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Data from Beam Tube Pump Down II

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Distribution:

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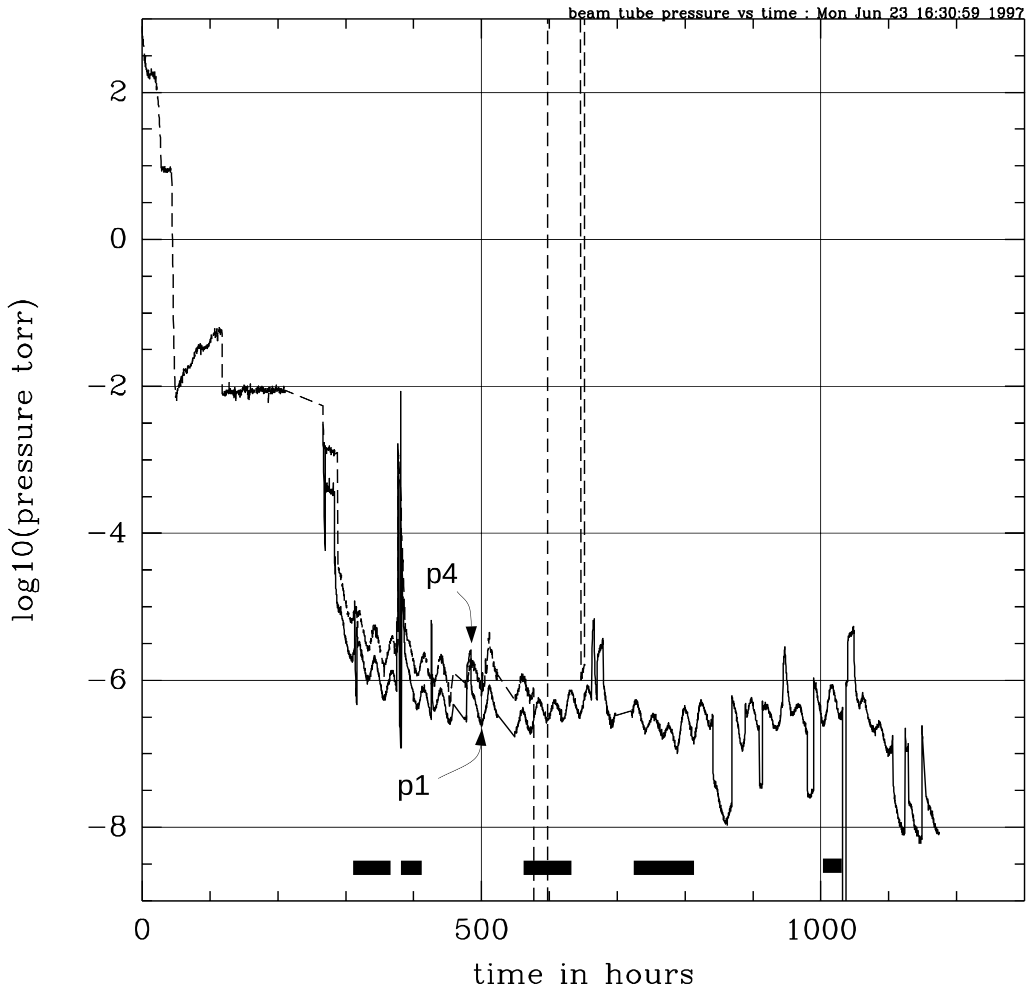

Indicates times used to estimate the water outgassing parameters

Figure 1 Beam tube pump down. The system is rough pumped at port 4 and 6 and has turbo pumps at ports 1 and 9. The rough pumping was carried out between 0 to 50 hours. The pressure p4 rises between 50 to 120 hours because of accumulation in the small isolated volume between gate valves. The beam tube accumulates between 50 to 260 hours. At 260 hours the turbo pump at port 1 is turned on and then the system is isolated from this pump between 270 to 280 hours. At 280 hours turbo pumps at both port 1 and port 9 are turned on. By about 300 hours the system pressure is limited by the water outgassing which shows the expected temperature dependence, a pressure doubling temperature increase of about 6 K. The 24 hour pressure modulation is due to the daily temperature cycle. The pressure ratio p4/p1 is due to two factors. The first, a factor of about 2, is due to the parabolic profile of the pressure in the uniformly outgassing tube coupled to the diffusion of the water molecules in the tube in free molecular flow. Another factor of about 1.5 comes from the fact that the gauges are not directly mounted on the beam tube but rather on the pump port hardware and there is a pressure drop in the pumping line.

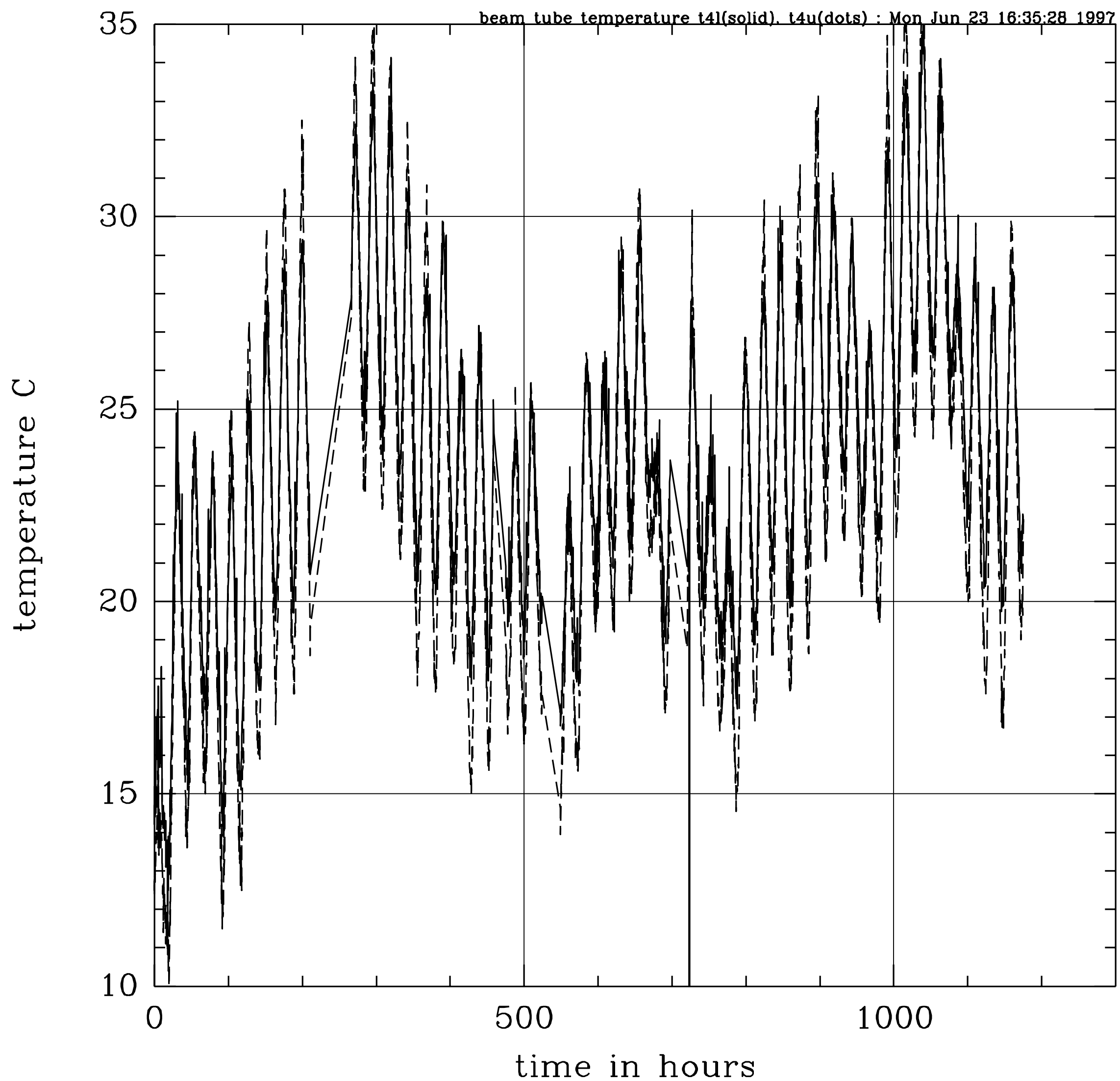

Figure 2 Temperature vs time on the beam tube at port 4. The curve labeled t4l is the temperature measured by a thermocouple on the bottom of the tube, while that labeled t4u is measured at the top of the tube. The tube is enclosed in the concrete enclosure. 0 hours corresponds to 12:38 PDT May 3, 1997.

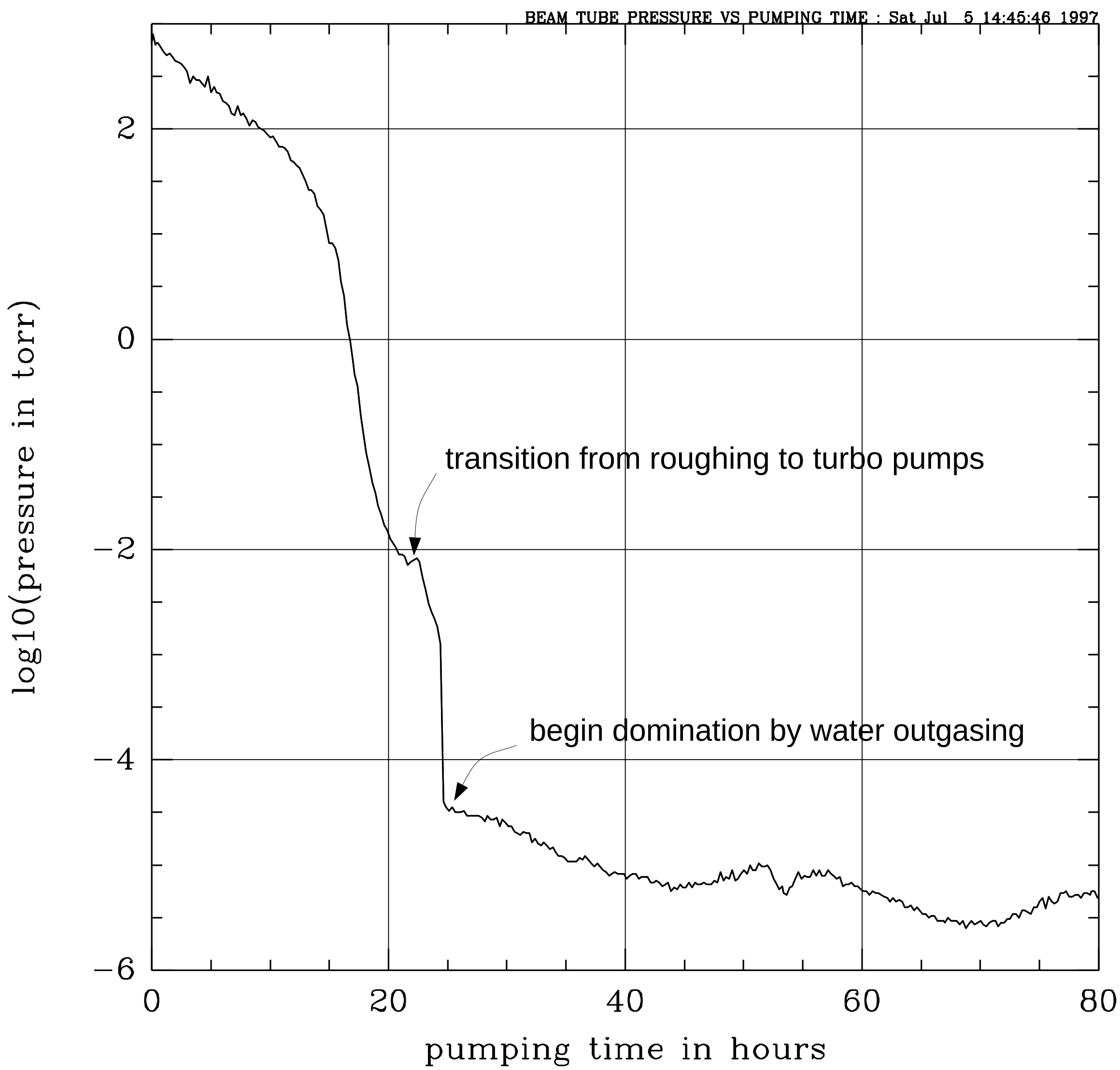

Figure 3 The pumpdown curve corrected for stops in the pumping. The time axis is in terms of the time that the pumps are applied to the module. The particular presentation allows an easier comparison to the predicted pumpdown curve. It also represents the fastest the beam tube module can be pumped down with the present pumps. The beam tubes reach the residual water outgassing limits for the unbaked tube by about 24 hours of continuous pumping.

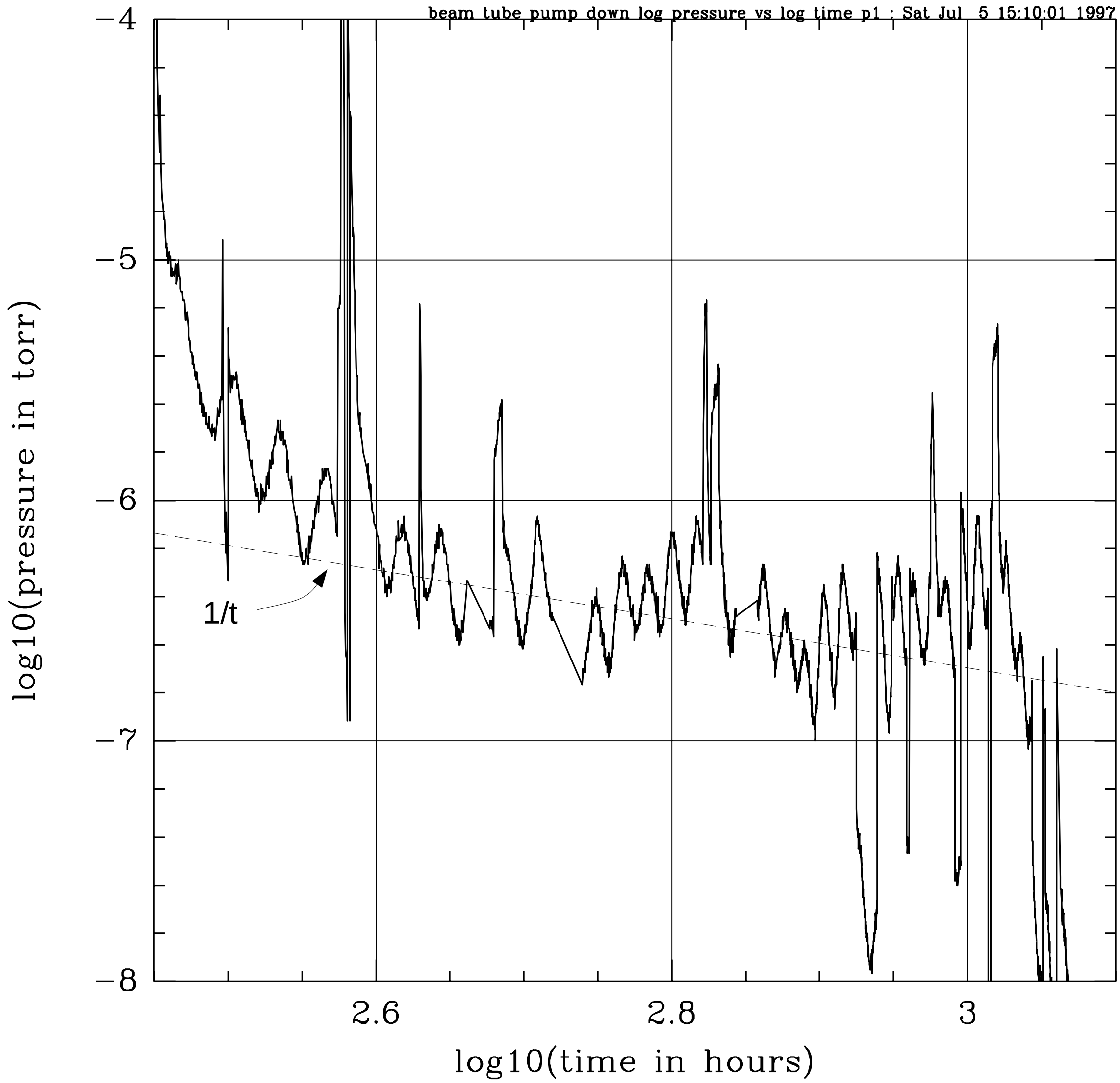

Figure 4 A log pressure vs log time plot of the pressure measured at P1. The water outgassing under constant temperature is expected to vary as 1/t. The curve sketched in the plot corresponds to $P(t) = 3.1 \times 10^{-4}$ /t(hrs) torr. More thorough analysis including the temperature dependence of the outgassing is given in **Tables 7** and **8**.

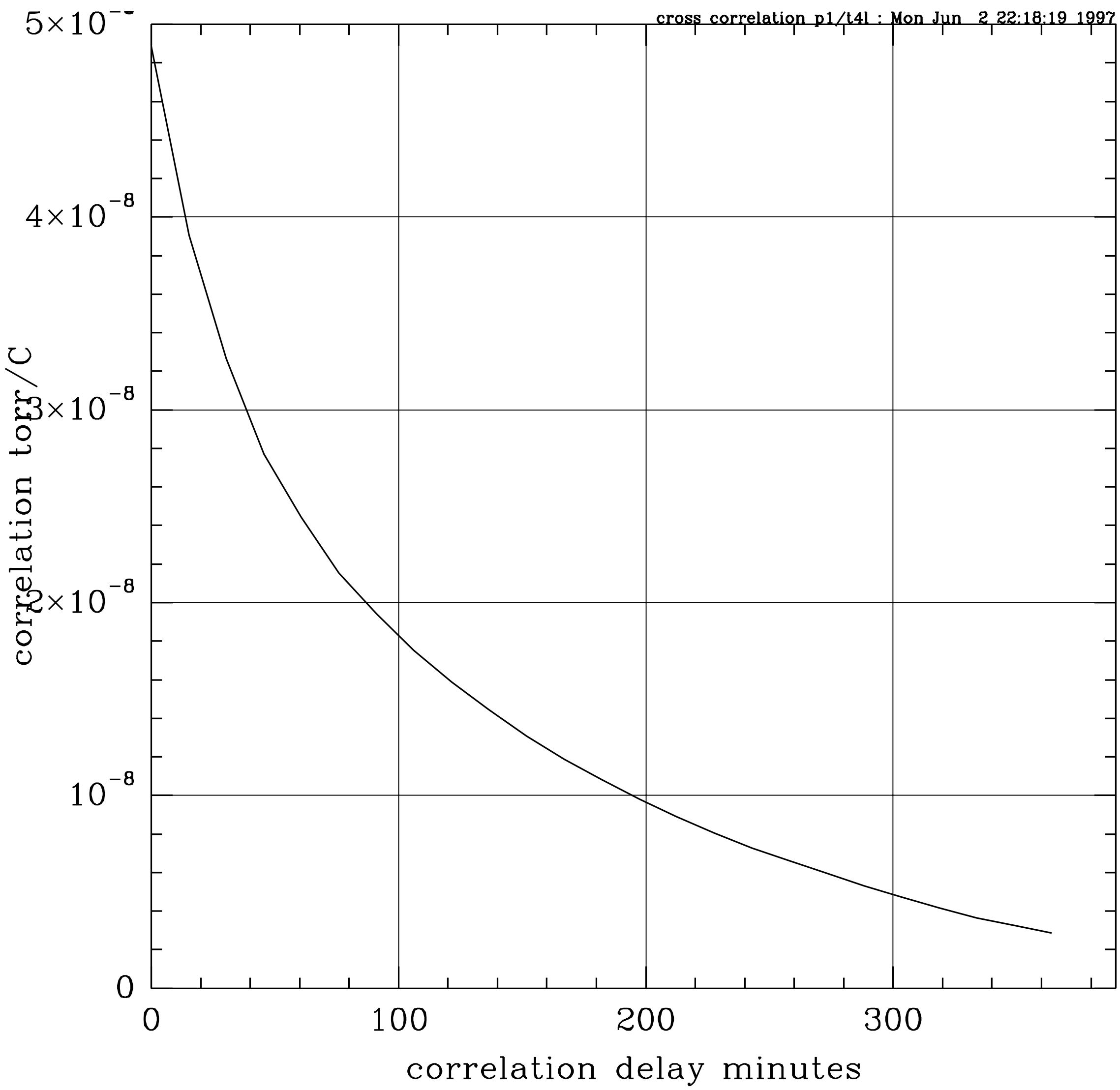

Figure 5 Cross correlation between p1, the pressure at port 1, and the temperature t4l as a function of the delay time in the correlation. The temperature changes at the various measurement points along the 2km module track to better than 5 minutes. The fact that the correlation peaks at 0 delay is consistent with outgassing as the source of the gas.

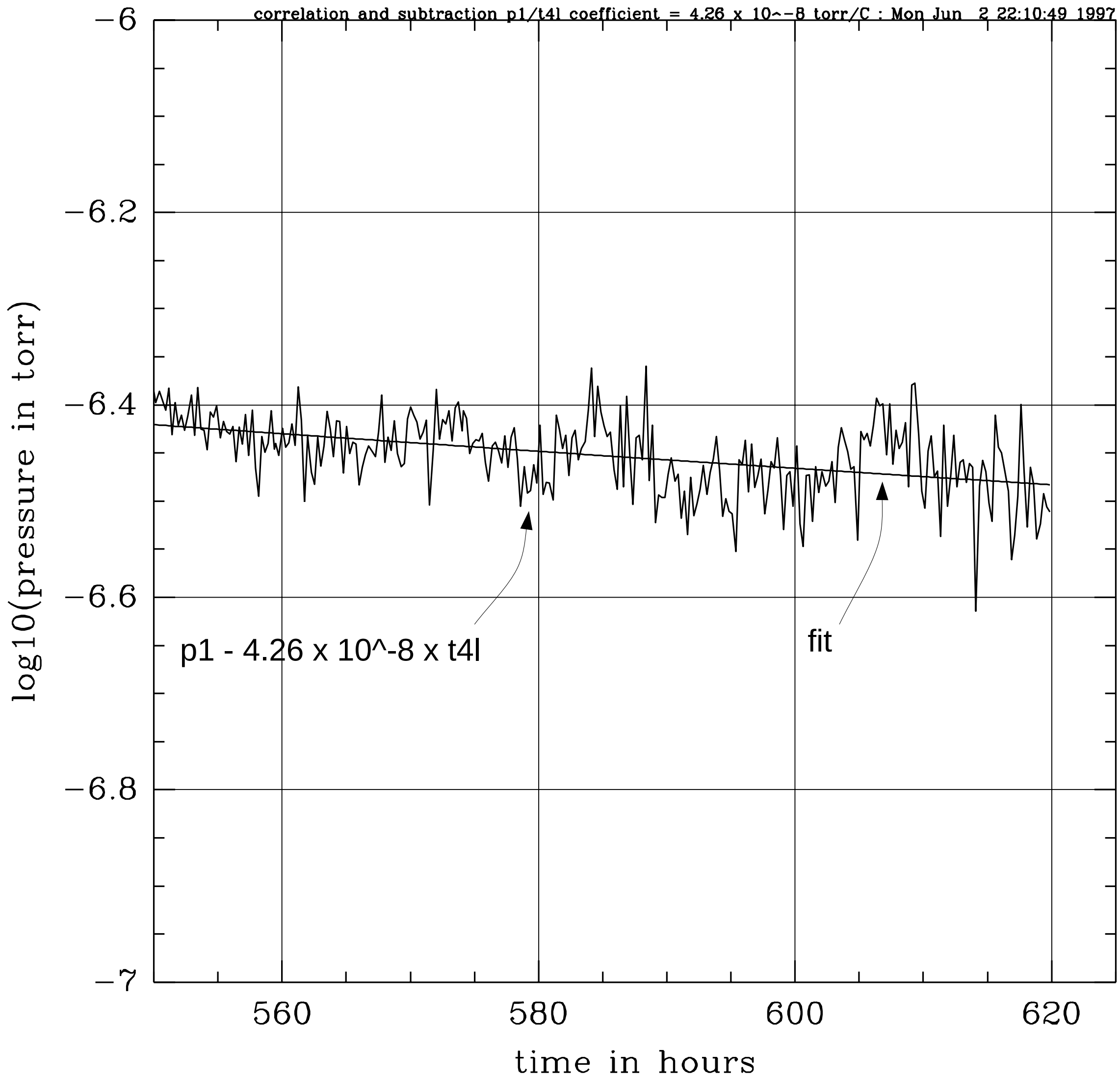

Figure 6 A plot of the residual pressure (p1) after correcting for the temperature using the cross correlation determined in **Figure 5.** The temperature dependence of the pressure is a doubling for every 6.6K increase in temperature. From this one can solve for the binding energy of the water on the surface which is equivalent to 9400K (about 1 ev) (also see **Table** 7). Prior outgassing measurements of beam tube material have given binding energies between 9000 and 10000K. The fit to the residual gas pressure is dropping as $p(t) = \frac{2.9\times10^{-4}}{t(hrs)}$ torr where t is measured from the initiation of the pumping. With an estimated pumping speed for water at ports 1 and 9 of 1000 liters/sec, the calculated outgassing rate for water becomes, $J(t) \approx \frac{8\times10^{-9}}{t(hrs)}$ torr liters/sec cm^2 about a factor of 2 smaller than that experienced in the beam tube qualification tests in 1995.

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Table 1: Prebake 2km module gas load t ≈ 1100 hr **(10^{-8} torr liters/sec)**

contributors	amu	06/18/97	06/19/97	06/20/97	6/26/97
H_2 , H_2O	2	749.4(19.5)	790.7(32.4)	**1235.5(13.5)**	583.0(4.2)
CO,CO_2 CH_4	12	4.29(0.11)	3.88(0.23)	5.26(0.13)	10.8(0.52)
N_2 ,CH_4 ,NO	14	**14.1(0.12)**	9.44(0.49)	**25.9(0.58)**	9.13(0.063)
CH_4,N_2	15	3.08(0.05)	3.33(0.19)	5.94(0.12)	4.66(0.054)
CH_4 ,O_2,CO_2	16	9.89(0.14)	8.02(0.53)	10.3(0.34)	22.38(0.97)
H_2O	18	0.31(0.007)	0.61(0.34)	0.52(0.11)	0.25(0.012)
N_2	27	0.50(0.019)	0.41(0.042)	0.64(0.038)	0.61(0.030)
N_2 ,CO	28	**116.1(3.59)**	73.4(2.89)	**189.1(4.41)**	72.0(0.56)
N_2	29	0.89(0.03)	0.71(0.04)	1.20(0.05)	0.81(0.018)
NO	30	41.0(0.773)	43.4(2.10)	61.8(0.69)	62.1(0.788)
O_2	32	**11.29(0.23)**	4.83(0.22)	5.01(0.13)	2.92(0.036)
A	40	**0.367(0.009)**	0.217(0.017)	0.224(0.016)	0.154(0.007)
CO_2	44	35.46(0.51)	31.9(1.94)	28.8(1.83)	143.7(6.28)
H_2 torr/cps	2	$1.08x10^{-13}$	$1.60x10^{-13}$	$1.54x10^{-13}$	$1.00x10^{-13}$
N_2 torr/cps	28	$1.20x10^{-13}$	$1.40x10^{-13}$	$3.53x10^{-13}$	$1.96x10^{-13}$
avg T C		26.0	24.9	25.7	27.2
T cor to 23C	2	0.76	0.84	0.78	0.68
T cor to 23C	all others	0.71	0.81	0.73	0.62
Cal Air Lk	14	**4.96(1.2)**			dis. gauge off
Cal Air Lk	28	**38.2(7.7)**			LN2 RGA only
Cal Air Lk	32	**6.15(1.5)**			
Cal Air Lk	40	**0.15(0.04)**			
H_2 Lk	2			**410**	
N_2 Lk	14			**14.3**	
N_2 Lk	28			**110**	

Table 2: QT gas loads 216 hrs after start of pumpdown before bake and after bake

amu	before bake	after bake
	10^{-8} torr liters/sec	10^{-8} torr liters/sec
2	26.0	13.0
12	8.56	0.029
14	7.9	0.00051
16	12.6	0.0046
28	35.8	0.066
30	20.1	< 0.0001
32	2.71	< 0.0001
40	0.37	0.00013
44	35.2	0.027

Table 3: Gas solutions prebake 2km module (10^{-8} torr liters/sec)

gas	06/18/97	06/19/97	06/20/97	06/26/97
H_2	748.0(15.0)	789.7(28.4)	1235.0(12.9)	583.3(2.98)
CH_4	1.88(0.046)	2.55(0.186)	5.15(0.135)	3.99(0.085)
H_2O	0.31(0.046)	0.61(0.252)	0.522(0.08)	0.246(0.01)
N_2	64.5(0.89)	13.1(2.92)	110.3(3.57)	12.5(0.67)
CO	56.3(2.83)	59.9(3.98)	83.4(4.76)	51.8(0.93)
O_2	11.3(0.22)	4.83(0.22)	5.01(0.130)	2.93(0.36)
A	0.36(0.009)	0.215(0.001)	0.225(0.012)	0.155(0.059)
CO_2	36.3(0.30)	34.4(1.39)	28.9(1.27)	149.6(3.31)
NO	40.9(0.77)	43.3(2.05)	61.7(0.69)	61.9(0.78)
C_2H_6	0.79(0.032)	0.75(0.051)	1.02(0.065)	1.42(0.041)
χ^2/12 dof	20.5	11.3	19.4	13.7
# iterations	2	2	2	2
Cal. leaks	air 38.2(7.7)		H_2 410 N_2 110	
discharge gauge	on	on	on	off
LN2 trap	on tube	on tube	on tube	on rga only

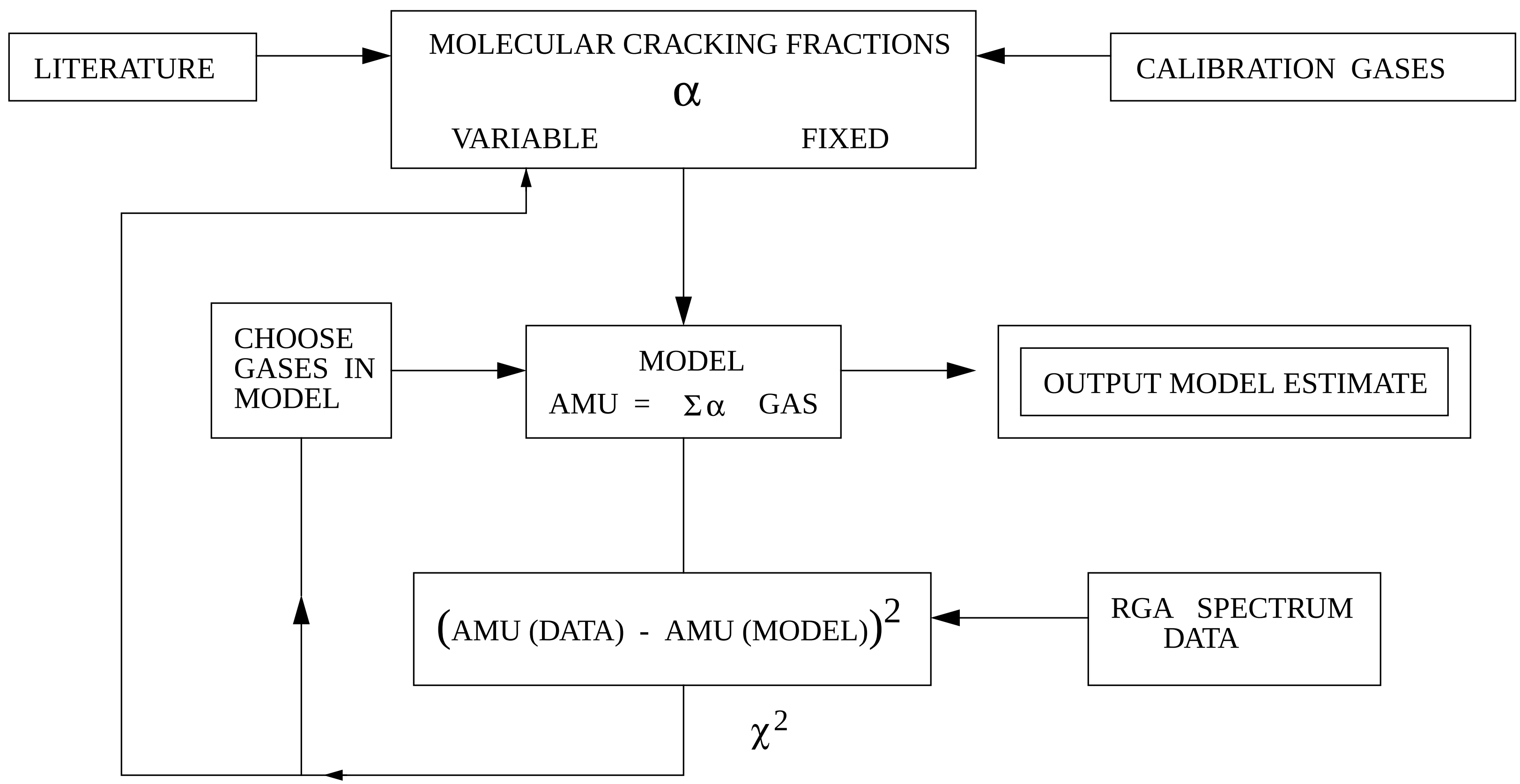

Figure 7 Schematic of gas model program

Table 1: Gas Model/AMU interaction matrix (Bold face=mini model)

	amu	**1**	**2**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**20**	24	**25**	**26**	**27**	**28**	**29**	**30**	**32**	**34**	37	38	39	**40**	41	42	**43**	**44**	**45**	48	49	50	51	52	53	54	55	56	57	58	64	65	66
	gas																																										
cal	**H_2**	X	1																																								
cal	**CH_4**	X		X	X	X	X	1	X																																		
	H_2O		X					X	X	1																																	
	C_2H_2	X	X	X	X							X	X	1	X																												
cal	**N_2**					X	X									1	X																										
cal	**CO**			X	X	X		X							X	1	X	X																									
	C2H4	X	X	X	X	X						X	X	X	X	1	X																										
	NO					X	X	X										1																									
	C_2H_6	X		X	X	X	X						X	X	X	X	X	1																									
cal	**O_2**							X											1	X																							
cal	**A**										X													1																			
	N_2O					X		X								X		X										1	X														
cal	**CO_2**			X	X			X								X	X										X	1	X														
	C_3H_6						X							X	X						X	X	X	X	1	X																	
	C_3H_8	X		X	X	X							X	X	X	X	1	X			X	X	X	X	X	X	X	X	X														
	C_4H_4												X	X							X										X	X	X	1	X								
	C_4H_6													X	X	X							X									X	X		X	1							
	C_4H_8													X	X	X	X						X		1										X		X	X					
	C_4H_{10}														X	X	X						X		X	X	1													X			
	SO_2							X				X							X											X		X									1	X	X
	"oil"																								X		X								X		X	X	1				

Table 4: Steady State Beam Tube Pumping Values

amu	τ uniform to parabolic profile	pumping speed at tube end	P(middle)/P(ends)	pumping speed of tube at middle
	minutes	liters/sec		liters/sec
2	53(10)	690(110)	1.43	1570
28	66(6)	1290(130)	4.06	419
40	104(9)	646(56)	2.83	354

Table 5: Prebake Outgassing Rates (torr liters/sec cm^2)

gas	measured at 1100 hrs	assumed 1/t	comments
H_2	< $7.4\text{x}10^{-14}$		larger than QT by 2 max correction for ordinary 304 SS 2.7×10^5 cm^2 at $J(H_2) = 1 \times 10^{-11}$ $J_{equiv}(H_2) < 3.5 \times 10^{-14}$
CO	6.9×10^{-15}	$7.6\ \text{x}10^{-12}$ / t(hr)	smaller than QT by 10
CO_2	1.9×10^{-14}	$2.1\ \text{x}10^{-11}$ / t(hr)	smaller than QT by 2
CH_4	5.2×10^{-16}	$5.6\ \text{x}10^{-13}$ / t(hr)	larger than QT by 4
H_2O		8.0×10^{-9} / t(hr)	*see table 7 and 8* smaller than QT by 2
Hydrocarbons $\sum$41, 43, 55, 57		$8 \times 10^{-3} * J(H_2O)$	larger than QT by 2

Table 6: Leaks and Leak Detection Sensitivity

Max air leak from accumulation	1.5×10^{-7} torr liters/sec
Min air leak measurable by accumulation	3.0×10^{-8} torr liters/sec
Min air leak for localization while pumping	$1 - 2 \times 10^{-7}$ torr liters/sec
N_2 estimate from VITON 1270 cm^2 $O_2/N_2 = 0.4$, $A/N_2 = 0.002$	$1 - 3 \times 10^{-7}$ torr liters/sec

Table 7: Steady state water outgassing parameters from pressure at P1 and the temperature T4l

time	*<T>*	*<p)*	$\frac{(dp)/(dT)}{p}$	T_0	*p corrected to 296K*
hrs	*K*	*torr*	K^{-1}	*K*	*torr*
345	299.3	1.33×10^{-6}	0.1095	9.802×10^{3}	9.20×10^{-7}
427	295,4	4.49×10^{-7}	0.1174	1.025×10^{4}	4.80×10^{-7}
585	295.2	3.32×10^{-7}	0.1240	1.081×10^{4}	3.65×10^{-7}
785	295.2	3.61×10^{-7}	0.1498 (?)	1.305×10^{4} (?)	4.09×10^{-7} (?)
1010	301.8	4.97×10^{-7}	0.1264	1.151×10^{4}	2.37×10^{-7}

The table indicates that the binding energy of water increases with time. This was also the observation during the BTD and QT bakes ; the less well bound molecules leave the surface before the more tightly bound ones. Using the data in the temperature corrected pressure column vs time one gets $P(t) = \frac{2.89\times10^{-4}}{t^{1.02}(\mathrm{hr})}$ torr . Providing the water pumping speed is 1000 liters/sec (as calculated from plumbing restrictions and not directly measured) at each end of the module, the water outgassing rate $J(t) = \frac{7.4\times10^{-9}}{t^{1.02}(\mathrm{hr})}$ torr liters/sec cm^{-2}

Table 8: Transient water outgassing measurements at 985 hours : include readsorption

$$\mathbf{V(equiv)/V} = \frac{\tau_{\text{pumpout with adsorption}}}{\tau_{\text{no adsorption}}} = 11.9$$

method	$\frac{dp}{dt}$ *(296K)*	*J(t, 296K)*	*comments*
	torr/sec	*torr liters/sec cm^2*	
H_2O	2.2 x 10^{-11}	8.0 x 10^{-9}/t(hr)	direct using discharge gauge
H_2O/H_2		5.0 x 10^{-9}/t(hr)	amu18/amu2 “snapshot”
H_2O/CO		6.1 x 10^{-9}/t(hr)	amu18/amu28 “snapshot”
H_2O/CO_2		1.2 x 10^{-9}/t(hr)	amu18/amu44 “snapshot”
H_2O/CH_4		1.1 x 10^{-9}/t(hr)	amu18/amu16 “snapshot”

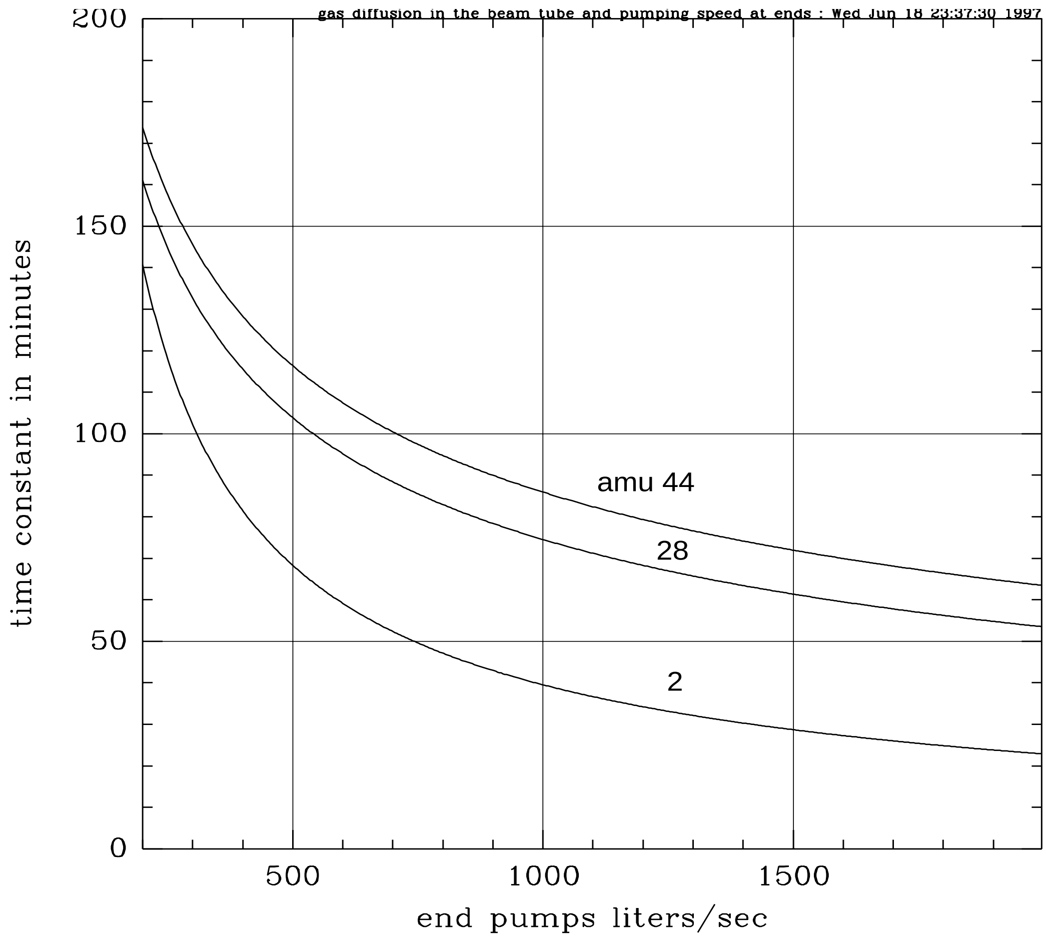

Figure 8 Relation between the pumping speed at the ends of the tube and the time constant ofthe system due to diffusion of the molecules in the tube. The simple minded lumped parameter estimate for the system time constant , $\tau = \frac{V}{F}$, is a poor approximation.

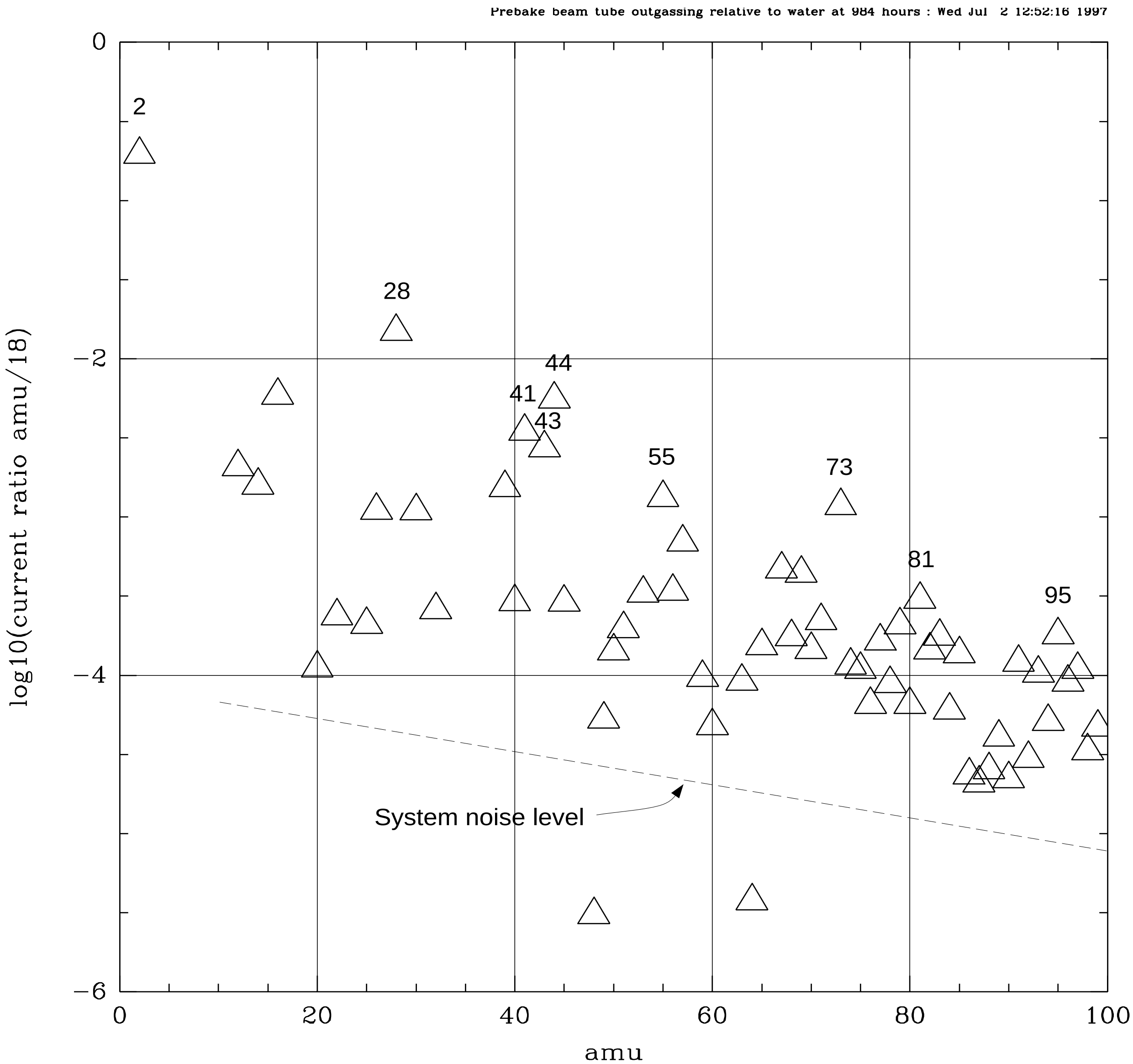

Figure 9 The beam tube hydrocarbon outgassing relative to water at 984 hours. The sum of 41,43,55,and 57 is approximately 2 times larger than the QT. The peak at 73 needs to be investigated. Is this characteristic of NYLON? (Preliminary investigations using published mass spectra for Carpolactum, $C_6 H_{11}NO$ and Carboximide, $C_{12} H_{17} O_2 N$, both principal components in the Polyamide polymer that comprises Nylon, show no peak at 73 but rather the standard hydrocarbon complexes in the amu 40's. 50's and 80's.) The water outgassing during these accumulation measurements needs to be multiplied by the ratio of the system time constant for pump down after the accumulation/ estimated time constant with diffusion. The readsorption of the water by the surface is responsible for the increase in the system time constant. The ratios in the figure do not take the readsorption into account - this would further reduce the outgassing ratio of the hydrocarbons to the water by another 11. The readsorption of hydrocarbons is not measured so the safe assumption is to use the outgassing ratios as given in the figure.

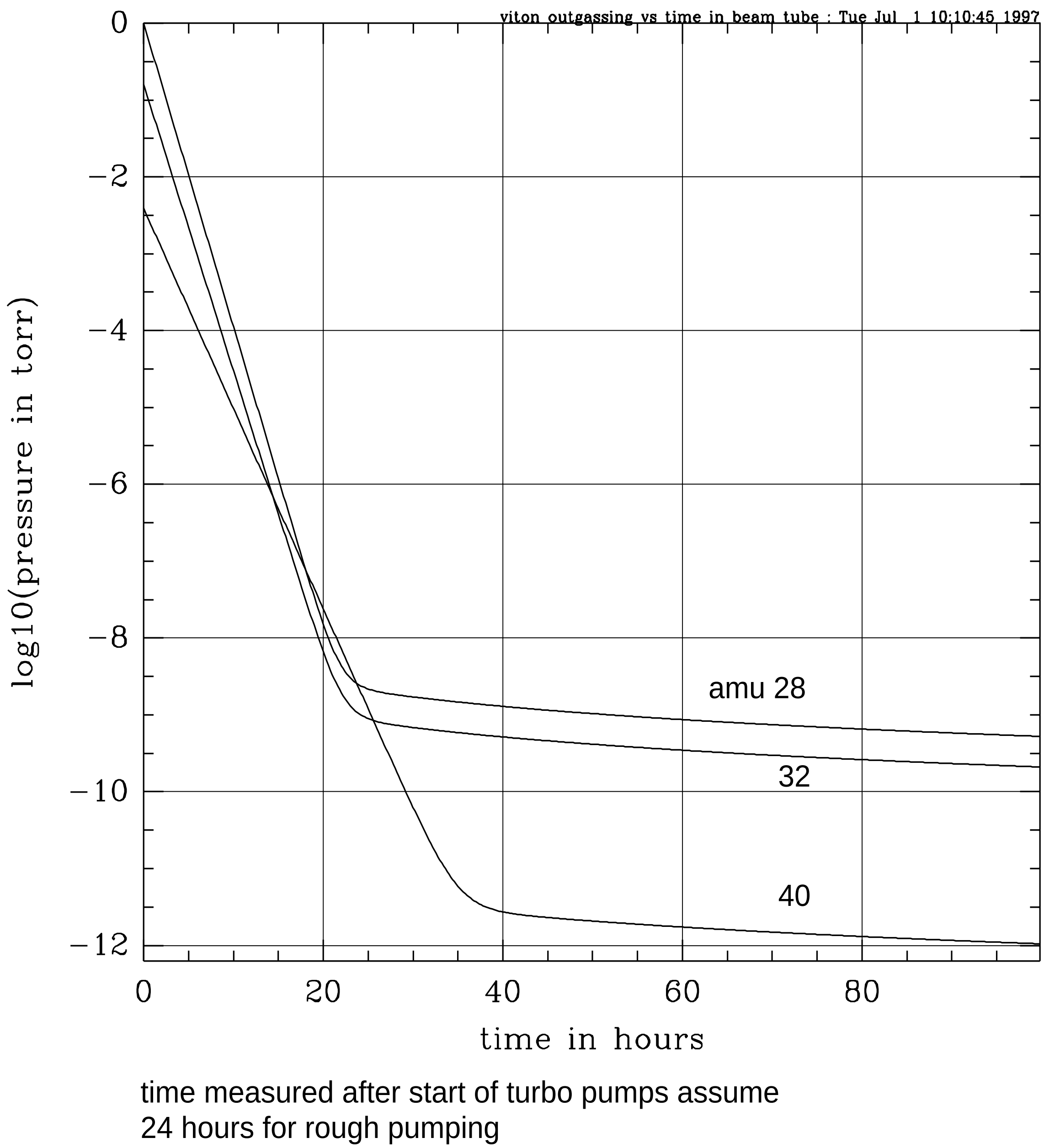

Figure 10. Viton outgassing as a function of time after intial pumpdown. The figure assumes a 24 hour rough pumpdown leaving the system at 1 torr. The turbo pumps are turned on at this time. The primary Viton outgassing is assumed at the 48 inch gate valves. The pumping time constants vs amu measured in the first module are used. The PSI measurements are described in PSI Report V049-1-124 "*10 Inch Chamber VITON O-Ring Ougassing Test Data*" 04/03/97 R. Than. The nitrogen, oxygen and argon retention give ion current ratios: O_2 /N_2 = 0.4, A/N_2 = 0.002 .

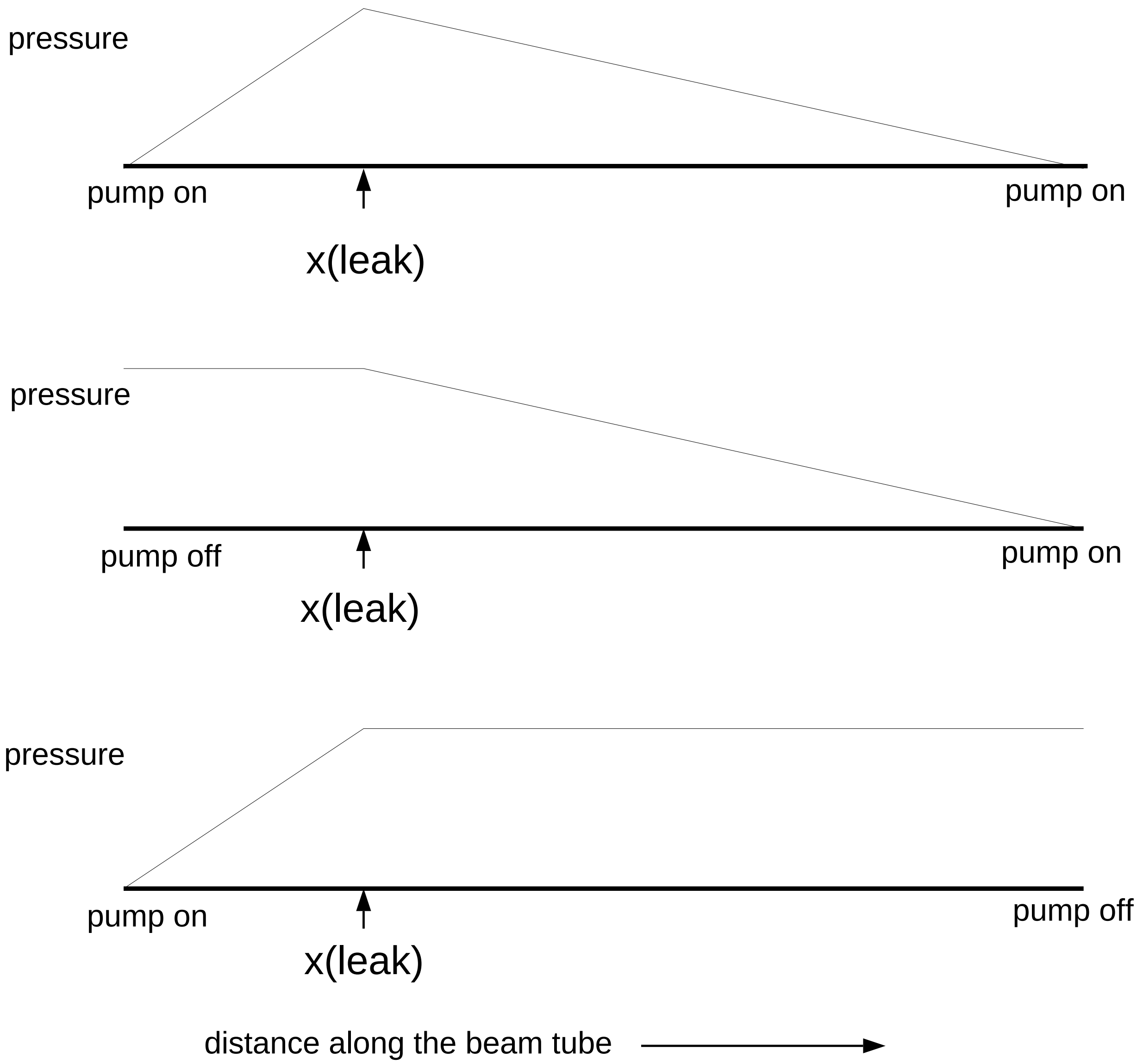
pressure
pump on
pump on
x(leak)
pressure
pump off
pump on
x(leak)
pressure
pump on
pump off
x(leak)
distance along the beam tube

Figure 11

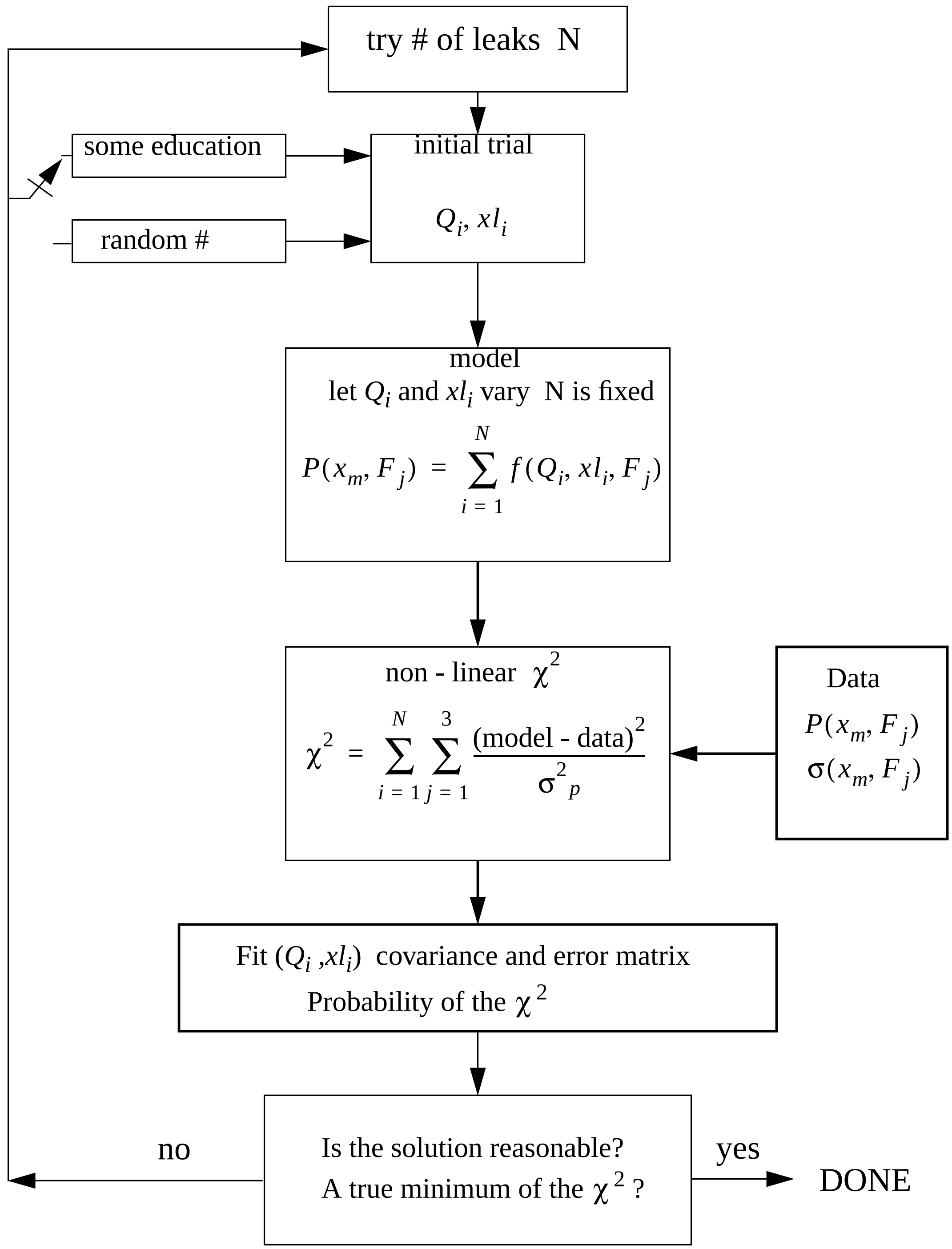

Figure 12 Flow diagram of the leak finding program. The data are the averaged air signature pressure readings and associated variances at the 9 residual gas analysers placed at the ends and along the beam tube. The model solution for an assumed N number of leaks provides the leak size and location. The significance of the solution is determined from the value of the χ^2 and the reasonableness of the model.

Fortran Programs used in the analysis

acumfix.for: converts rgaspec files from accumulations into useful form: converts files into torr liters/sec using accumulation times, H_2 and N_2 calibrations, makes the temperature correction to 23 C, and applies the volume and area of the system.

airsig.for: General purpose program to manipulate the RGA files developed by the Balzer's instrument as *****.mid files converted to *****.asc files and sent to the LIGO project by CB&I. The input files need first to be passed through EXCEL and rewritten as *****.txt files. Next they are purged of tabs and replaced by spaces. This is done automatically by the DOS edit program. The files also need to be edited to remove carriage returns between lines. Then the fortran program can read and plot rga spectra as a function of cycle or time vs mass number, take averages, make linear fits, write files from the input file for the rgaspec program. This is the most generally useful of the analysis programs.

airsigcp.for: Reads rgaspec files and manipulates them to: take differences between files, normalize to a specific amu, can apply the calibration. Produces new files for the rgaspec program.

airsigpa.for: Reads rgaspec files and manipulates individual files to normalize to a specific amu, apply the calibration

btpump.for: Program uses the finite difference solution to the diffusion equations for the beam tube pump down with pumps at the ends and a uniform outgassing

btpump.f : (UNIX not PC) Program to generate pumpdown curves of the beam tube based on: the number of pumps, imposed times to make the pump transitions, roughing pump speed, the turbo pump speed, various models of the outgassing of the different gas species (1/t,1/sqrt(t). constant)

btvac.for: Program uses the finite difference solution to the diffusion in the beam tube with temperature dependent 1/t outgassing, a leak placed anywhere, pumps placed anywhere, pressure measured anywhere.

btvac1.for: Same as btvac.for but allows different amu values for the gas constituents.

btvacd.for: Same as btvac.for but uses double precision - test of the algorithm

correlat.for : Determines the crosscorrelation between two data files and calculates the lagged crosscorrelation function. Useful program.

datafit.for Dumb program that plots data and a theoretical model - not a fit!

dataft.for: A PC version of the datafit.f program developed for the SUN unix machines. The program plots input data, makes a non-linear least squares fit to the data, plots both data and the fit. It can also show a plot of the residuals. The program needs to be recompiled for eaxh fit function. Presently configured for exponentials and a constant.

datapl.for: General plotting routine for input data files. Can plot up to 10 files simultaneously. Converts data into linear/linear, log/linear, log/log. The key analysis tool in the field. I prefer it to EXCEL

.

dragc.for: Subroutine used in calculating Reynolds #, drag coefficient and flow while rough pumping.

expfit.for: Subroutine for dataft.for used in fitting to exponentials and a constant.

leastsq2.for Program calculates least squares fit with formal errors to a straight line of an input file. One can enter data directly into the program or use data from existing files. Designed to fit to lines, exponentials and power laws. Program produces an output file of the fit.

makesum.for: Program used to concatenate pressure and temperature files produced by mdh-conv.for. The format of the concatenated files is ready for all other Fortran analysis and plotting routines.

mdhconv.for: Program reads the mdh**.prn or mdh**.txt files of pressure and temperature produced by CB&I and which have been sent to the LIGO project. The program has hard "wired" the start of the pumpdown. In order to use the program one needs to look at the last date and time in the original mdh file since this is required to terminate reading of the input file. The program makes files of the temperature vs time and pressure vs time. CB&I is not consistent in the format of this file and depends on the person running the computer. So occasionally one has to edit the ****.prn or ****.txt file to allow it to be read by this program. The major problem is the length of the line between carriage returns which is usually shorter than 270 spaces. Occasionally, however, it becomes over 300 spaces.

pumpdfix.for : Program removes designated sections of the pressure vs time or temperature vs time files and recalculates the time. Useful in removing the dead times in the pump down if one wants to make a record of pressure vs pumping time.

rgaspec2.for: The χ^2 fitting program for the gas model from the rga spectrum. This version calculates a 21 component gas model from 42 recorded amu values. The program is described in the LIGO document on the leak assay.

rgaspec5.for: The χ^2 fitting program for the gas model from the rga spectrum. This version calculates a 10 component gas model from 22 amu values. It uses the same input files as rgaspec2.for so either program can be used in calculating the gas model fit, however, experience has now shown that both the speed and reliability of the program depends on not adding additional gasses that reduce the χ^2 only marginally.

roughp.for: Interpolation subroutine for the rough pumping system pumping speed vs pressure.

subtract.for: General utility program to subtract two data files ,with time interpolation if needed, write difference file and calculate variances.

tempavg.for: Program calculates the average temperature over a chosen time interval for upto four temperature records.

timeconv.for: Program converts calendar date and local time to elapsed time in hours since the beginning of the pumpdown.

try1.f: (Sun Unix not PC program) Calculates the rough pump pressure vs time profile for a gas flow model using the transition from turbulence to viscous flow. The rough pump pressure vs gas flow is an input file.

In-field procedures

Turbopump down: The continuous monitoring of the pressure and temperature at the pump ports 1 and 9 provides one of the major records for the qualification of the tube. One gets:

the water outgassing rate as a function of temperature and time
the first diagnostic for leaks in the system
the water readsorption and pumping rates

Accumulation measurements for non-condensible gases with the RGA: The measurement of the outgassing rates of non-condensible gases (CH_4 ,CO, CO_2 ,NO, H_2) and the assay for air leaks come from this procedure. The accumulation is done with the LN_2 trap between the tube and the rga opened to the beam tube. The accumulations are all done for 14 to 16 hours beginning in the late afternoon and finishing in the morning so that the temperature profiles for the accumulations are as much the same as possible. The data is corrected for the temperature (reduced to 296K) and local calibrations with nitrogen and hydrogen before and after the accumulation. A global calibration is carried out by accumulating a known air leak as well as calibrated nitrogen and hydrogen leaks in two separate runs. The measurements have been carried out by opening and closing B5 the valve between the pump port hardware and the RGA with the trap continuously on the beam tube. This is the preferred method. The other way to carry out the measurement has been to leave B5 open and modulate B1 thereby closing the beam tube from the trap except during the measurement with the RGA. Although this method reduces the contamination on the trap, the prior method is preferred since the H_2O and CO_2 pressure in the beam tube remain constant during the accumulation. To preserve the sensitivity of the RGA, the SEM voltage is turned off between taking samples of the accumulated gas. CB&I has also turned the electron filament off over night. I question the value of this step since it changes the internal temperature of the RGA and thereby the instrument outgassing.

Accumulation measurements for condensible gases with the RGA: The measurement of the outgassing rates of hydrocarbons and other condensible species is carried out by reference to the outgassing rate of H_2O, CO_2 ,CO and CH_4 which are measured in other procedures. The LN_2 trap is not used during this procedure. The accumulated gas is measured every 2 hours over a 10 hour run by sampling the gas in the tube with the RGA. The sample is adjusted by valve B5 to make the amu18 peak (primarily H_2O) the same in each reading to avoid saturation in the RGA. The RGA script records all the amu values in an air signature record in addition to all amu values above amu 70. Post processing gives the hydrocarbon outgassing relative to water. The readsorption of water has to be measured after the accumulation by fitting the exponential during the pumpdown, This can be done from the continuous record of the pressure measured on the discharge gauges.

Beam tube model gas cracking patterns: A local calibration procedure which introduces easily measurable pressures of CH4 ,CO2 ,CO, NO, H2 , N2 and air into the RGA volume . The data is used in the rgaspecxx programs to fix the cracking patterns of the major residual gases in the air signature script known to be in the beam tube.