rate. These pumps will be fitted with cold traps to achieve this speed, as well as protect the pumps from the roughly 34 kilograms of water contained in each 480 meter cryostat.[4]

This model was used to predict the pumpdown of an SSC dipole. When compared to the actual pumpdown rate, the model showed a much shorter pumpdown rate. This is primarily due to the orientation of the insulation in the SSC cryostat. The orientation of the MLI for the outgassing tests, which the model is based on, was more loosely packed than in an actual SSC or RHIC magnet. The orientation of the MLI is an important variable that must be considered when applying this model to an MLI system.

1. Welch, K.M., Capture Pumping Technology, (Pergamon Press Inc., New York, 1991), p.28.

2. Welch, K.M., et al. "Comments on Leak Checking RHIC Components and Assemblies", (in preparation).

3. Welch, K.M., "The Pressure Profile In A Long Outgassing Vacuum Tube," Vacuum 23, 271 (1973).

4. Todd, R.J., Pate, D., Welch, K.M., "Outgassing Rate of Spunbonded Polyester and Dupont Double Aluminized Mylar", Brookhaven National Laboratory, Upton, NY, (1992).

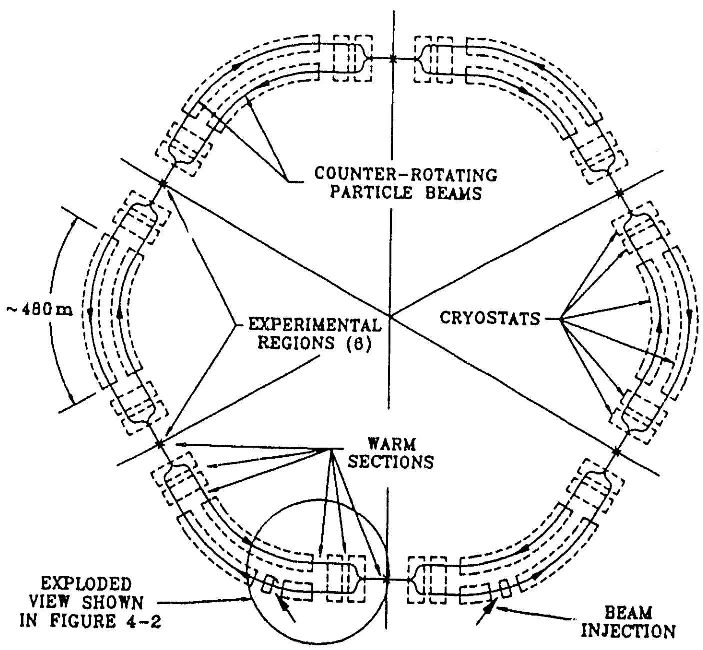


Figure 1. The Brookhaven Relativistic Heavy Ion Collider.

"rhicring"
0.4=1; 1.5,2
Kimo M. Welch

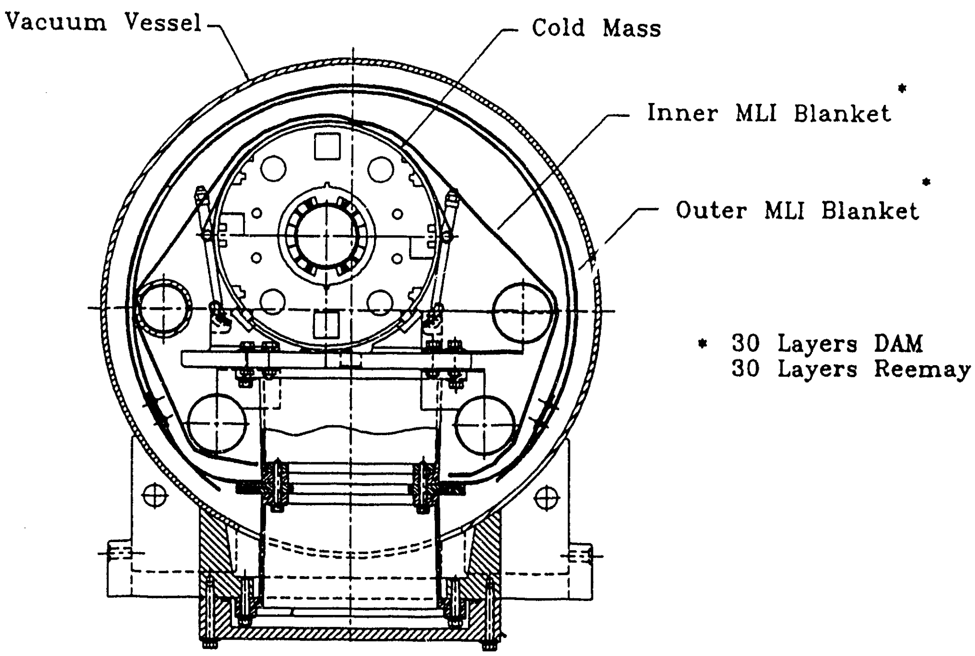


Figure 2. Cross Section of 480 Meter Cryostat.

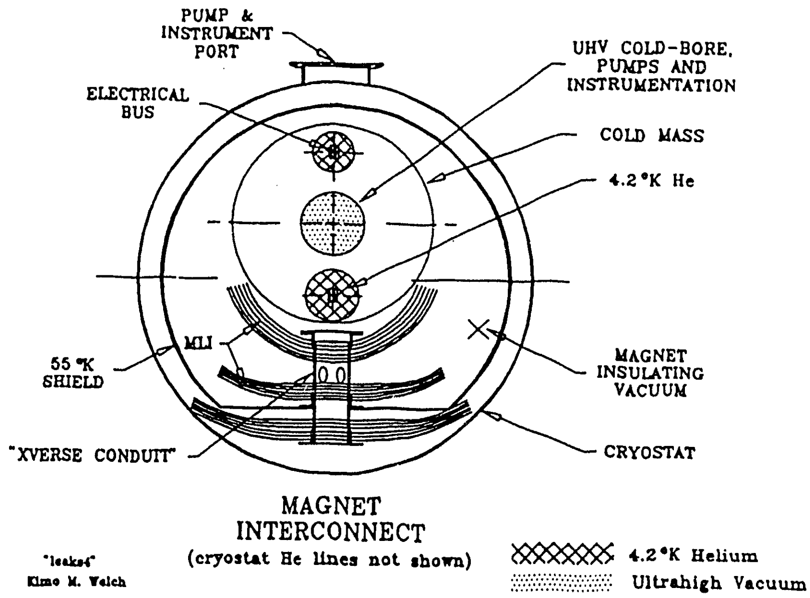


Figure 3. Transverse Conduit used to Vacuum "Couple" Instrumentation or Turbopumps to Magnet Interconnect.

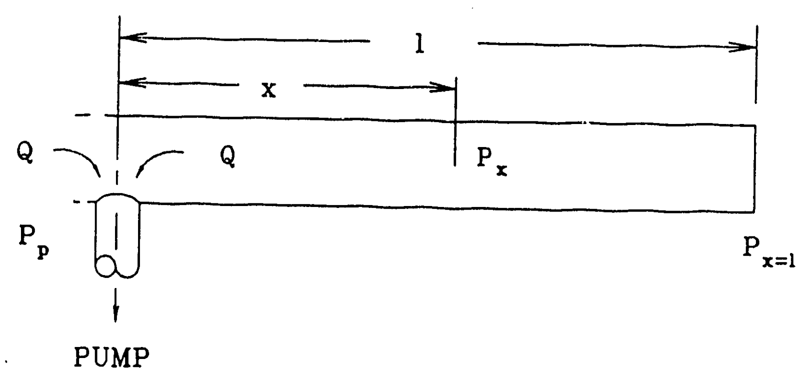
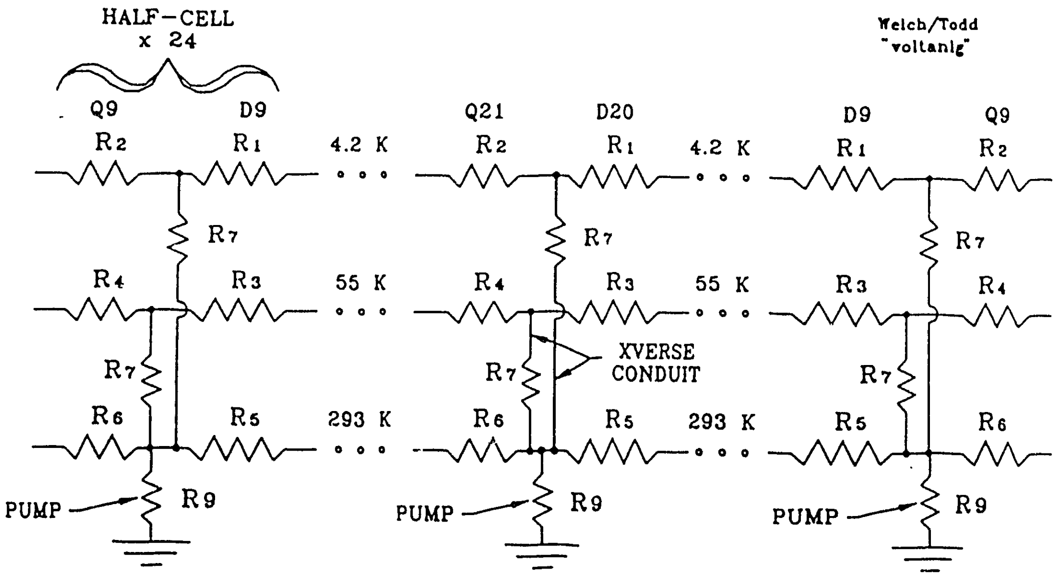


Figure 5. Long Outgassing Tube

Figure 4. Voltage analogue of 360 meter RHIC cryostat.



ALL CASES RESISTOR	EQUIV. IMPEDANCE K Ohm	SPEED OR CONDUCTANCE *l*/sec
R_1	3.08	325
R_2	1.00	1000
R_3	6.25	160
R_4	2.48	403
R_5	9.12	110
R_6	4.24	236
R_7	9.19	109
R_9	OPEN	0

Table 1. Vacuum Impedences in a 480 Meter Cryostat.

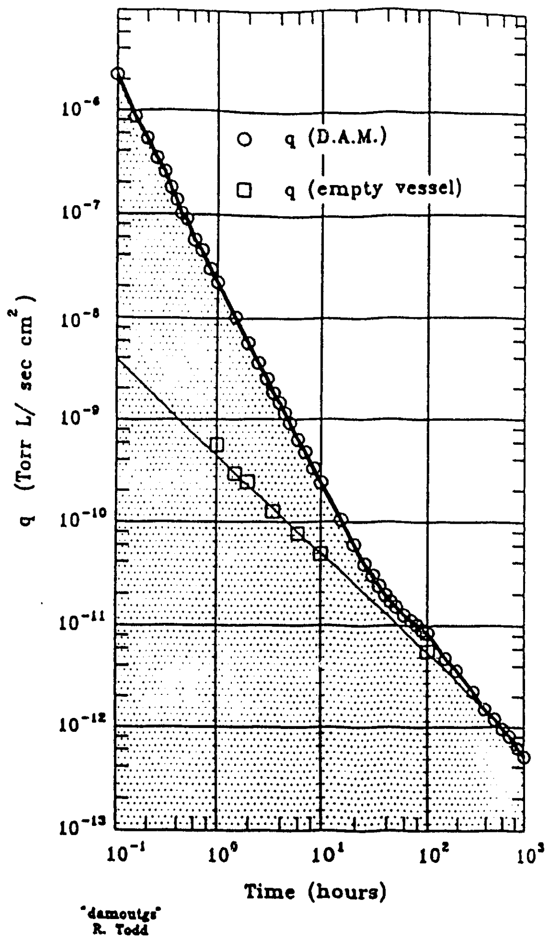


Figure 6. DAM Outgassing Rate vs. Time.

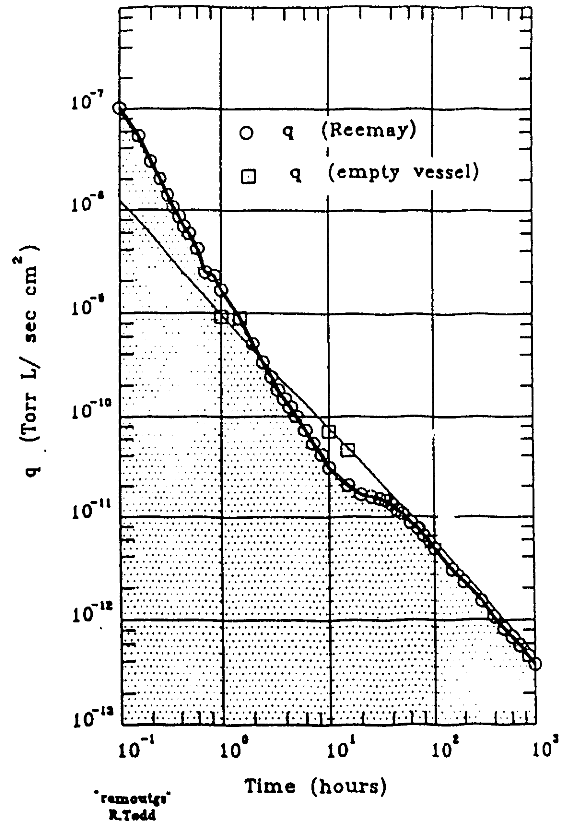


Figure 7. Reemay Outgassing Rate vs. Time.

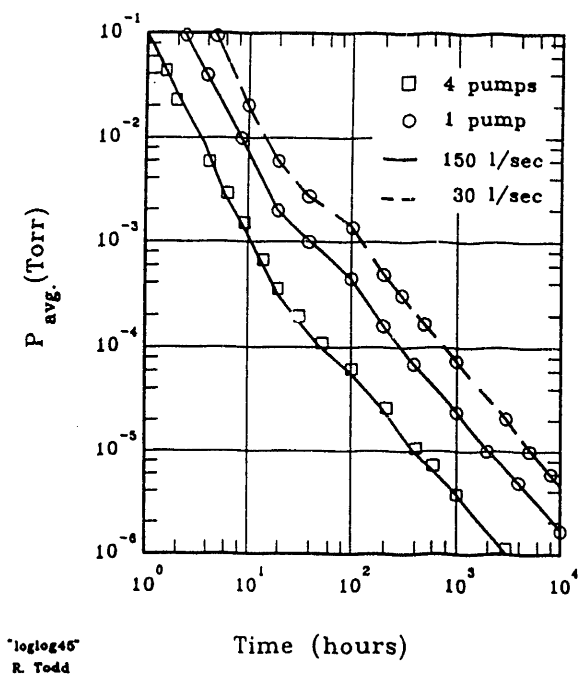


Figure 8. Rate of pumpdown for a 480 meter cryostat.

PUMP QTY.	PUMP SPEED (*l*/sec)				
	30	60	90	120	150
1	91	62	47	40	36
2	49	28	22	19	17
3	33	20	16	14	13
4	25	17	14	12	11

Table 2. Time (hours) to reach $1x10^{-3}$ Torr.

PUMP QTY.	PUMP SPEED (*l*/sec)				
	30	60	90	120	150
1	677	489	383	337	300
2	394	249	179	145	132
3	285	156	122	96	81
4	220	125	87	67	55

Table 3. Time (hours) to reach $1x10^{-4}$ Torr.

PUMP QTY.	PUMP SPEED (*l*/sec)				
	30	60	90	120	150
1	4867	3631	2848	2511	2239
2	2935	1840	1447	1105	932
3	2000	1254	847	699	599
4	1705	875	647	525	444

Table 4. Time (hours) to reach $1x10^{-5}$ Torr.

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