Date: October 18, 2014
Refer to: **LIGO-T1400667-v1**

From: M. Zucker
To: VRB
cc: H. Overmier, K. Ryan, J. Giaime, R. Oram
Re: **Post-repair LLO Y beamtube leak rate (preliminary)**

Abstract: The air leakage into the LLO Y beamtube declined sharply after we evacuated the cap over the stem of GV7 on 13 October. With the dominant air source removed, we now want to know if there is any residual leakage elsewhere.

An opportunistic accumulation performed while the tube remained closed, 2-4 days after the repair, gives a rough upper limit $Q_{leak} < 5 \times 10^{-7}$ Tl/s (1% of the previous rate), evidently consistent with zero. However, about 3×10^{-7} Torr of static air remained in the tube after the repair, limiting the test's sensitivity. This arises partly from the unknown rates of self-pumping by the pressure instruments, which contribute significantly at high mean pressure.

Readings from the 8 cold-cathode discharge gauges distributed along the beamtube were inconsistent with readings from the RGA monitoring the tube midpoint. The gauge data's derivative was also physically inconsistent with the known autogenous hydrogen flux (measured after the original tube bakeout). As a result, only the RGA data were used here. The discharge gauge discrepancy is not understood.

The test should be repeated after the tube has been evacuated and stabilized at normal operating pressure, in the 10^{-8} Torr range, and preferably with reduced incidental self-pumping from the instruments.

Method: The beamtube was sealed at both ends (GV4 and GV9 closed). We monitored the tube midpoint with the Pfeiffer QMA220 RGA in multiple-ion detection mode at 2, 14, 18, 28 and 40 AMU, with a cycle period of approximately 14 seconds. All channels were recorded with a fixed amplifier range of 0.1 nA full-scale. The empty channel at 5 AMU was also monitored to correct for preamplifier drift. The ion source emission current was derated from the nominal 1.65 mA to 0.5 mA to improve linearity, at the expense of sensitivity. The RGA tree is fitted with a small (nominal 2l/s) ion pump which operates continuously.

Tube wall temperature was recorded by six thermocouples distributed along its length. These all tracked each other closely, so they were simply averaged. It was empirically found that gas pressure effects lagged changes in tube surface temperature by 3.1 hours. This delay was inserted *ad hoc* in the analysis.

The average cold cathode pressure was about 3×10^{-7} Torr, and the sum of RGA ion currents typically indicated RGA gauge factor $\langle P_{cc} / I_{sum} \rangle = 4.2 \times 10^{4}$ Torr/ampere.

However, the instantaneous value varied by ± 15% over the course of the measurement; so this absolute calibration is unreliable.

A 50 l/s ion pump was inadvertently left pumping on the tube at the Y end during the valve repair, and was not discovered until the following day. Correcting this oversight produced a relaxation transient lasting about 8 hours. To avoid distortion, only the later 40 hours of data, from 17:10 CT on 10/14 to 09:10 CT on 10/16, were scrutinized.

After removing preamplifier offset, the time series of 28 AMU (N_2) ion current was fitted to a linear drift plus a term proportional to (time-delayed) tube temperature. A simple linear fit was adequate to accurately model 2 AMU (H_2) and also the sum of currents corresponding to 2, 18, 28 and 40 AMU. Results are given in Table 1 and shown in Figure 2.

Species	*Mean partial pressure (10^{-7} Torr)*	*Slope (10^{-7} Tl/s)*	*Tempco (10^{-10} T/K)*	*Fit r^2*
N_2	2.2	-1.86	+3.7	0.97
H_2	0.8	+26.5*	-	0.99
Σ (2,18,28,40)	3.2	+24.2*	-	0.97

Table 1: Fitted residual gas influxes during drift test. Without regressing correlated temperature deviation, N_2 yielded slope of -2.3 x 10^{-7} Tl/s with r^2 = 0.68. The mean tube temperature during the test was 24.7 C with peak-to-peak variation of 11.3C.

(* = air-equivalent)

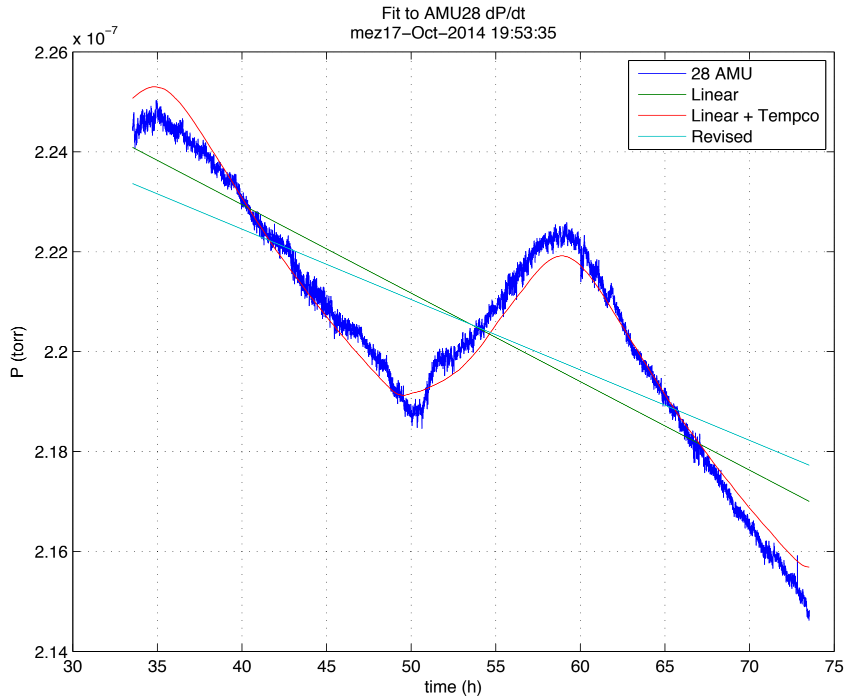

Figure 1: Fit to AMU28 ion current with simple linear regression (green), regression including tube temperature delayed by 3.1 hours (red), and the linear component of the latter (turquoise). Final slope corresponds to a net rate of -1.86 x 10^{-7} Tl/s.

Results:

Hydrogen: After correcting for hydrogen's reduced ionization cross-section with respect to air (a factor of 2.4), the implied tube wall desorption flux is

$$\langle J_{H2} \rangle = 4.1 \times 10^{-14}\ \text{Tl/s/cm}^2\ @\ 24.7\ \text{C}$$

According to Weiss[1], original H_2 desorption measured after bakeout (averaged between Y1 and Y2, corrected to 24.7 C) was about 3.7 x 10^{-14} Tl/s/cm^2. This is in reasonable agreement, given the crude absolute calibration.

Nitrogen: We see evidence of a slight *negative* leak rate. This is not unexpected; in addition to the small ion pump on the RGA tree, mentioned above, it is known that each of the eight discharge gauges arrayed along the tube also has some net pumping action. Chambers et al[2] estimate F_{gauge} ~ 0.1 l/s for inverted magnetron cold-cathode gauges (the general type we use). Li and Jousten[3] report direct measurements of 0.045 l/s and 0.065 l/s self-pumping on two different inverted magnetrons (a Varian and an Inficon).

[1] LIGO-G1300116, p.43. Note that the H_2 figure for Livingston Y2 is missing a decimal point. The correct value is 2.6 x 10^{-14} Tl/s/cm^2 . cva

[2] *Basic Vacuum Technology 2nd ed.* A. Chambers, R.K. Fitch and B.S. Halliday. IOP (1998), p. 96.

[3] Detian Li and K. Jousten, *Vacuum* 70 (2003), p. 531–541.

The small RGA ion pump has led a difficult life, and is lately known to be a net source of noble gases. Its nitrogen speed might plausibly be anywhere from 0 to 2 l/s (its nameplate rating).

Taking the range of quoted values for the cold cathode units (x 8 active gauges), we estimate the total gauge and RGA pumping speed should be

$$0.4 \text{ l/s} < \Sigma\,(F_{gauges}) < 3 \text{ l/s}.$$

Self-pumping would thus subtract a bias of 0.8×10^{-7} Tl/s < Q_{gauges} < 6.5×10^{-7} Tl/s at the mean N_2 partial pressure of 2.2×10^{-7} Torr. The measured nitrogen slope could therefore correspond to a true leak rate of

$$-1.1 \times 10^{-7} \text{ Tl/s} < Q_{leak} < 4.6 \times 10^{-7} \text{ Tl/s}.$$

Repeating the test at reduced mean pressure will constrain any possible effects of self-pumping and improve these limits accordingly. The small ion pump should also be shut off or (preferably) isolated. Some or all of the cold-cathode gauges can probably also be temporarily shut off without penalty.

About the cold-cathodes: A similar temperature-corrected regression analysis on the average of the 8 cold-cathode gauges gave an apparent positive rate of 4.7×10^{-7} Tl/s with $r^2 = 0.98$. This quantity does *not* track the RGA current sum; indeed, it is inconsistent with expected hydrogen desorption, given plausible limits of gauge self-pumping. Figure 3 shows the problem. The ion gauges do correlate well with each other, however.

One possible explanation is that somehow these gauges are partially "blind" to hydrogen. This seems unlikely, although Li and Jousten do report variations in relative H_2 sensitivity with respect to nitrogen, specific to the pressure range tested here. Another possibility might be some subtle common nonlinearity or other flaw in the internal nonlinear conversion from ion current to output voltage, or in our conversion of this voltage to readout. We will have to investigate this; in the meantime, we should be careful about trusting cold cathode pressures.

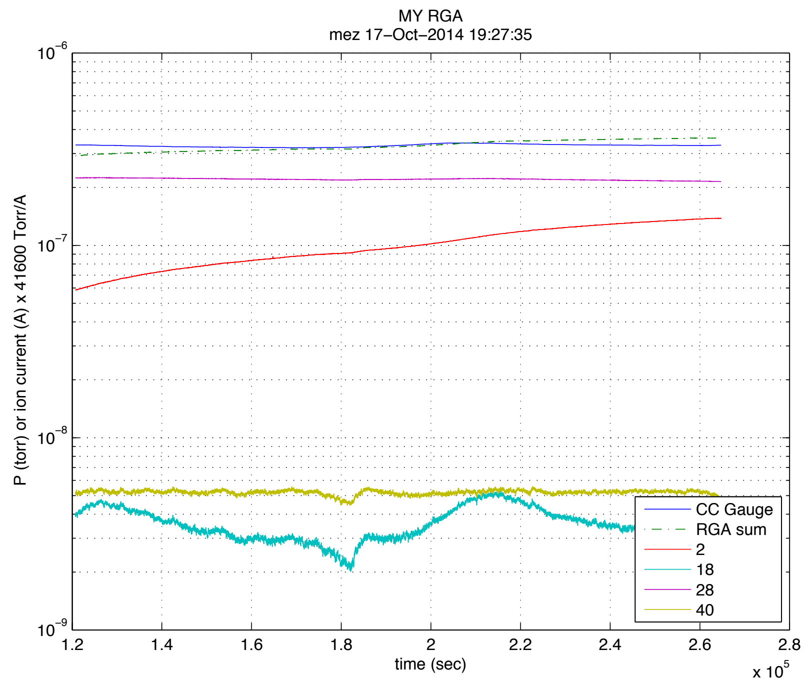

Figure 2: RGA ion currents and their sum (dotted green) plotted with the mean of the cold-cathode gauges (blue). Conversion coefficient is based on the time averages over the test duration. Each ion current has been corrected to remove preamplifier offset, derived from the 5 AMU null channel (typically about 100 fA, or 4 x 10^{-9} Torr on this scale).

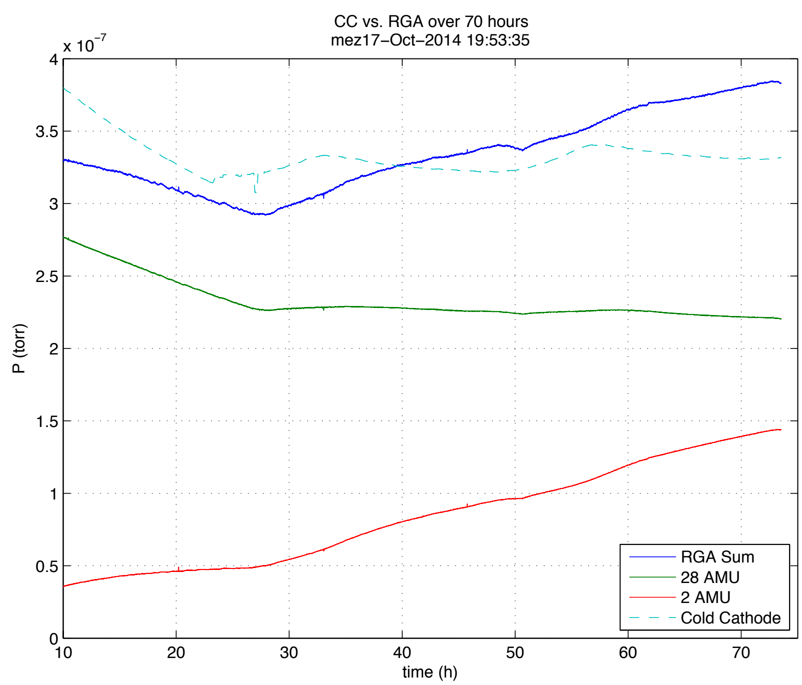

Figure 3: Expanded view of RGA currents (scaled by 4.1x104 Torr/A) along with the mean of the eight cold-cathode gauge pressures. Data from t < 30h were not analyzed due to the errant pump transient, but are shown here to emphasize the discrepancy between RGA cold-cathode measurements.