Date: June 17, 2013

Refer to: LIGO-T1300553-v1

To: D. Coyne, S. McCormick, F. Raab, J. Worden, R. Weiss

From: M. Zucker

Re: **Effect of leak-test port separation; measurement of He transient at z = 250m**

Abstract: In T1200375 (Weiss and MZ, July 2012) we calculated *P(t,z)* for impulse and finite-step helium injections into the beam tube. A practical application is to determine degradation of He mass-spectrometer leak detector (MSLD) test sensitivity as a function of separation *z* between test site and sampling port.

Here I plot expected MSLD response to a nominal 30-second injection of helium at various distances *z*. The expected peak deflection is found to be degraded by about a factor of five at *z* = 250m (corresponding to the separation between beamtube pump ports), and by a factor of ten at *z* = 500m. The time delays from injection to peak response are about 1 and 5 minutes at these locations, respectively.

I then compare the prediction to a test injection at *z* = 250m, performed 15 May 2013 on the LLO Y tube. Agreement looks adequate for the present purpose, but the detailed transient is not completely understood. More investigation of the leak detector's impulse response is needed.

Because the limiting MSLD test sensitivity at *any* position is not comfortably below our threshold for concern, I conclude that wherever feasible it makes sense to locate the MSLD on one of the test ports nearest each zone under investigation.

Test method: A Pfeiffer ASM 310 helium mass spectrometer leak detector backs a small 50 l/s (nominal) turbopump, connected to the beamtube through two 1.5" nominal angle valves in series (one all-metal, and the second Viton-sealed).

Since turbopump compression is high, effective conductance from the tube to the leak detector is mainly defined by conductance from the tube to the turbo inlet. Valve data indicate this conductance is about $C_{LD}(He)$ = (45 ± 10) l/s at 300K. This is taken as the coefficient linking MSLD apparent "leak rate" to local He partial pressure. The MSLD analog monitor output is recorded at 1-second intervals by a datalogger.

A VTI Teflon-plug type helium calibration source is mounted on an isolation valve 2 meters north of GV7 (essentially the beamtube midpoint), and the leak detector assembly is located at the first pump port south of the midstation, 250 meters south. The factory calibration of the calibration source gives a rate *Q(He)* = (3.8±0.2) x 10^{-6} Tl/s, after correcting for age depletion. The test tree also carries a small turbopump with its own isolation valve, such that the calibration gas can either be diverted to the turbo or admitted to the beamtube. We can control the complementary valve strokes to about ±5 seconds precision, giving ±15% uncertainty in a nominal 30-second injection.

Figure 1 shows the expected response to a 30-second injection of the above magnitude, with the putative source placed at various distances from the detector.

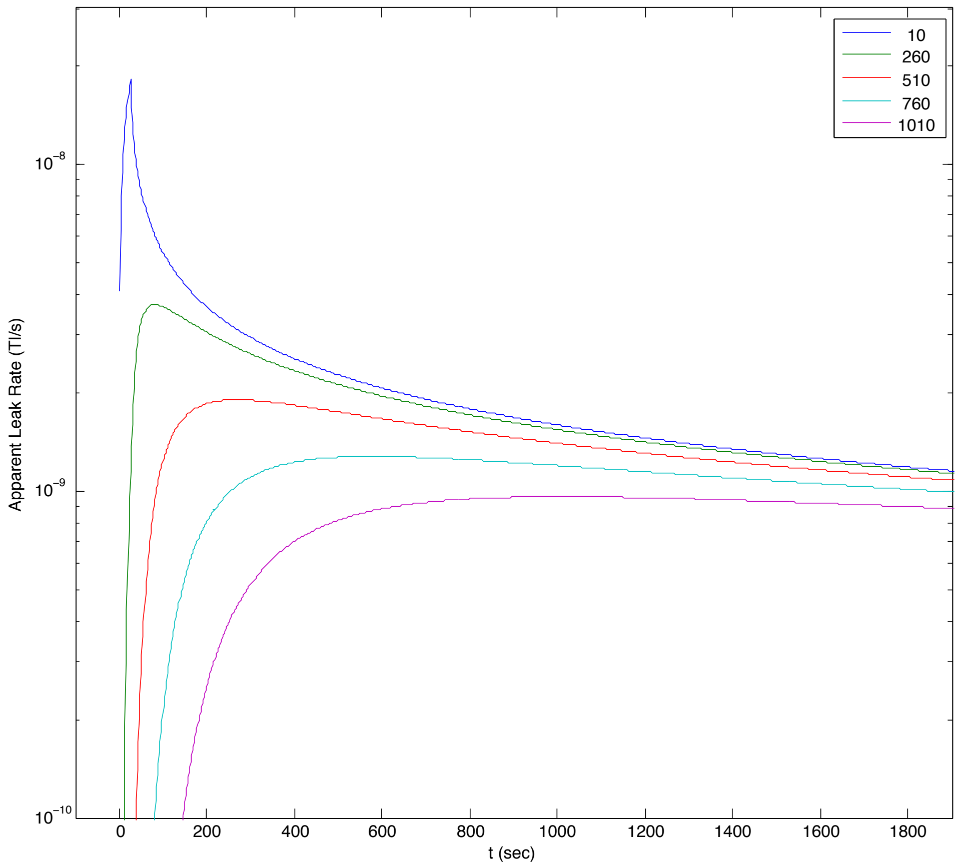

Figure 1: Model leak detector response for He test injections as described in text, assuming different injection positions *z* ranging from 10m (blue) to 1.01 km (purple). The actual test (Fig. 2) was performed at *z* = 250m (green).

Using this model, Table 1 gives the expected air-equivalent leak detectability limit for tests conducted by briefly surrounding a given section of tube with helium. I assume the test zone (bag or ambient volume) acquires at least 10% He concentration for at least of 30 seconds, and that a positive test requires a minimum of 3 x10^{-10} Tl/s deflection on the leak checker readout.

In reality, the deflection criterion should depend on the MSLD noise and background drift over whatever observing duration is required to establish a signal. As a lower bound on this duration, the expected peak delay (governed by diffusion) is given in the third column of the table. The MSLD noise may sometimes be the range of a few x 10^{-11} Tl/s, as seen at left in Figure 2, or better; but we've found in practice that long-term stability at this level is far from typical. The machine isn't really designed for very long test durations.

z (m)	Min. detectable $Q(air)$ (10^{-6} Tl/s)	Time to peak deflection (s)
1	1.6	-
250	8	75
500	16	260
1000	32	1020
2000	65	3900

Table 1: Minimum detectable air leak for MSLD readout deflection of $3\text{x}10^{-10}$ Tl/s, assuming exterior is flooded with 10% He concentration for 30 seconds.

Experimental test: The recorded leak detector response is shown in Figures 2, along with the range of model predictions after combining in quadrature various estimated errors described above. The time stamp of the data logger was only recorded to ~ minute precision, so the model abscissa was time-shifted to coincide with the observed onset.

Overall the observed response magnitude conforms within errors. However there seems to be an unmodeled filter characteristic in the gas dynamics or in the leak detector/data logger response (Figure 3). This is inferred from an observed delay in the peak response (about 2 minutes, vs. ~ one expected), and from apparent attenuation of the initial peak height with respect to the asymptotic diffusion tail.

Another systematic effect may also distort the asymptote. After intermittent He exposure, the MSLD background is sometimes found elevated above the prior baseline for tens of minutes. This hysteresis has been attributed to absorption and delayed reemission of gas by elastomer seals inside the machine, and would tend to “flatten” the apparent transient recovery.

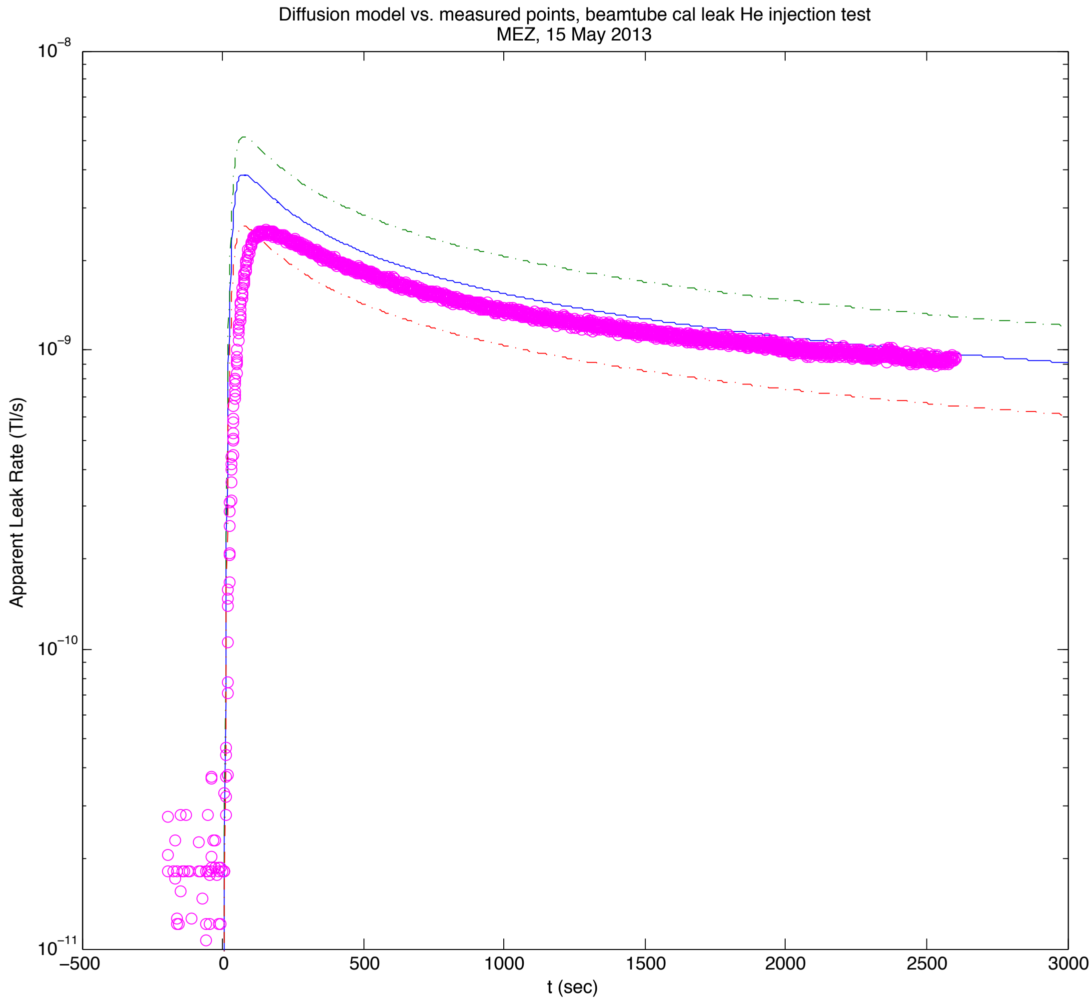

Figure 2: Leak detector response to 30 second calibrated injection of helium test gas at z = 250 meters (pink circles). Also plotted is predicted response from diffusion model (solid blue) and approximate standard error margins (dash-dot red and green).

Discussion: As shown in Figure 1, the modeled response is down by a factor of five between z = 10m and z = 250m, and falls a further factor of two at z = 500m. The added systematic delay seen here, if it can't be eliminated, further degrades the sensitivity of tests monitored far from the injection site.

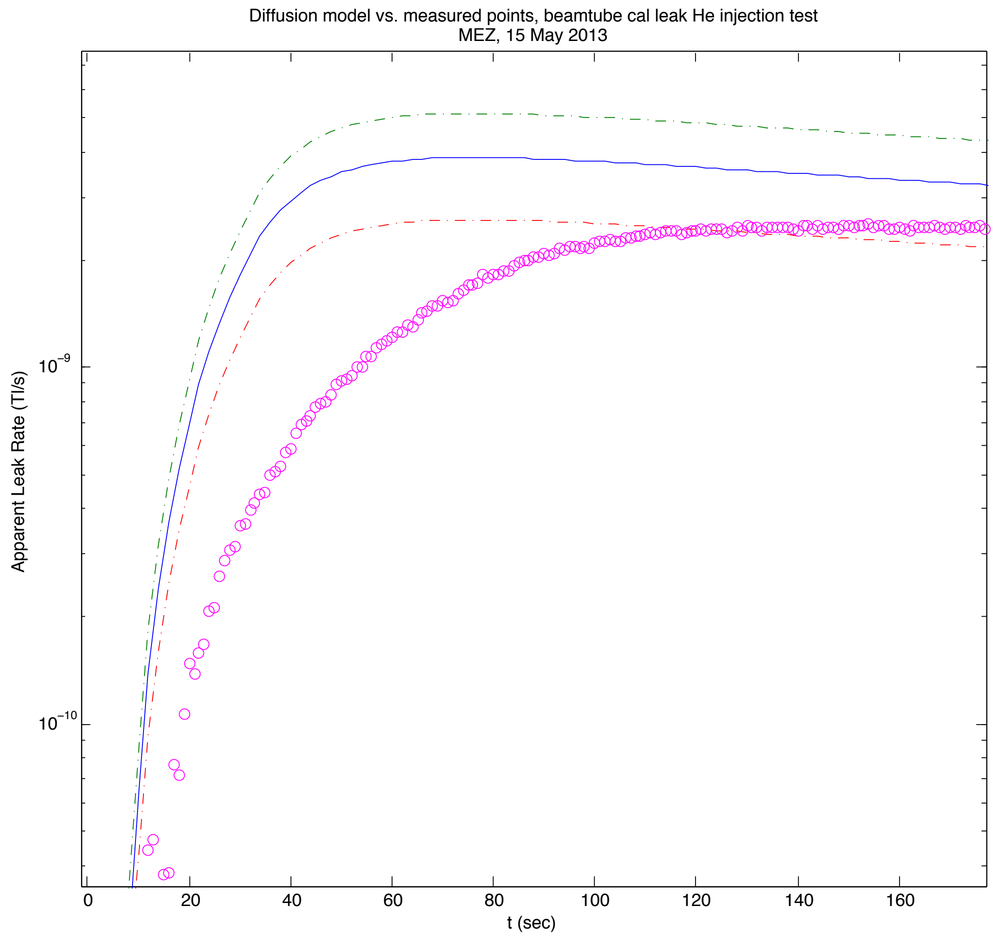

Figure 3: Magnified view of first three minutes, highlighting apparent transient response model discrepancy.

At this writing the total air signature in the LLO Y tube is equivalent to about 5 x 10^{-5} Tl/s. While the test configuration described here could in principle find a single leak of that size at z = 1km, SNR would be marginal and test latency would be very long due to the diffusion time. This latency also may increase the risk of false readings due to MSLD drift or ambient backstreaming.

There's also strong circumstantial evidence that the current problem in fact comprises several smaller distinct leaks. Unfortunately, even the adjacent z = 0 test threshold, in the range of 10^{-6} Tl/s air equivalent, is a factor of 10-100 higher than we'd consider harmless.

As a result, I conclude that we'll typically want the leak detector (and associated power, safety and climate control infrastructure) on one of the two pump ports nearest each zone under test. This in itself raises the risk of spurious He backstreaming (false positives), so along with this practice, we'll also need to direct and maintain strong fresh air flow away from the MSLD location at all times. Ambient thermal stabilization of the MSLD, necessary to control drift, may also be more challenging at remote BTE locations.