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Gun Vacuum Performance Measurements February 2003

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Abstract. The vacuum in the polarized photoguns at Jefferson Lab is crucial to long lifetime operation of the polarized source. In order to characterize the vacuum in these guns, an extractor gauge and a residual gas analyzer have been incorporated into each gun. The purpose of this tech note is to document the gun vacuum measurements performed in the CEBAF polarized electron guns during tests made in February 2003, and to compare this with the previous vacuum measurements made in the electron guns throughout their evolution. The results of these measurements, suggesting that the raw extractor gauge readings are $7x10^{-12}$ and $4x10^{-12}$ for guns 2 and 3 respectively, are at least as good as any previous measurement of the vacuum in these systems.

INTRODUCTION

The polarized source photoelectron guns at CEBAF, Jefferson Lab have excellent vacuum properties. The guns are 304 stainless steel chambers with a high voltage ceramic attached, and are routinely baked for 30 hours at 250ºC in preparation for use. The system is pumped by a combination of differential ion pumps and WP950 non-evaporable getter (NEG) pumps, with an oil free roughing system consisting of turbo-molecular drag pump backed by a diaphragm pump. Routine changes of photocathodes are performed with a dry nitrogen purged glove bag as well as a nitrogen purge of the chamber to reduce water vapor backstreaming into the chamber. The photocathode lifetimes are excellent in this system, with a lifetime of at least 200 C of charge delivered before the quantum efficiency (QE) of the cathodes drops by a factor of 1/e.

During the accelerator shutdown in February 2003, an effort was made to measure the pressure accurately in these ultra high vacuum (UHV) chambers. Two devices were used to determine the pressure in the two guns. The first is a Leybold extractor gauge, with a controller from ionivac model IM520, and extractor gauge head model number 15867. An extractor gauge is a hot filament UHV gauge with a base pressure of $1x10^{-12}$ Torr. The second device used to measure vacuum is a Stanford Research Systems (SRS) Residual Gas Analyzer (RGA). The RGA is able to determine the gas

species present in the vacuum at pressures as low as $1x10^{-12}$, but is less well calibrated as a total pressure gauging device.

DEGASSING

Before beginning the measurements, both the extractor gauge and the RGA were turned on for 4 days in the UHV environment of the gun. This allowed the gasses adsorbed on the filaments to degas and for the gauges to come into thermal equilibrium with the chamber. The commercial degas cycles on the gauges were not used since the degas cycle reduces filament lifetime and significantly increases the pressure in the chamber during the degas.

EXTRACTOR GAUGE MEASUREMENTS

After four days of running both the extractor gauge and the RGA, the RGA was turned off and the pressure read by the extractor gauge was recorded as a function of time. The extractor gauge calibration factors for each head, as determined by the manufacturer, were used in these tests.

A clear drop in the pressure as a function of time is seen in Figure 1 for the first 30 hours, and the pressure is still dropping slowly at 175 hours. A number of factors could contribute to this observation. The RGA is close to the extractor gauge head and uses a hot filament. The RGA is a hot filament gauge and was on just prior to the start of the tests, so the filament was cooling and giving off less gas for the first several hours. In addition, if the extractor gauge filament was not fully degassed at the start of the test, it could still be degassing through the test. A final scenario is that the extractor gauge is actually pumping the system slowly, bringing it to a lower pressure than during operation. Since we have seen that the extractor gauge tends to be a source of gas rather than a pump at low pressures, however, this is not likely.

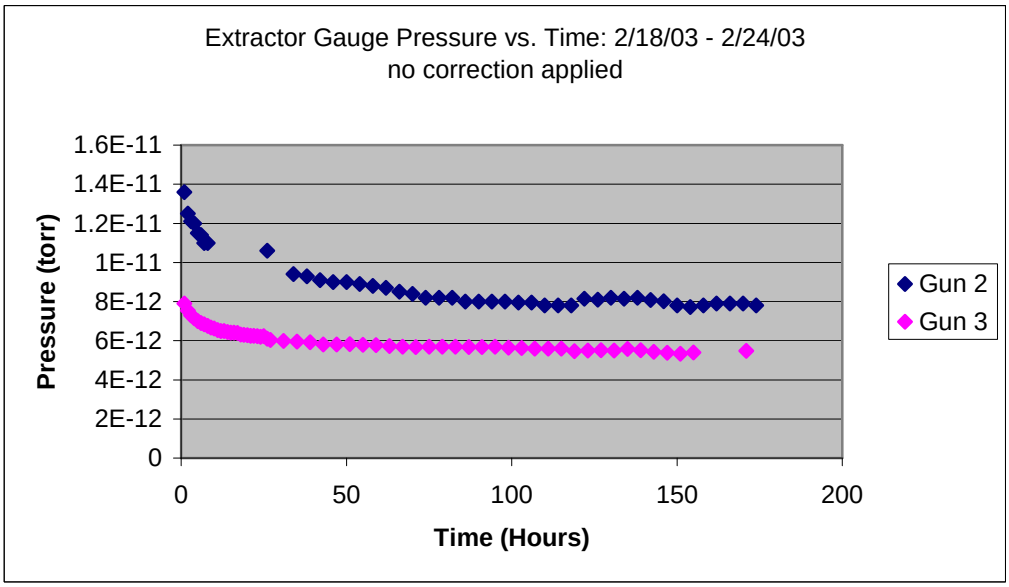


Figure 1. Shown here is the pressure recorded by the extractor gauge as a function of time. Before starting the measurement, both the RGA and the Extractor gauge were turned on and allowed to degas for 4 days. The RGA was then turned off and this measurement was started. The bump in the Gun 2 data around 120 hours is due to the recording device changing scales.

A measurement [1] performed in 1987 by H. Schmidt and H. Eichler at Inficon Laboratory showed that the reading of the extractor gauge should be multiplied by a factor of 2.7 to account for the ionization cross section of hydrogen in systems consisting primarily of hydrogen such as this chamber. Figure 2 shows the pressure readings of the extractor gauge modified with the calibration factor. This increases the ultimate pressure readings into the 10^{-11} Torr range for both guns.

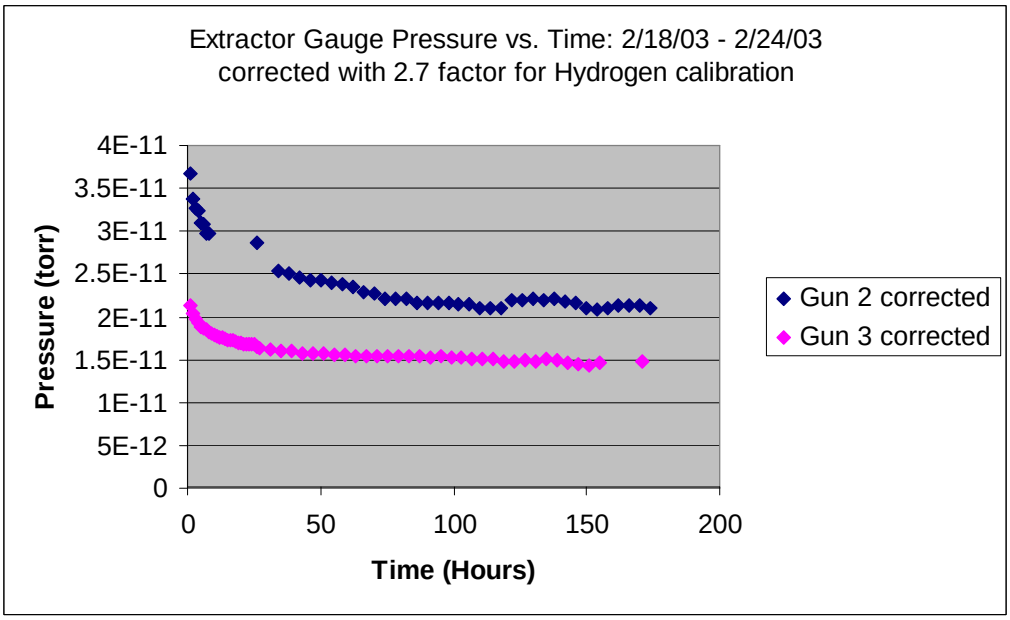


Figure 2. Extractor Gauge readings vs. time with correction factor to account for hydrogen applied.

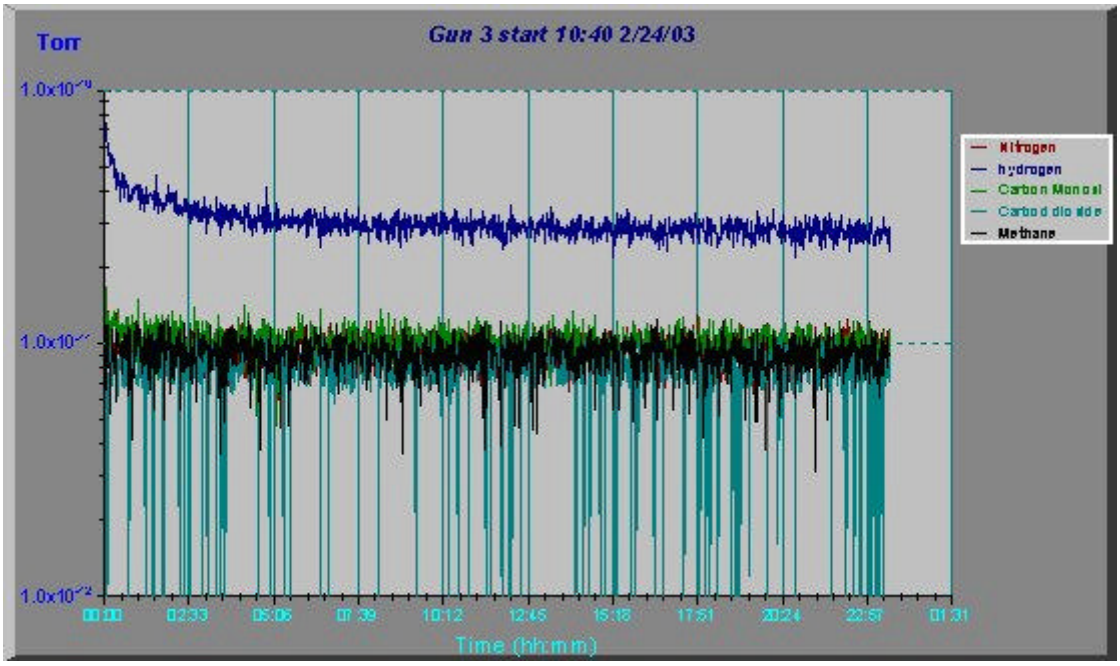
RGA MEASUREMENTS

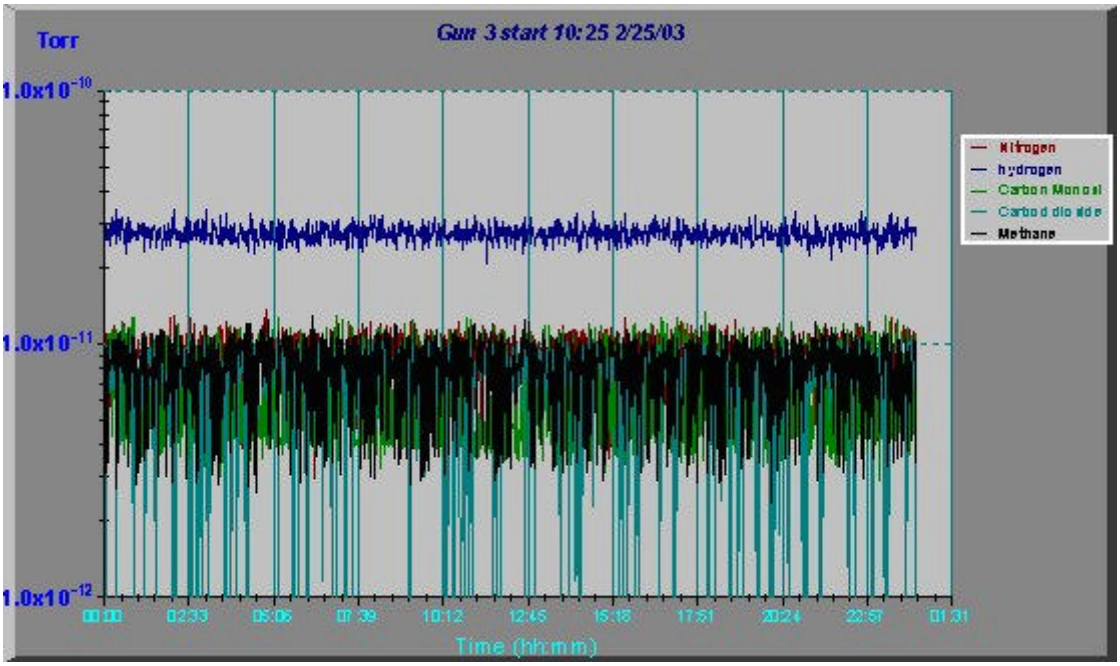
The other device which is used to measure pressure in the photoelectron guns at Jefferson Lab is an SRS RGA model 200. The RGA is a less sensitive total pressure measuring system, but is able to distinguish gas species through the use of a small quadrupole mass spectrometer with computerized readback of partial pressures of gasses of various masses.

The RGA in each gun was turned on along with the Extractor gauge for 4 days, then it was turned off for a week while the Extractor gauge measurement of pressure as made. The RGAs were then turned back on and the partial pressure of the most common gasses in a UHV system (H2, N2, CO, CO2 and Methane) were recorded as a function of time.

The RGA for Gun 2 was not functioning properly during these tests due to a CEM board that was failing, so data is not available for this gun. All RGA measurements discussed in this section will be for Gun 3.

Error! Reference source not found. shows RGA pressure vs. time for the partial pressures of the most common UHV residual gasses in Gun 3. In the first graph, it is clear that the highest partial pressure in this system is hydrogen, and that N_2, CO, CO_2 and Methane contribute much less significantly to the pressure of the gun chamber. The time that it takes for the RGA to settle to a steady state value is on the order of 10 hours, after which little pressure change is seen.


Torr
Gun 3 start 10:40 2/24/03
1.0x10⁻⁹
1.0x10⁻¹¹
1.0x10⁻¹³
00:00
02:33
05:06
07:39
10:12
12:45
15:18
17:51
20:24
22:57
01:31
Time (hh:mm)
Nitrogen
hydrogen
Carbon Monoxi
Carbon dioxide
Methane


Torr
Gun 3 start 10:25 2/25/03
1.0x10⁻¹⁰
1.0x10⁻¹¹
1.0x10⁻¹²
00:00
02:33
05:06
07:39
10:12
12:45
15:18
17:51
20:24
22:57
01:31
Time (hh:mm)
Nitrogen
hydrogen
Carbon Monoxi
Carbon dioxide
Methane

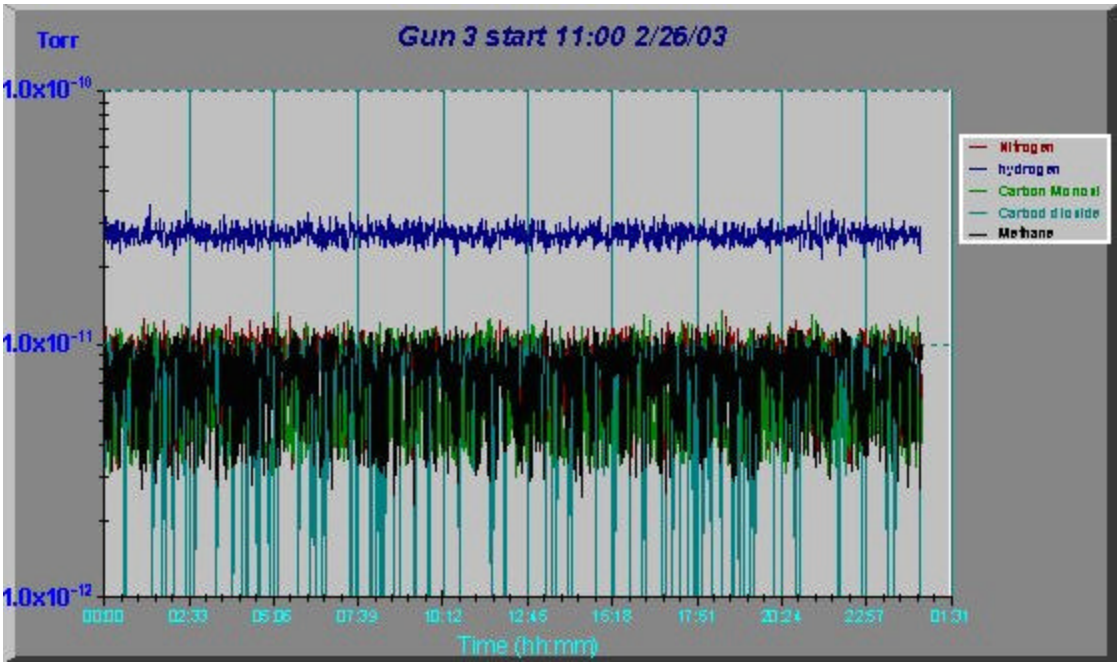
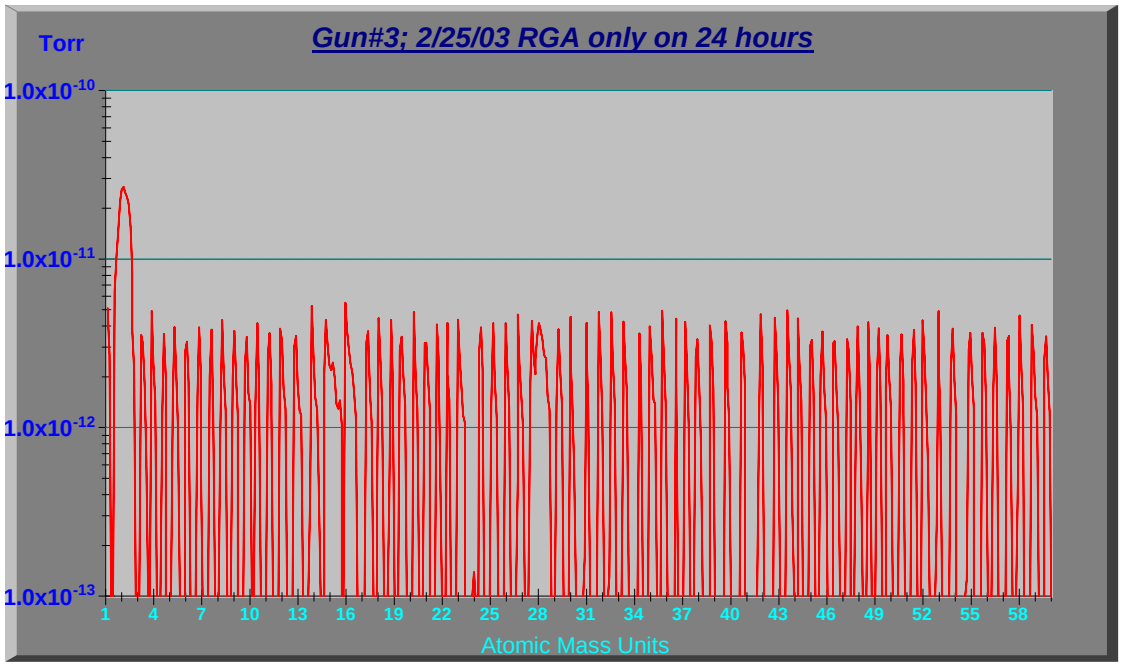
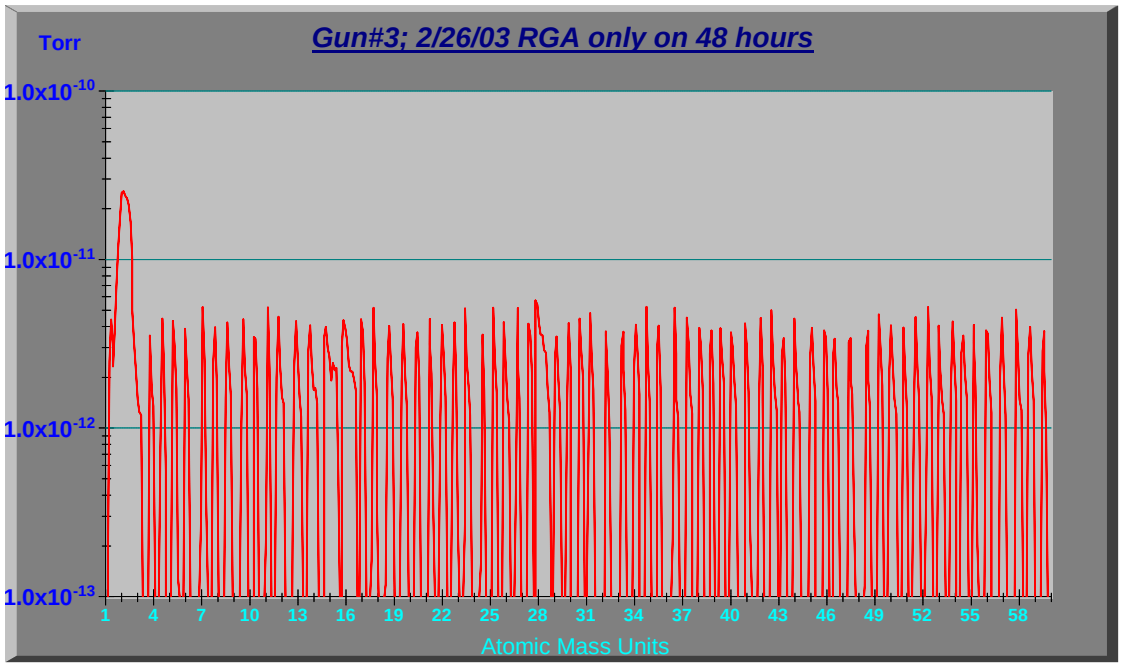


Figure 3 Pressure vs. Time graphs for Gun 3. Hydrogen is the top curve in all graphs, and the other residual gasses (N_2, CO, CO_2 and Methane) are all in the lower lines. Each graph is approximately 25 hours in the x-axis, and the y-axis scale is logarithmic from $1x10^{-12}$ – $1x10^{-10}$.

The RGA traces of pressure vs. gas species are shown in figure 4. The predominant species in the system, as is true of most UHV systems, is Hydrogen at mass 2. Slight peaks are seen at 14, 19, and 28, indicating residual of N_2, CO and F. The fluorine is from dissociated NF_3 gas that is used in these chambers to activate the photocathodes.


Gun#3; 2/25/03 RGA only on 24 hours
Torr
1.0x10-10
1.0x10-11
1.0x10-12
1.0x10-13
1 4 7 10 13 16 19 22 25 28 31 34 37 40 43 46 49 52 55 58
Atomic Mass Units


Gun#3; 2/26/03 RGA only on 48 hours
Torr
1.0x10-10
1.0x10-11
1.0x10-12
1.0x10-13
1 4 7 10 13 16 19 22 25 28 31 34 37 40 43 46 49 52 55 58
Atomic Mass Units

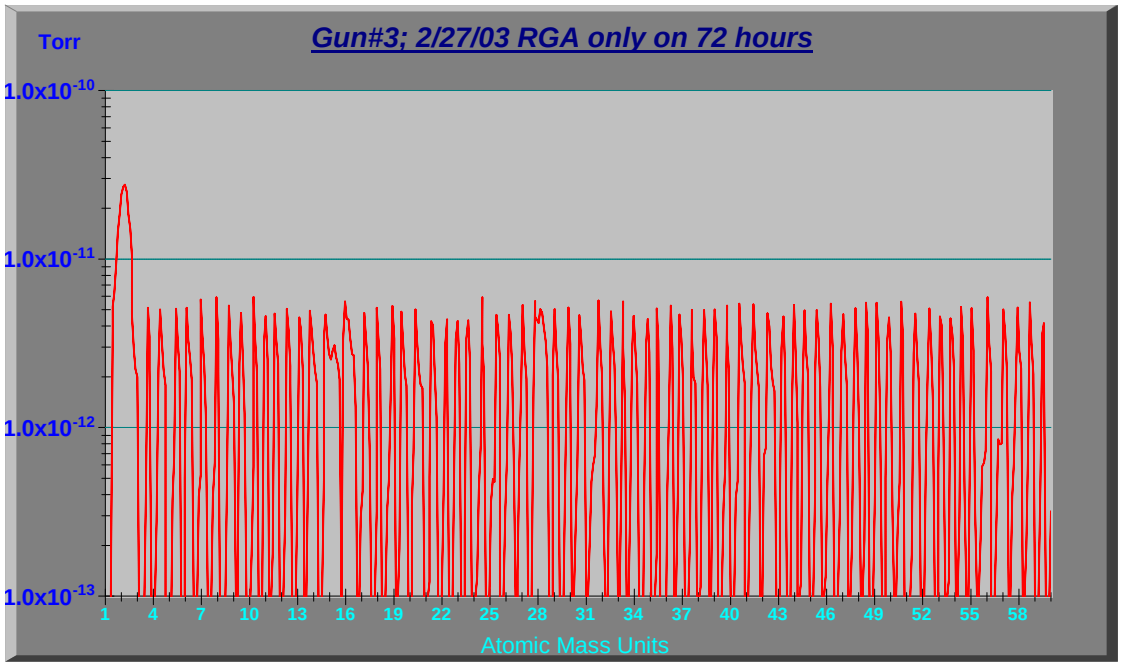


Figure 4. Shown here are RGA traces for Gun 3 at 24, 48 and 72 hours of only the RGA on. They look quite similar, with hydrogen partial pressure at 2.4×10^{-11} and everything else between 4×10^{-12} and 10×10^{-12}.

Using the RGA table function, which allows the RGA library to more significantly analyze the different mass ratios to determine species, the partial pressures of H_2, N_2, CO, CO_2 and Methane in the system at a time of 72 hours were as shown in Table 1. Included in the third column is a correction factor suggested by G.R.Myneni that may be necessary if the RGA software doesn't compensate properly for the pressure of hydrogen gas at low pressures.

TABLE 1. Residual Gasses, GUN 3

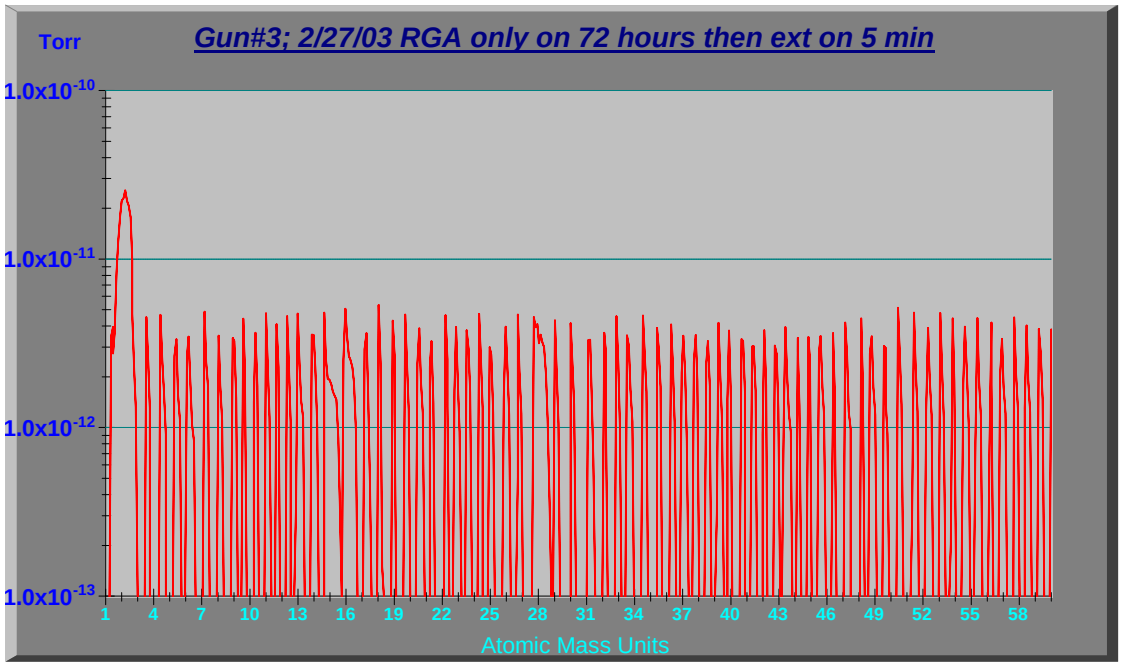
Gas Species	Partial Pressure	Correction for Hydrogen
Hydrogen	2.4×10^{-11}	1.6×10^{-11}
Nitrogen	9.8×10^{-12}	
Carbon Dioxide	3.8×10^{-12}	
Carbon Monoxide	7.9×10^{-12}	
Methane	1.1×10^{-11}	
Total Pressure (summation)	5.65×10^{-11}	4.85×10^{-11}

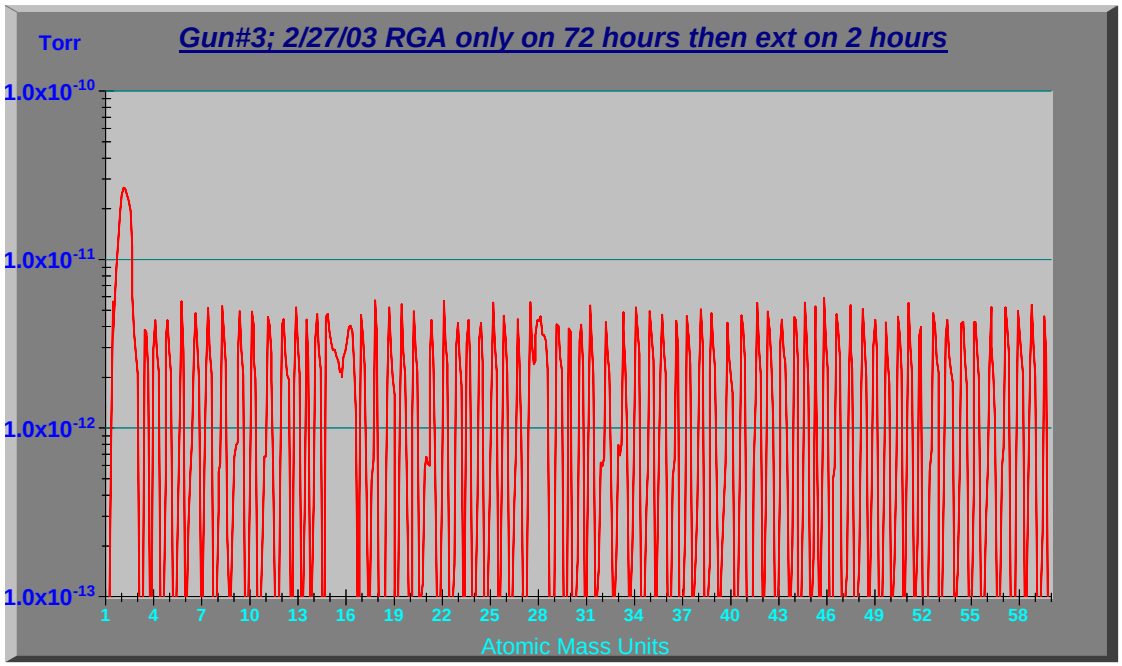
Table 1. Residual gasses by species after the RGA was on alone for 72 hours. Total pressure was determined by summing the partial pressures of the gas species detected in the system. A correction factor for hydrogen (divide by 1.5) has been suggested by G.R.Myneni may be necessary. Total pressure, obtained by summing the contributions of the shown gas species, is listed at the bottom.

The total pressure in Gun 3 as determined by the extractor gauge (with its scaling factor of 2.7) and by the RGA are quite close, at 1.5×10^{-11} for the extractor vs. 5.6×10^{-11} for the RGA.

To see what gases are introduced into the system by the hot filament of the extractor gauge, RGA scans were taken at 5 minutes, 2 hours and 22 hours after the extractor filament was turned on. As expected, the methane and CO background in the chamber rise slightly when the hot filament of the extractor gauge is turned on,

then fall back to nominal values as the extractor degasses by 22 hours. These traces are shown in Figure 5.


Gun#3; 2/27/03 RGA only on 72 hours then ext on 5 min
Torr
1.0x10-10
1.0x10-11
1.0x10-12
1.0x10-13
1 4 7 10 13 16 19 22 25 28 31 34 37 40 43 46 49 52 55 58
Atomic Mass Units


Gun#3; 2/27/03 RGA only on 72 hours then ext on 2 hours
Torr
1.0x10-10
1.0x10-11
1.0x10-12
1.0x10-13
1 4 7 10 13 16 19 22 25 28 31 34 37 40 43 46 49 52 55 58
Atomic Mass Units

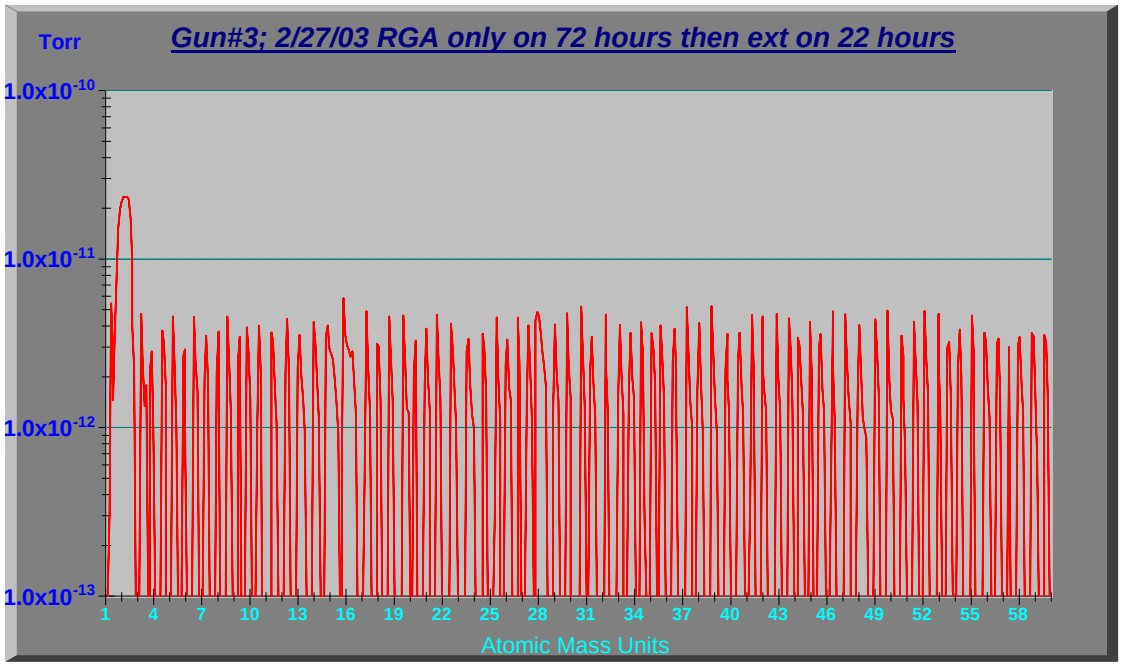


Figure 5. Pressure vs. Mass for 5 minutes, 2 hours, and 22 hours after turning on the extractor gauge with the RGA on. Between 5 minutes and 2 hours, the methane peak (mass 14-18) and CO (mass 28) are seen to rise a bit, then fall back to the nominal values by 22 hours.

HISTORICAL VACUUM PERFORMANCE

The original design for the polarized photoelectron gun came from the University of Illinois. Two guns were made from this design, with the first being installed in the tunnel and the second being installed in the Injector Test Stand (Test Cave). The original tunnel gun had no NEG pumping, and its vacuum performance is not recorded here. The first NEG pumped gun vacuum performance is recorded here from its initial tests in the test cave, its installation in the tunnel as a vertical and its eventual reorientation to become horizontal gun 2. Horizontal gun 3 was built at the same time as the first NEG gun was re-assembled as horizontal gun 2 in July 1999.

Throughout the history of the NEG pumped photoelectron guns at Jefferson Lab, vacuum measurements have been made whenever possible. Pressures for the extractor gauge throughout this section have not had the correction factor of 2.7 applied. RGA readings are primarily for the partial pressure of H_2 in the system only. Table 2 shows a compilation of many of the pressure measurements throughout the operation of the NEG guns at Jefferson Lab. Figure 6 plots these results vs. time.

TABLE 2. Historical NEG gun pressure readings

Date	Source	Gun	Pressure
13 Oct 1997	Polog 190	Vertical NEG (TC)	1.9×10^{-11}
22 Dec 1997	Polog 315	Vertical NEG (TC)	9×10^{-12}
7 Jan 1998	Polog 340	Vertical NEG (TC)	1×10^{-11}
February 1998: Vertical NEG Gun moved from Test Cave to Tunnel			
July 1999: Vertical NEG Gun becomes Horizontal Gun 2 and Gun 3 is built			
3 July 2000	Polog 7057	Gun 2	3.0×10^{-11}
15 Aug 2000	Polog 7619	Gun 2	3.62×10^{-11}
24 Oct 2000	Polog 8608	Gun 2	2.40×10^{-11}
2 January 2001	Polog 9467	Gun 2	8.40×10^{-12}
8 January 2001	Polog 9563	Gun 3	9.40×10^{-12}
24 Feb 2003	Polog 1138945	Gun 2	7.8×10^{-12}
24 Feb 2003	Polog 1138945	Gun 3	5.4×10^{-12}

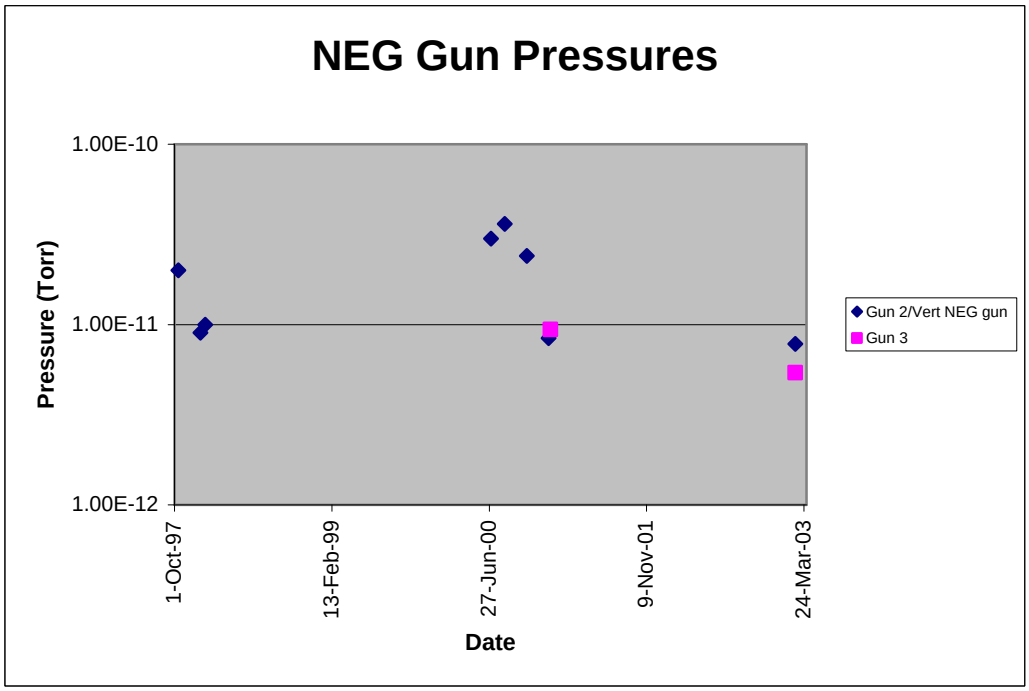


Figure 6: This graph shows the available data for pressure as a function of time in the Jefferson Lab NEG guns. Data from the first NEG gun, which operated in the test cave until February 1998 then as a vertical gun in the tunnel until July 1999 when it was turned into horizontal gun 2, is shown in blue. Horizontal gun 3 data is shown in pink. Data points that are quite high may be a result of the gauges not being allowed to degas fully before the measurements were made, or made shortly after the RGA was turned off.

SUMMARY

Both Gun 2 and Gun 3 of the CEBAF polarized source have excellent vacuum properties. The raw extractor gauge readings for these guns are 7.8×10^{-12} Torr and

5.4×10^{-12} Torr respectively, which are as good as the historical data for these chambers. Corrected with the calibration factor to account for hydrogen, Gun 2 is 2.1×10^{-11} Torr and Gun 3 is 1.5×10^{-11} Torr. While RGA data was not available for comparison with Gun 2, the data from Gun 3 was in rather close agreement with the hydrogen partial pressure at 2.4x10-11 Torr and the total pressure at 5.6×10^{-11}.

The lifetimes of these guns are comparable to past performance (JLAB-TN-03-007) and the vacuum levels are currently at least as good as any previously measured at CEBAF.

REFERENCES

1. H. Schmidt and H. Eichler, Inficon Laboratory, Report 03, *"Gasartabhangigkeit der Empfindlichkeit fur Verschiedene LH Ionisationsvakuummetertypen"*, 1987.