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Information for the Beam Tube Pump-down

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Table 1: Beam Tube Parameters

Volume of a 2km module	2.42 x 10^6 liters
Area of a 2km module	7.8 x 10^7 cm^2
Number of pump ports	9
Nominal spacing of the pump ports	250 meters
Pump port aperture (ID)	25.4 cm
Pump port length	6.4 cm

Table 2: Pumping system geometric parameters

Total length of 10 inch tubing from tube to turbo pump	161 cm
Total length of 10 inch tubing from tube to LN_2 trap	45 cm
Total length of 10 inch tubing from tube to roughing pump	117 cm
Total length of 6 inch tubing in roughing line	97 cm

Table 3: Turbo pump characteristics: Edwards STPH 2000C

gas	*cat. pumping speed*	*compression*	$\alpha\ 1/(\sqrt{amu})$	*meas.pumpingspeed*
N_2	2000 liters/sec	$> 10^8$	> 3.48	1100 to 1300 liters/sec
H_2	1600	10^3	4.89	
He	1800	10^4	4.60	

$$\text{compression} = e^{vg\sqrt{m/(kT)}} = e^{\sqrt{\alpha\text{amu}}}$$

Table 4: Calibration parameters

N_2 calibrated leak	1.1 x 10^{-6} torr liters/sec
H2 calibrated leak	4.1 x 10^{-6} torr liters/sec
Calibration volume	1 liter
Calibration gases	CH_4, CO, CO_2, He, Kr

Table 5: Outgassing Properties

gas	*outgas rate*	*module gas load*	*pumping speed/end*	*1/F*	*1/v*	*avg pressure*
	torr liters/sec cm^2	*torr liters/sec*	*liters/sec*			*torr*
H_2O	1.2 x 10^{-8}/t(hr)	0.9/t(hr)	5020 (LN_2)	7.8	49.4	6.85 x 10^{-4} /t(hr)
			646	60.4	49.4	1.32 x 10^{-3} /t(hr)
H_2	3.0 x 10^{-14}	2.4 x 10^{-6}	930	41.9	16.7	1.8 x 10^{-9}
CO	6.0 x 10^{-11} /t(hr)	4.7 x 10^{-3} /t(hr)	580	67.2	61.6	7.7 x 10^{-6} /t(hr)
CO_2	5.0 x 10^{-11} /t(hr)	4.0 x 10^{-3} /t(hr)	513	76.0	77.2	7.6 x 10^{-6} /t(hr)
Hydrocarbon 41,43,55,57	< 2.2 x 10^{-11} /t(hr)	<1.7 x 10^{-3} /t(hr)	500	78.0	116.0	<4.3 x 10^{-6} /t(hr)
CH_4	< 1.0 x 10^{-13}	< 8.0 x 10^{-6}	685	57.0	46.6	<1.1 x 10^{-8}

Parabolic profile with only end pumping

$$P(x) = J\left(\frac{\pi La}{F} + \frac{L^2}{va^2}\left(\frac{3}{8} - \frac{3}{2}x^2\right)\right).$$

$$0 \le x \le 0.5$$

x = normalized distance from the middle of the module = 0.5 at pumps

P(x) = pressure in torr

J = outgassing rate in torr cc/sec cm^2

L = module length in cm

a = radius of tube = 62 cm

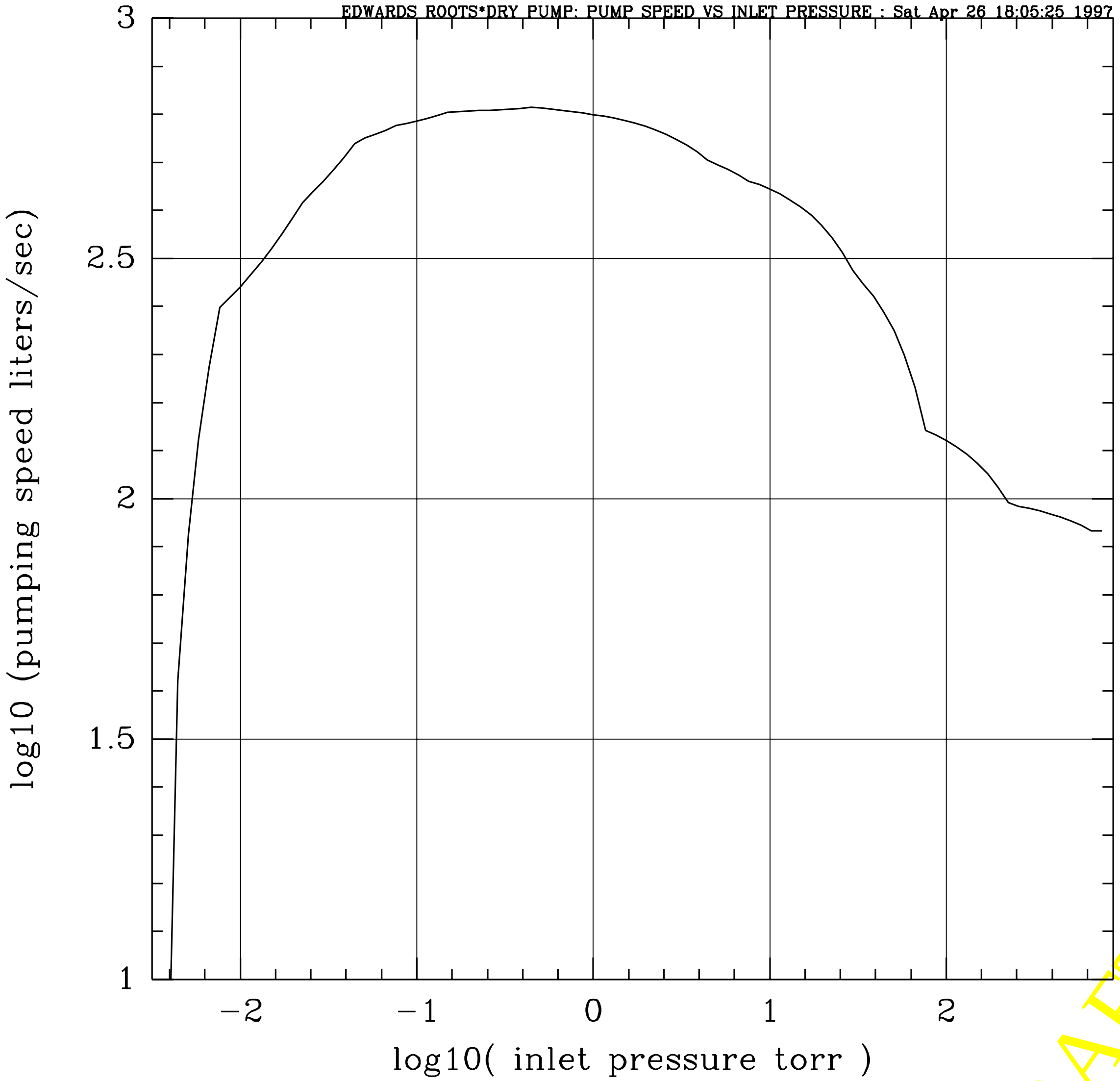
v = molecular speed at temperature = 4.22 x 10^4 $\sqrt{\frac{28}{\text{amu}}}\sqrt{\frac{T}{296K}}$ cm/sec

F = end pumping speed in cc/ sec

The average pressure along the tube is given as

$$\langle p \rangle_L = J\left[\frac{2\pi a L}{nF} + \frac{L^2}{4va^2(n-1)^2}\right]$$

n = the number of pumps on the module (assumed evenly spaced)



Edwards Roots Pump EH2600 * Dry Rough Pump EDP 200

Figure 1 Relation between pumping speed and inlet pressure of the combined Edwards roots * dry pump used on the LIGO roughing pump carts.

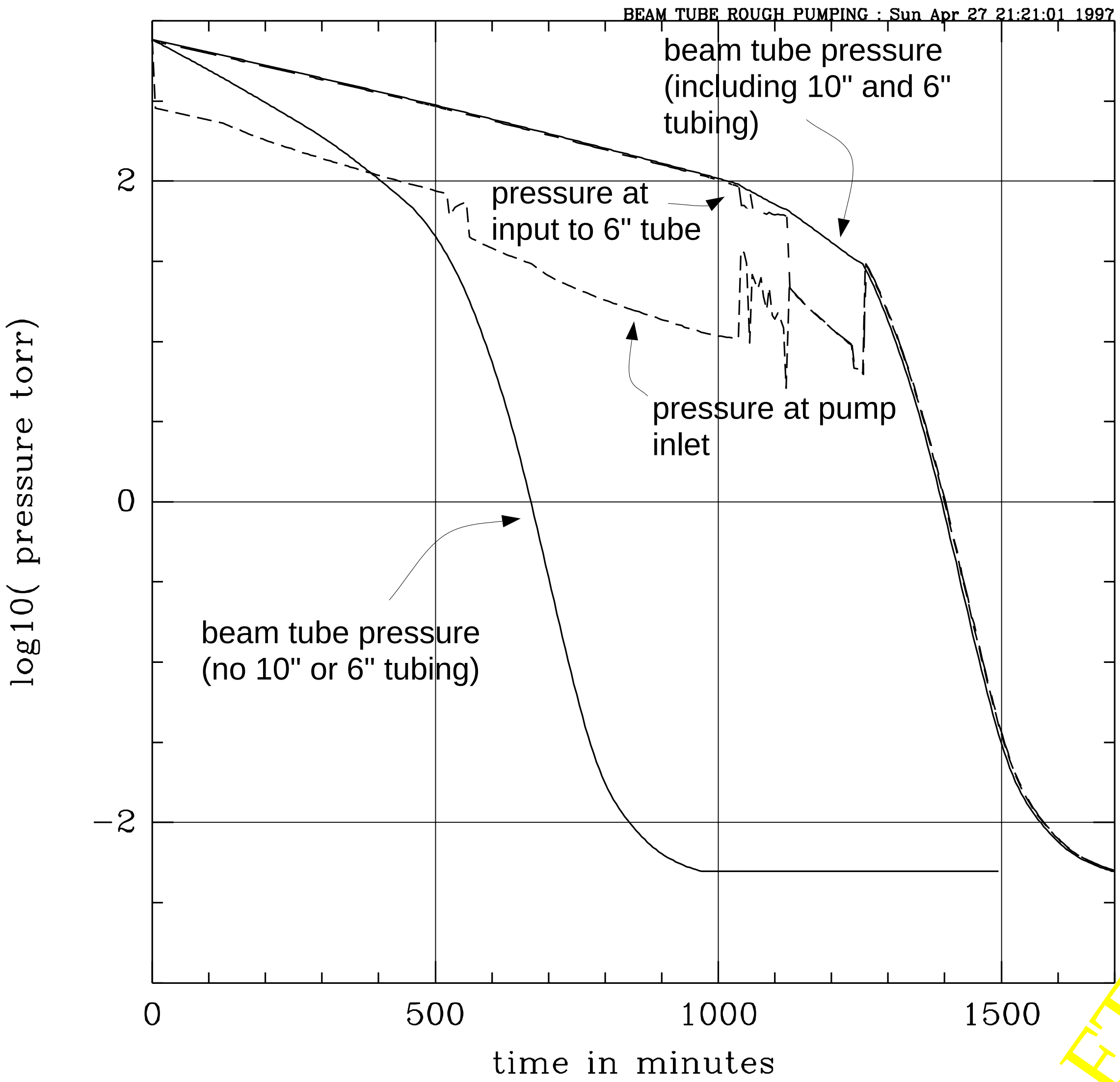


Figure 2 Beam tube rough pumpdown. The curve at the left is the fastest pump down possible with the present roughing carts providing there is no constriction in the tubing between the cart and the beam tube. The solid curve on the right is the best estimate for the rough pump down using the vacuum plumbing in **Table 2**. The dotted curve shows the pressure at the roots pump inlet on the assumption that the flow in the 6 inch tube is turbulent (Reynolds number greater than 2200). When the beam tube gets close to 80 torr (1050 minutes) the flow in the 6 inch tube makes a transition from turbulent to laminar. At about 1100 minutes the transition occurs in the 10 inch tube. The computer program that generated the curves became unstable in these regions because of the specific shape of the roughing pump flow vs pressure relations (**Figure 1**). The real system

should be watched closely at these times since it is possible that, it too will become unstable. The instability should be accompanied by an acoustic oscillation as the pressure varies rapidly at the roughing pump inlet. Should this occur it would be worth considering throttling the system at the pump inlet to avoid damage to the roots blower. Once the system has established laminar flow there is little pressure drop across the 10 and 6 inch tubing.

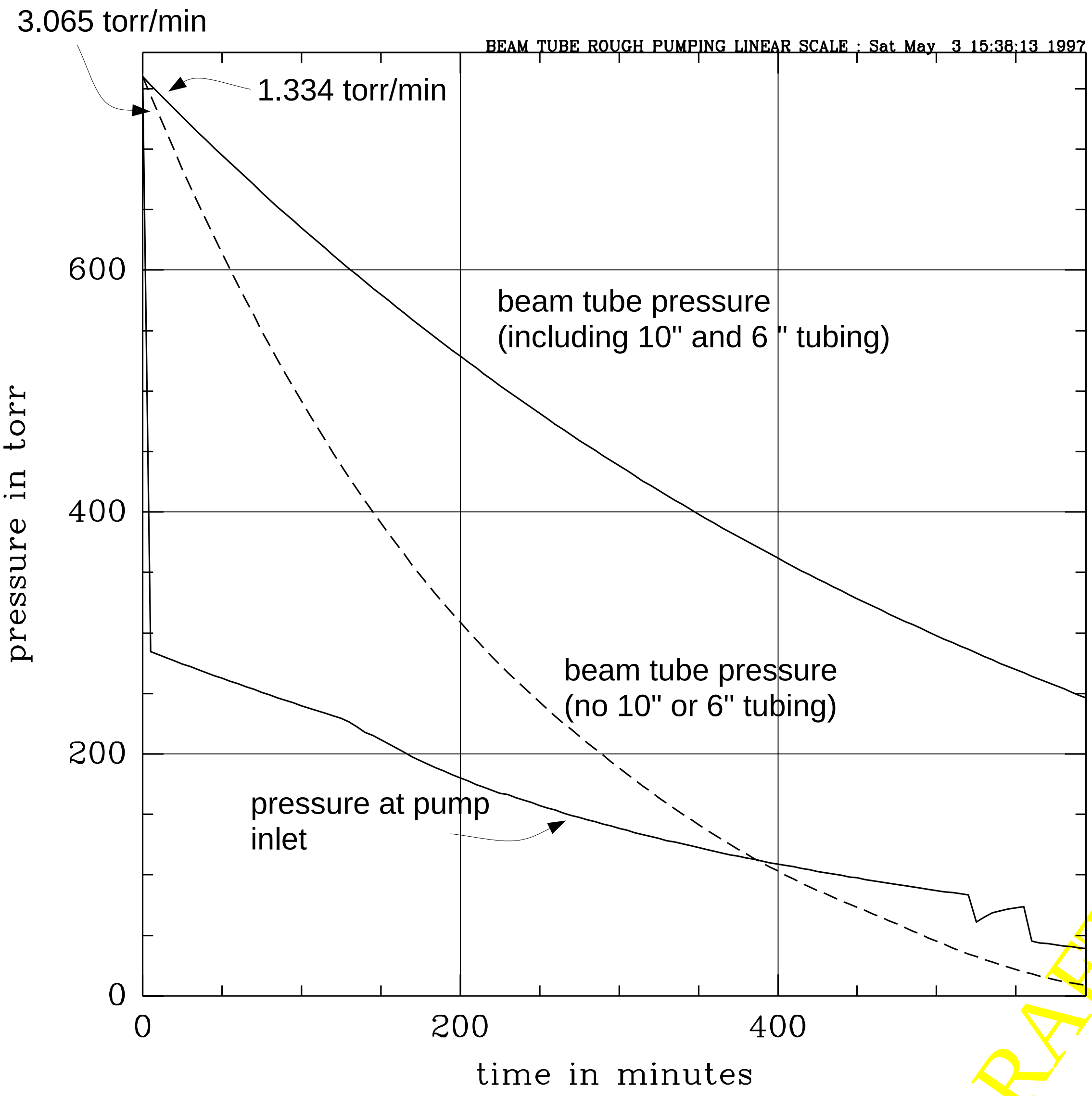


Figure 2a Linear version of **Figure 2** showing the initial pumpdown slopes.

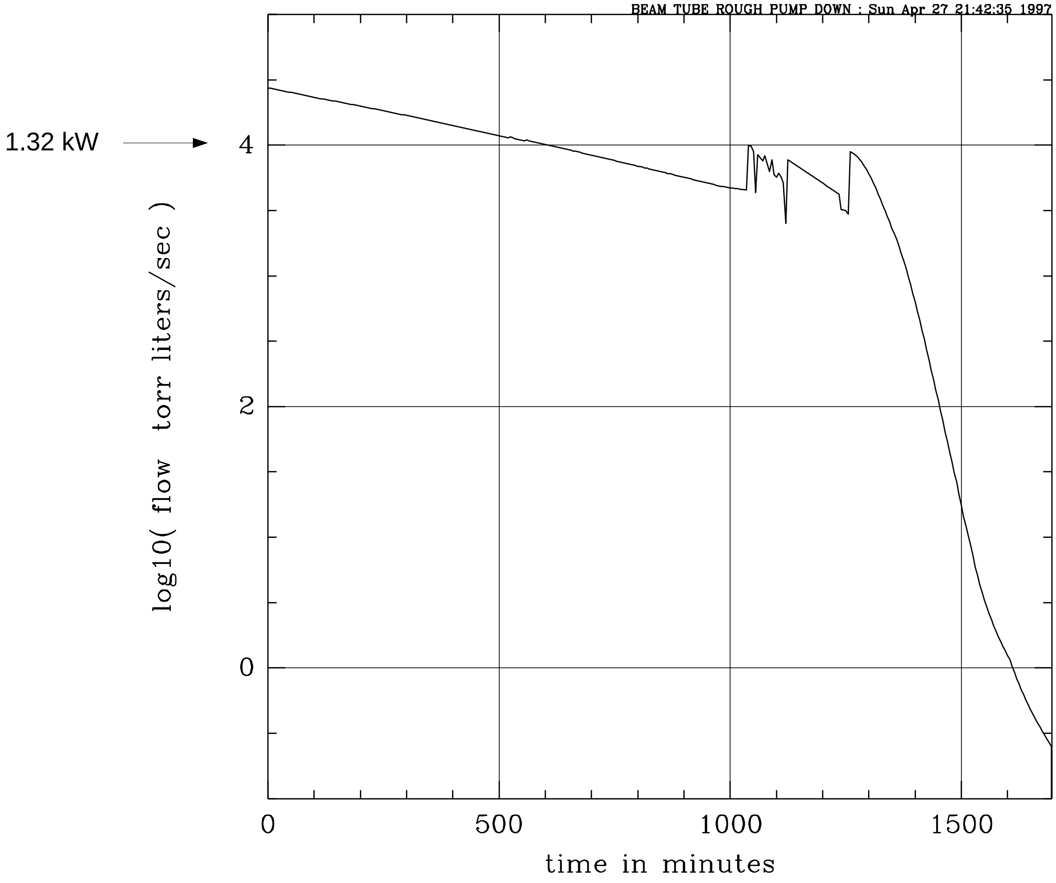
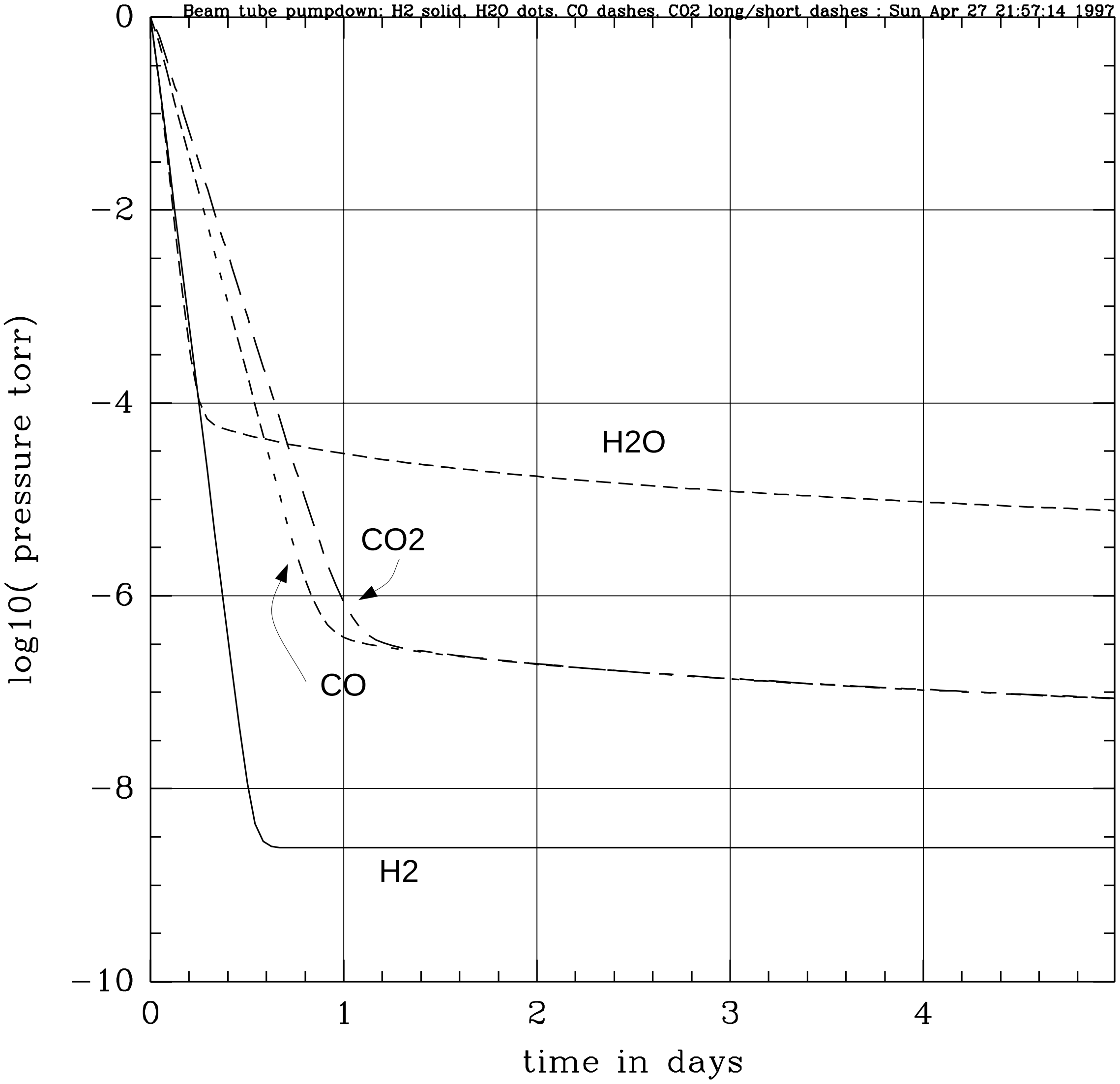
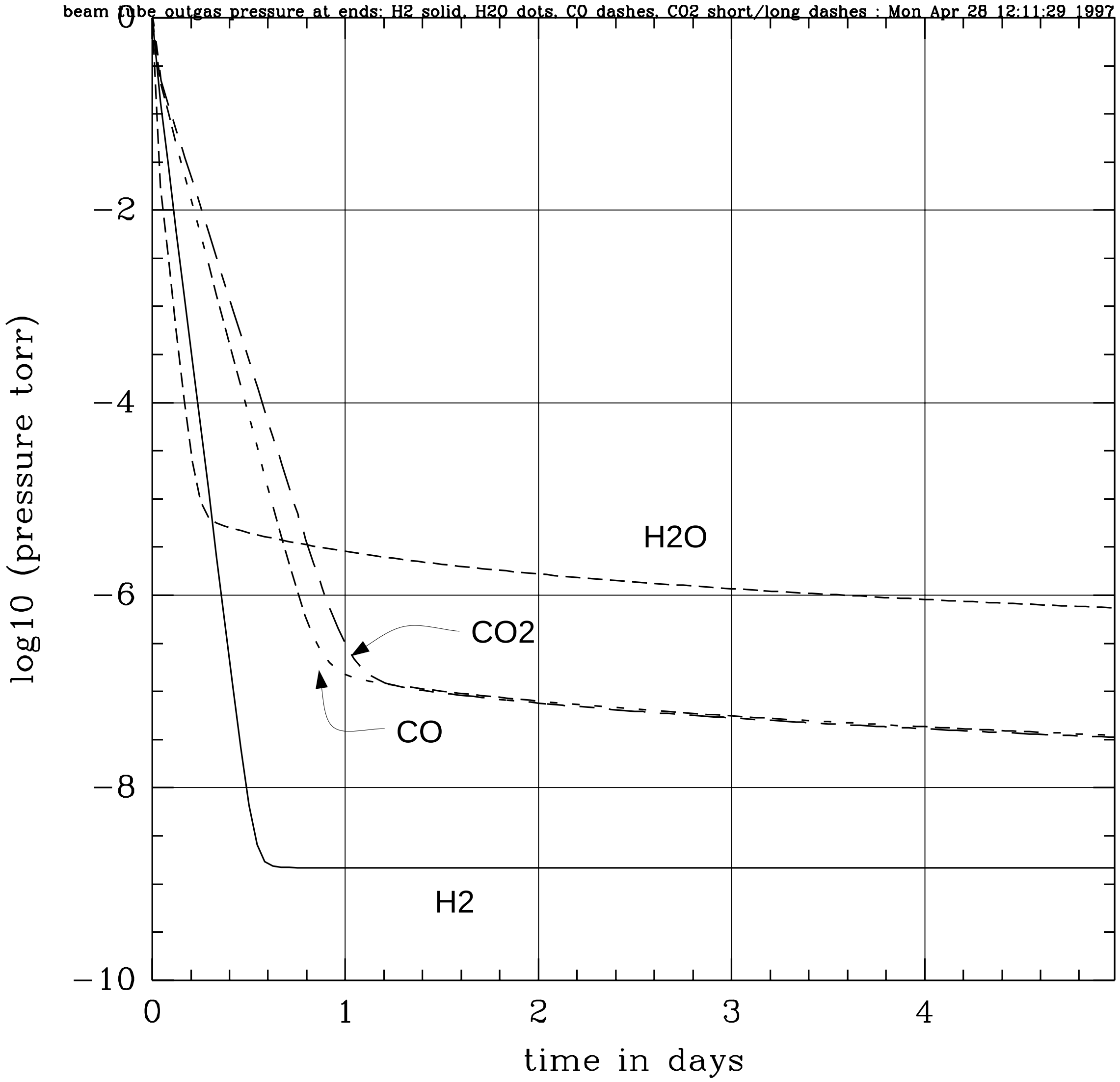


Figure 3 The flow in torr liters/sec through the pump during the rough pump. The peak power put into the gas is close to 5 kW . The efficiency of the pumps will not be larger than 50% so we need to be prepared to put at least 10 kW into the pumps for a sustained period of about 600 minutes.



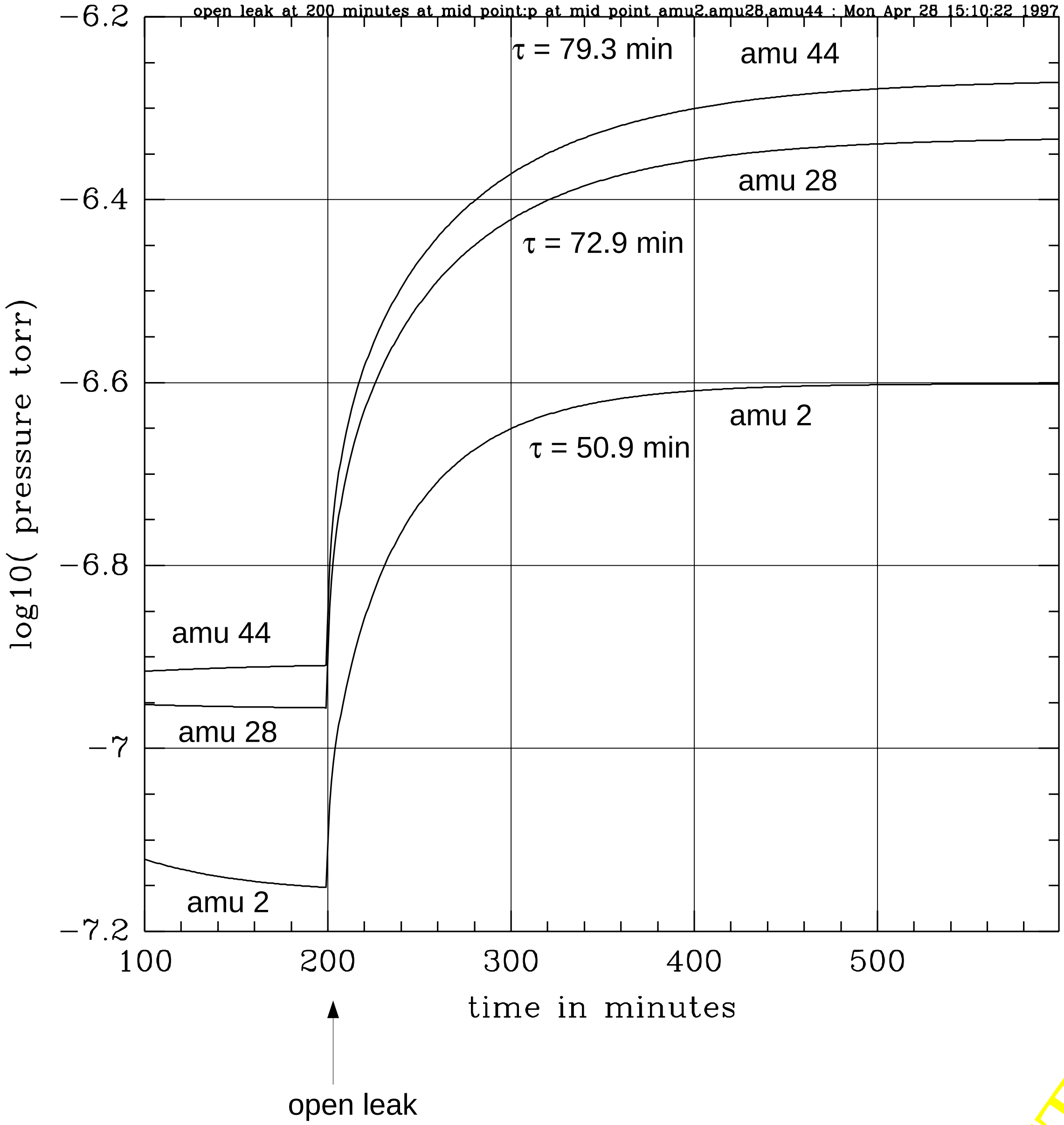
Pressures at mid-point of module
Pumps at ends of module

Figure 4 Beam tube pumpdown against the outgassing load given in **Table 5.** The pressure shown in this figure is measured at the mid point of the module. The water pressure assumes that the liquid nitrogen traps in the pumping lines at the module ends are cold but that the trap at the mid point hardware is warm. The water pressure represents the pressure in the tube. When operating the system for air signature and other noncondensible outgassing products, the traps in the pumping station at the module mid point will also be cold so that the water pressure is expected to be determined only by the outgassing in the RGA itself . We may need to bake the RGA to reduce the pressure in the RGA to a level low enough to perform sensitive outgassing measurements.



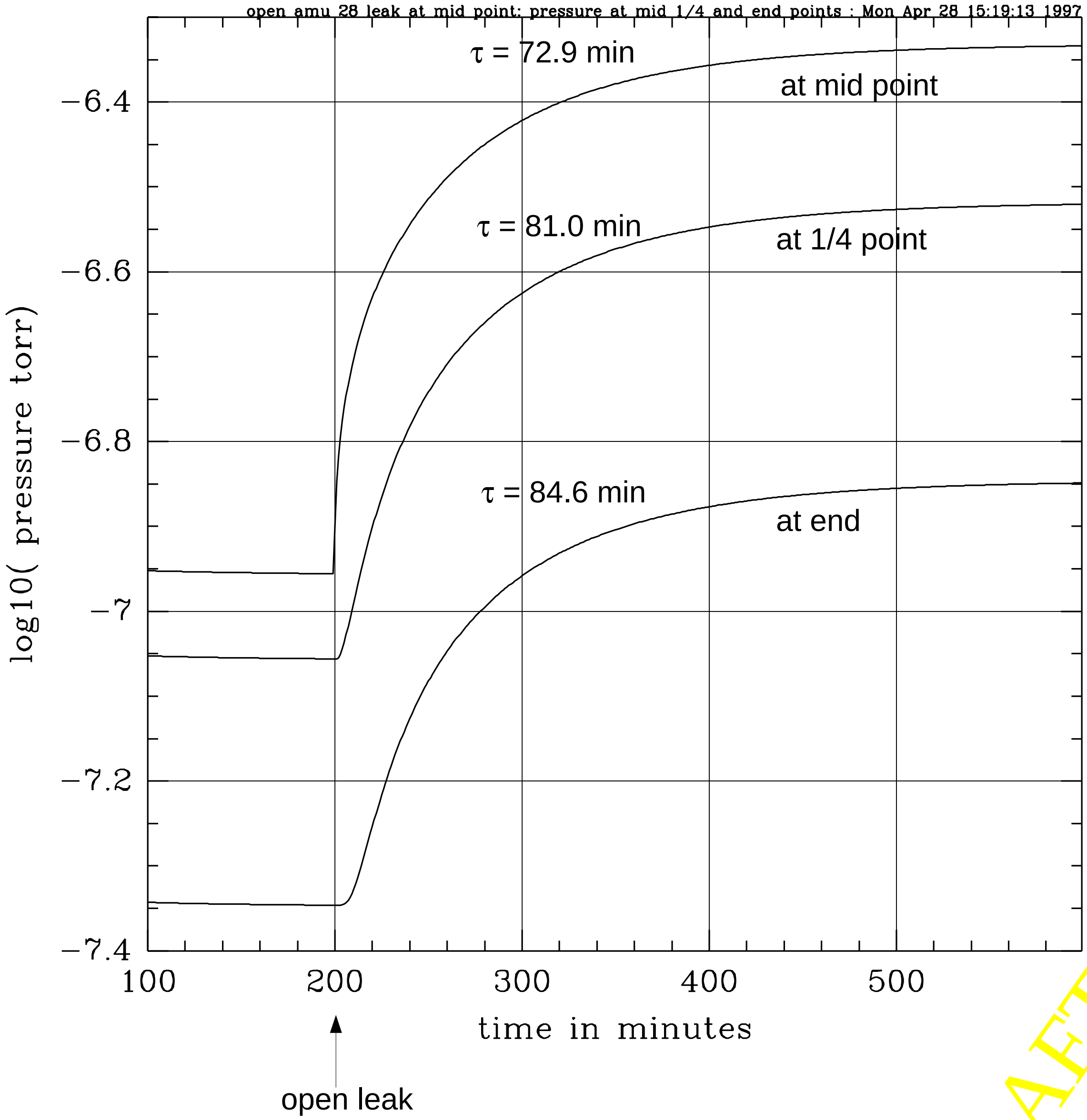
Pressures at module ends

Figure 5 Beam tube pumpdown against the outgassing load given in **Table 5.** The pressure is measured at the module ends next to the pump ports. The water pressure represents the conditions in the tube with the liquid nitrogen traps in the pump port hardware cold.



end pump 580 liters/sec
leak at mid point 1 x 10^-4 torr liters/sec all gases
pressure measured at mid point

Figure 6 Diffusion transient in the beam tube. A leak with amu 2, 28 and 44 is opened at the mid point of the beam tube module at time 200 minutes. The pressure as a function of time measured at the midpoint is shown. The leak is 1 x 10^{-4} torr liters/sec for all the gases and the pumping speed at the ends is held at 580 liters/sec. The formal lumped parameter time constant of the system, $\tau = \frac{V}{F}$, is 35 minutes.



End pump 580 liters/sec
Leak at mid point of tube 1.0 x 10^-4 torr liters/sec
amu = 28

Figure 7 Diffusion transient in the beam tube. A 1 x 10^{-4} torr leak of amu 28 gas is opened at the mid point at 200 minutes. The pumping speed at the ends is 580 liters/sec. The figure shows the pressure as a function time at the mid, 1/4 and end point of the tube.