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Characterization of Common Electron Multipliers in Harsh Environments

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Introduction

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- Mass Spectrometers are a valuable tool for use in demanding applications such as drug discovery, semiconductor manufacturing and food processing. The unique capability of a mass spectrometer to identify minute amounts of unknown materials sets this instrument apart from almost all others.

- The typical Mass Spectrometer has three key components: The ionization source, the mass filter and the detector.

Discussion

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- Homeland security requirements are now driving the development of field portable instruments that can provide laboratory grade analysis.
- In order to reduce the size, weight and power consumption of a portable mass spectrometer, it is often necessary to deviate from the normal operating environment inside the vacuum system.

Objective

- The objective of this project was to characterize the performance of various electron multipliers under harsh test conditions.

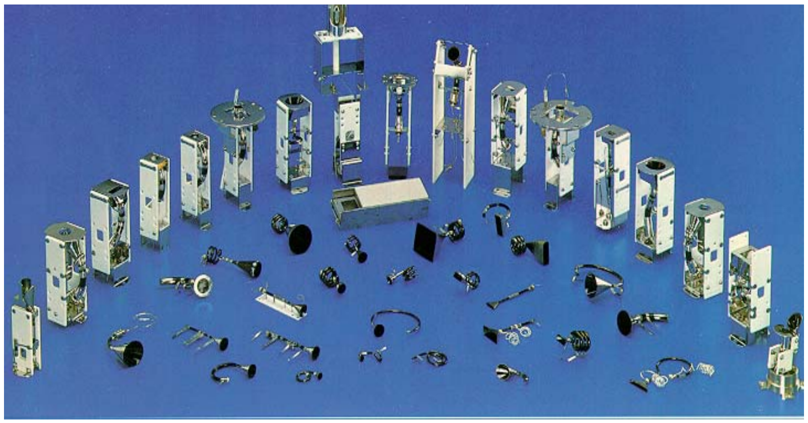
- There are 3 main types of Electron Multipliers:

- Single Channel Electron Multipliers

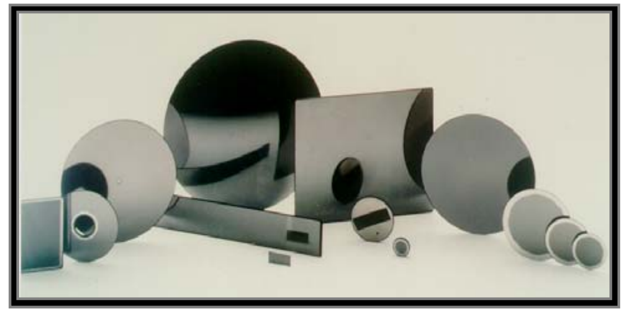
- Microchannel Plate based Detectors

-Discrete Dynode Multipliers

Various Types of Electron Multipliers



Single Channel Electron Multipliers



Microchannel Plates

Magnum® 6 Channel Multipliers

Discrete Dynode

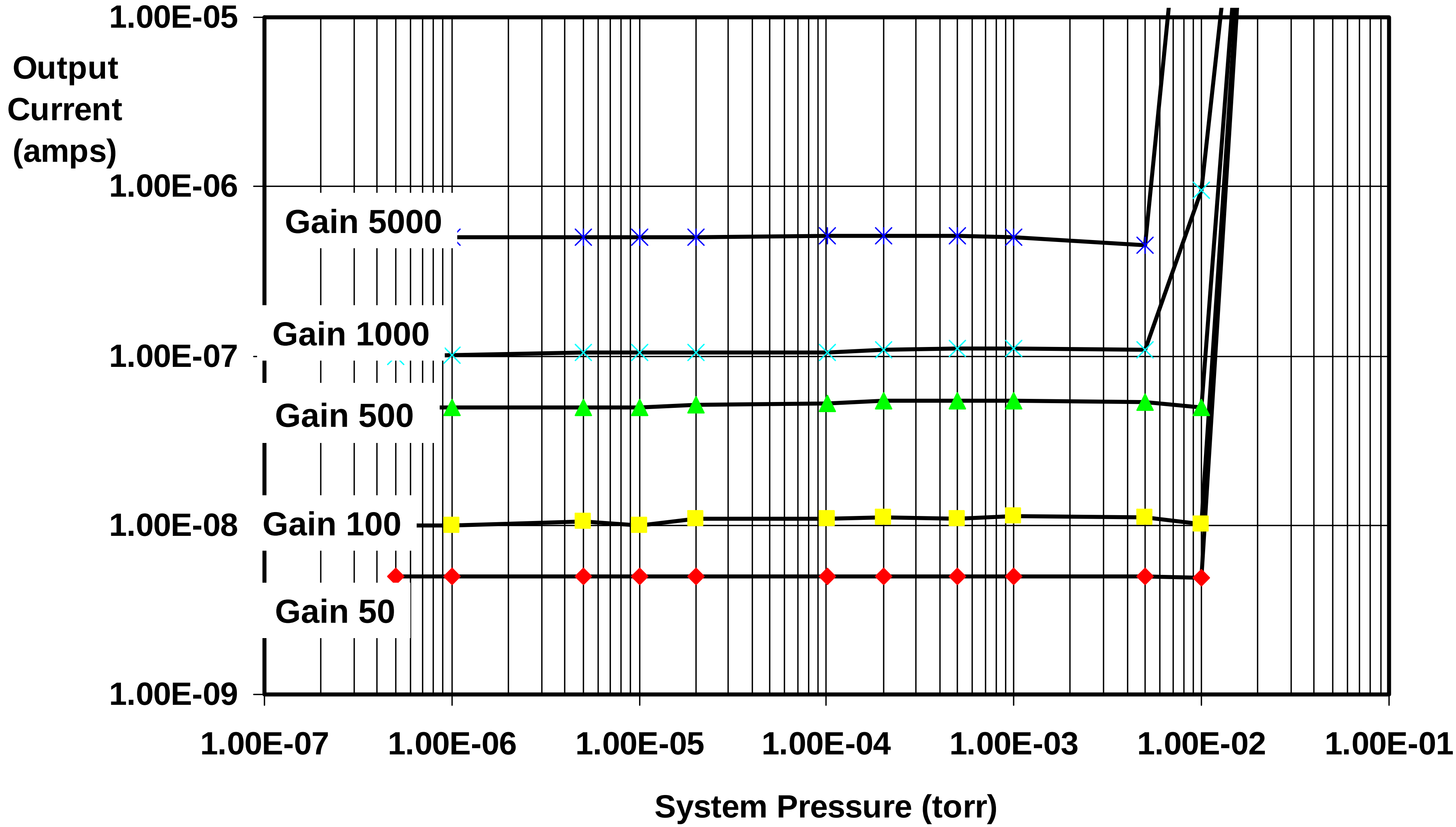
Microchannel Plate Detectors

Vacuum Conditions

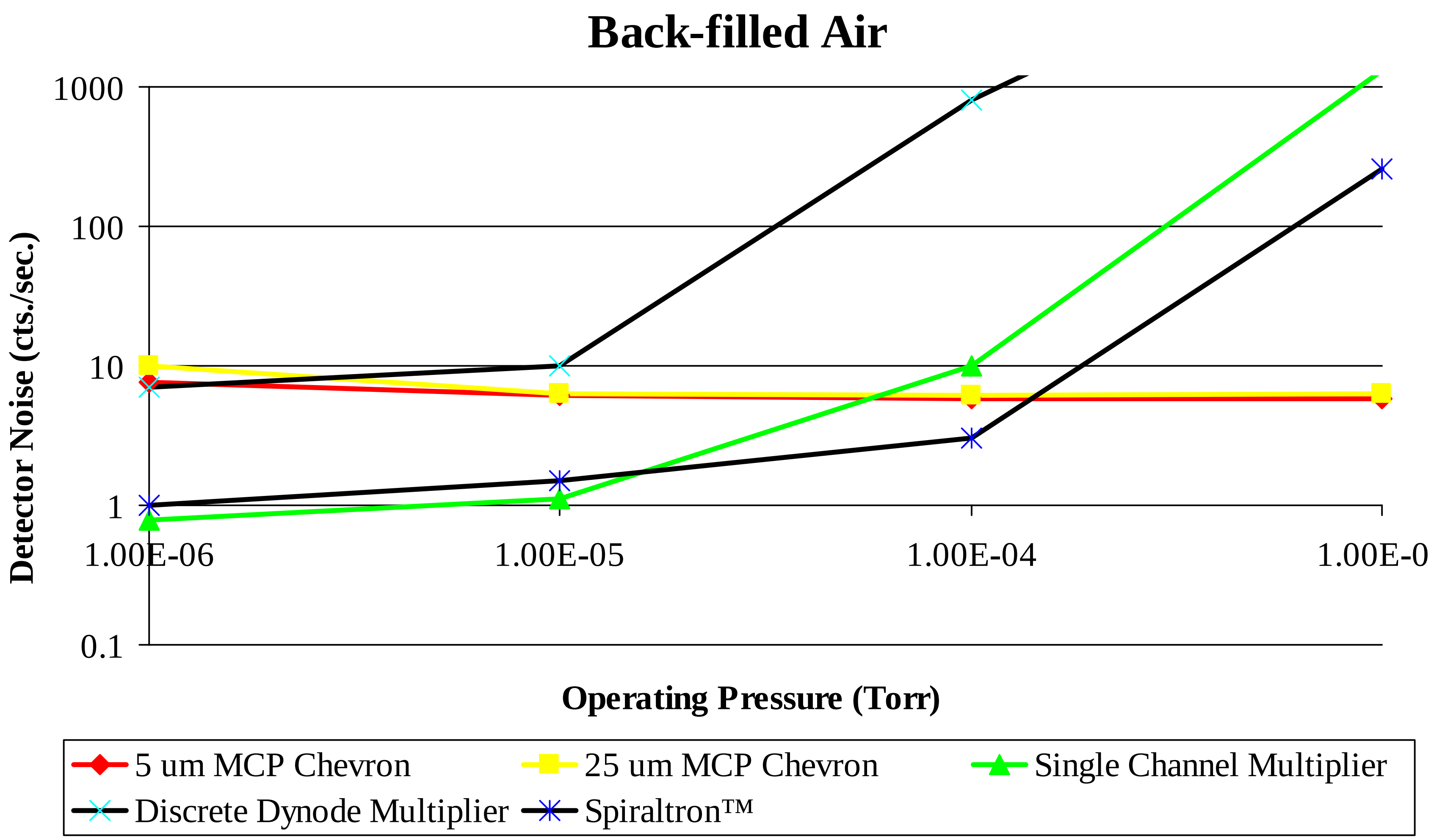
- Typical MALDI Time-of-Flight Mass Spectrometers require an ion flight path length of 1 to 2 meters.
- Modern quadrupole based instruments typically operate at vacuum pressures in the high 10^{-6} Torr range because ions need to travel 25 cm. or more before they reach the detector without colliding with residual gas molecules.
- If it were possible to shrink the flight path length requirement to less than 5cm (approx... 2”) then it should be possible to operate a system in the milli-Torr range.
- Milli-Torr vacuum levels can be achieved with simple low cost vacuum pumps.
- Multiplier performance outside of the normal 10^{-6} Torr operating range has not been well characterized.

The Effects of Poor Operating Pressure on Detector Gain and Noise

Single Stage MCP Analog Operation in Argon at Various Gain Settings



Noise vs. Operating Pressure For Various Electron Multipliers



Miniature MCP Detector Noise as a Function of Vacuum Pressure

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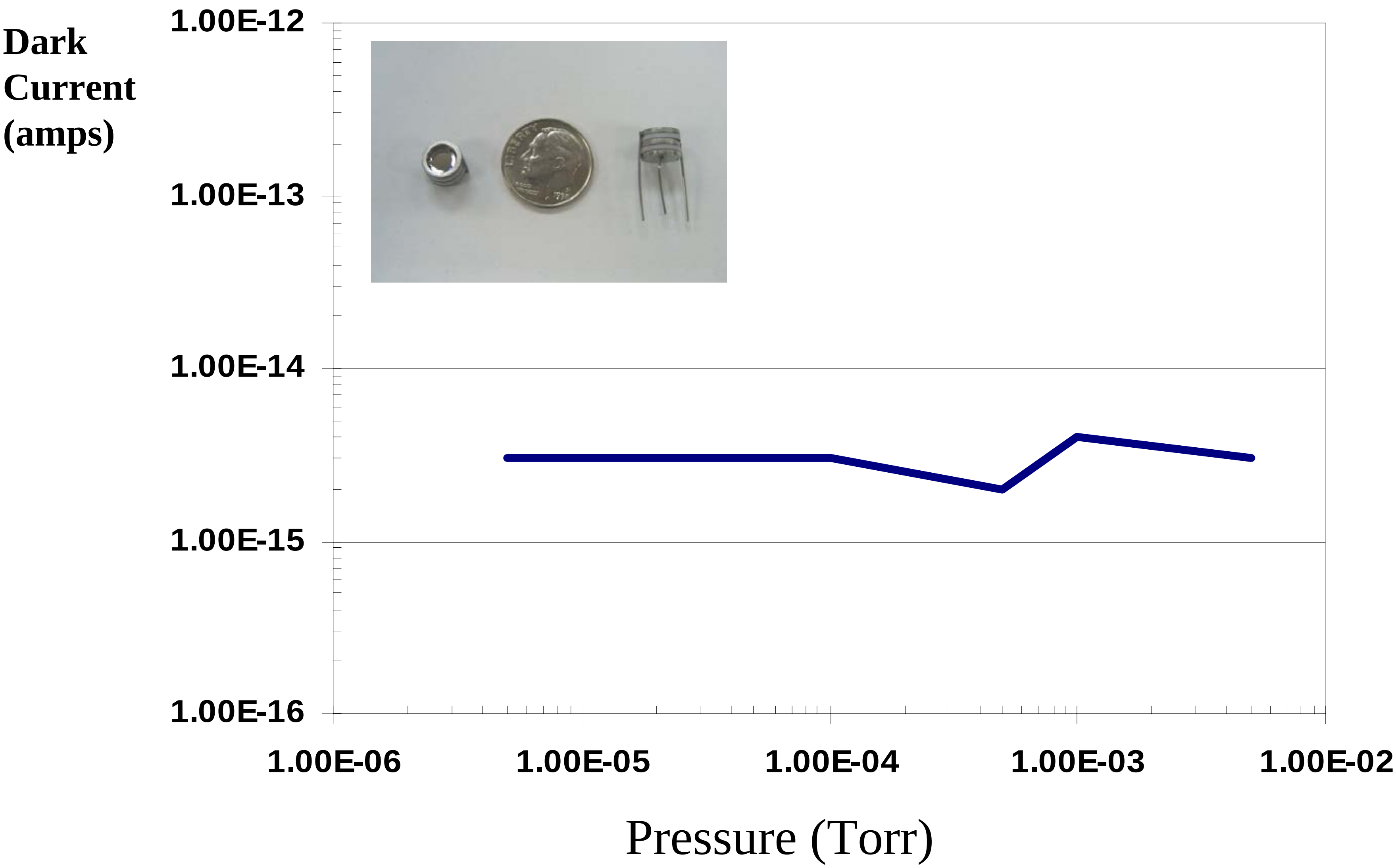
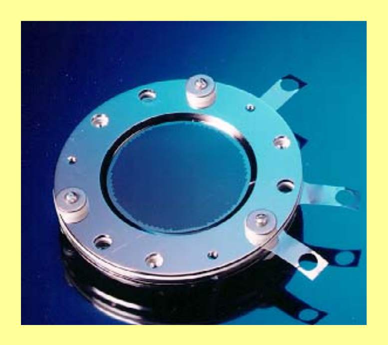
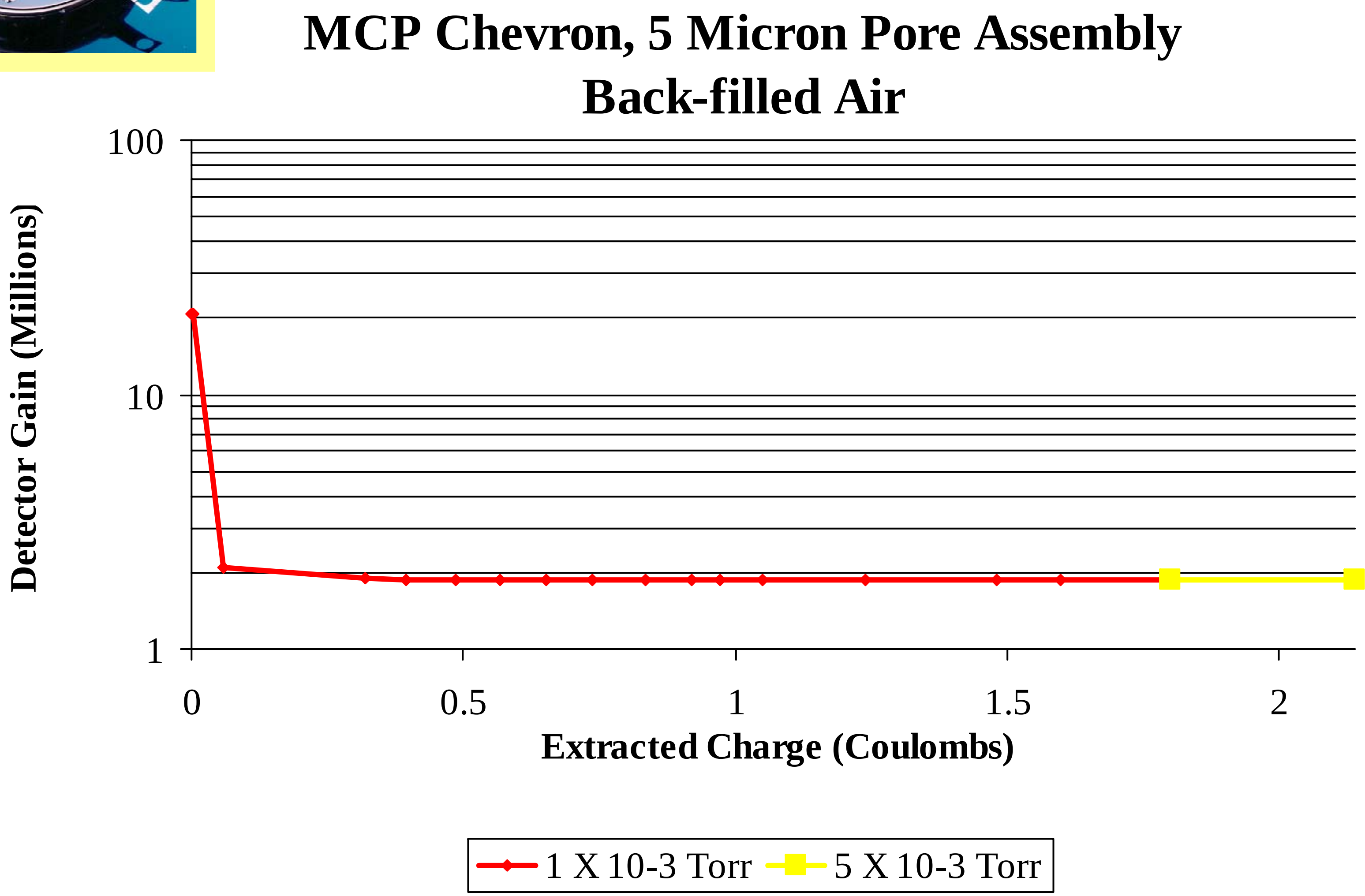
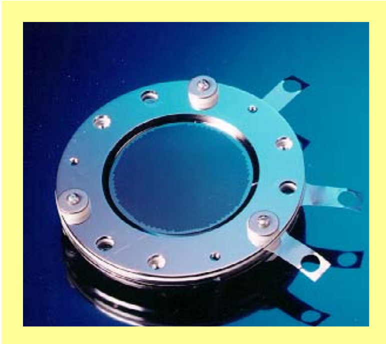


The Effects of Poor Operating Pressure on Multiplier Lifetime

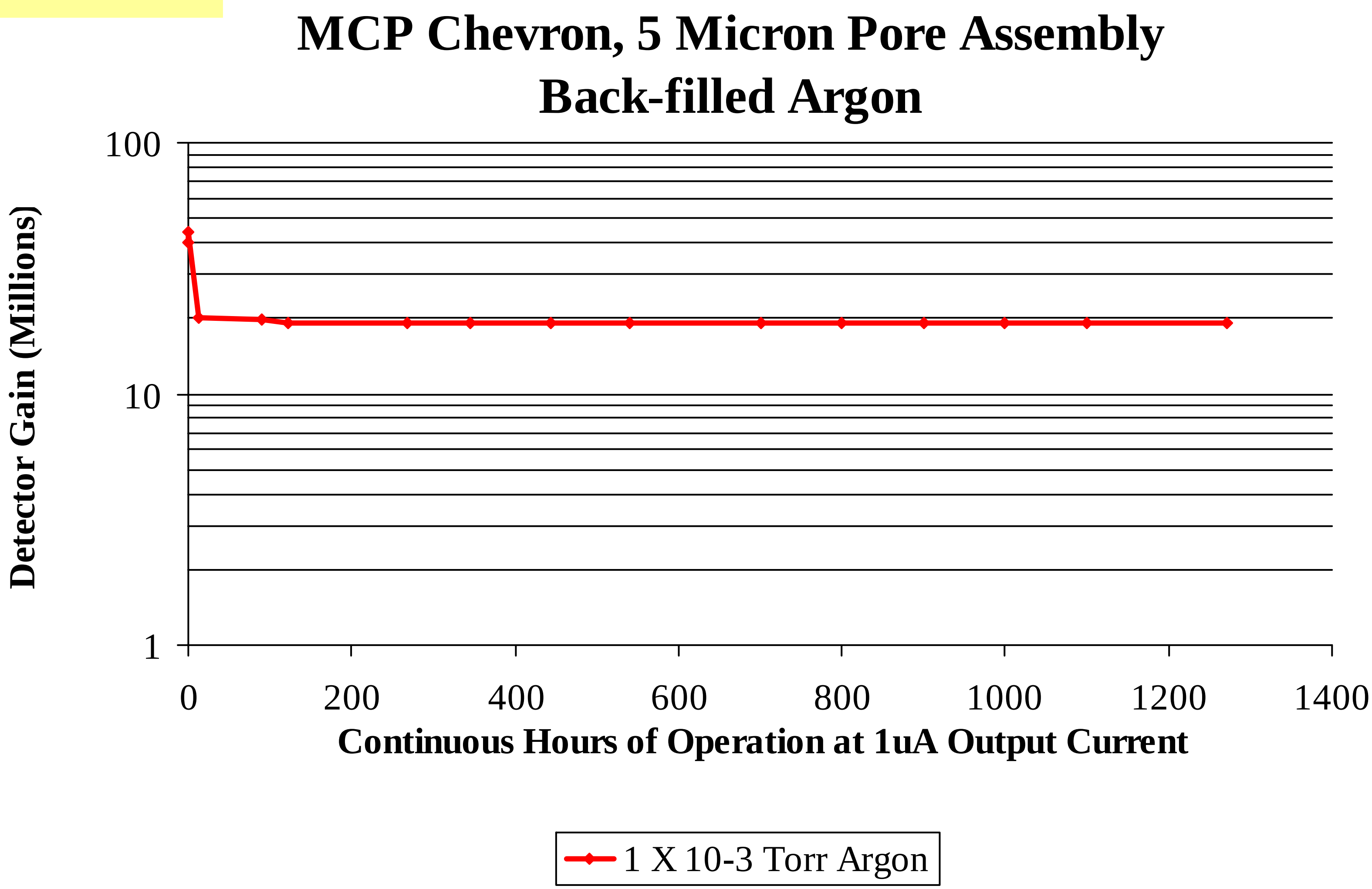


Lifetime at High Pressure:





Lifetime at High Pressure



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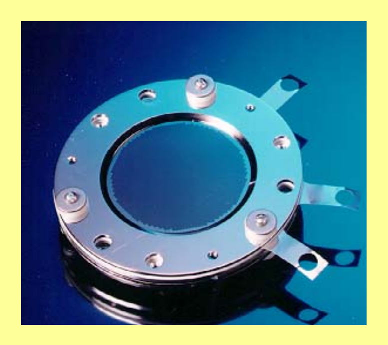
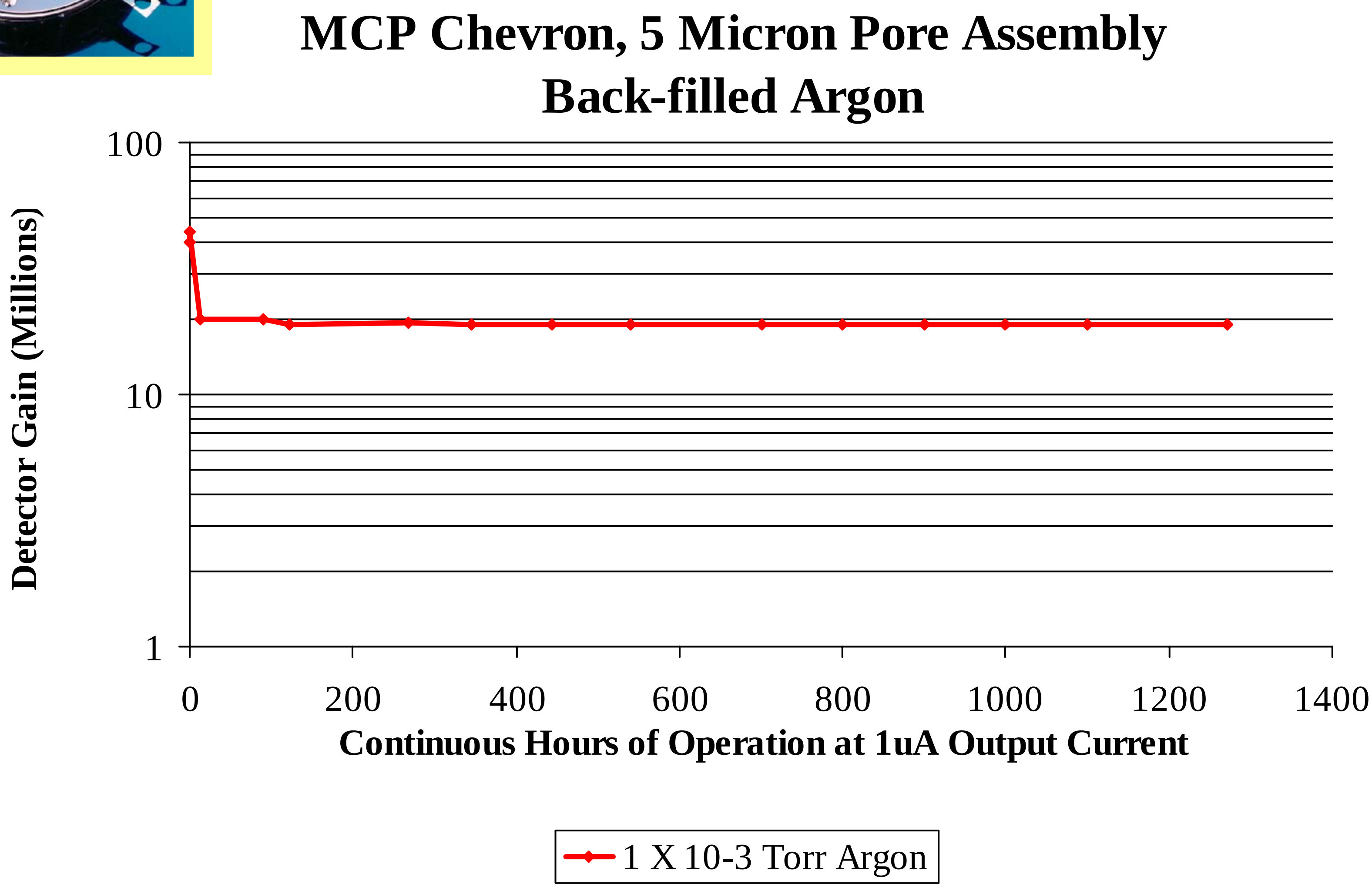
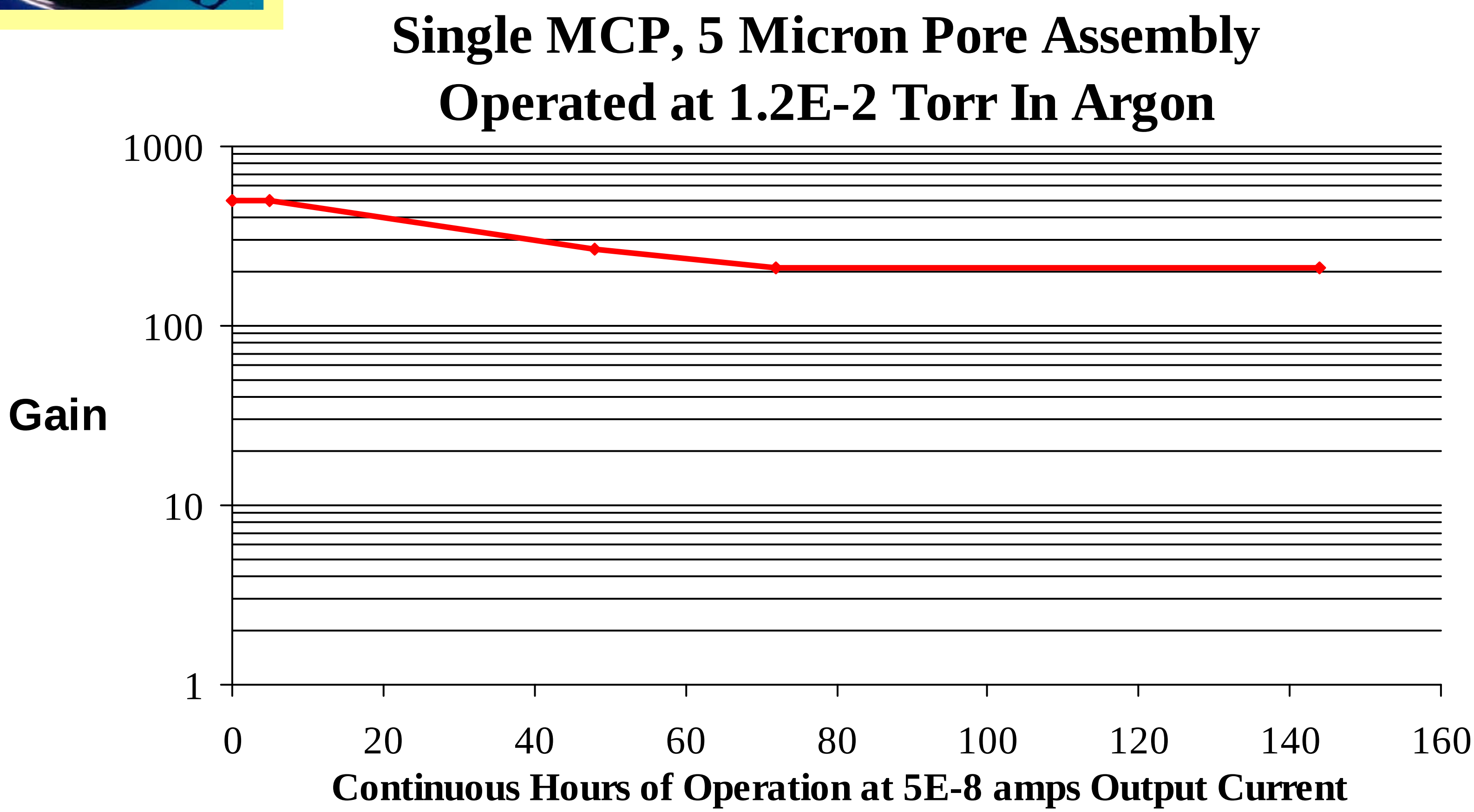
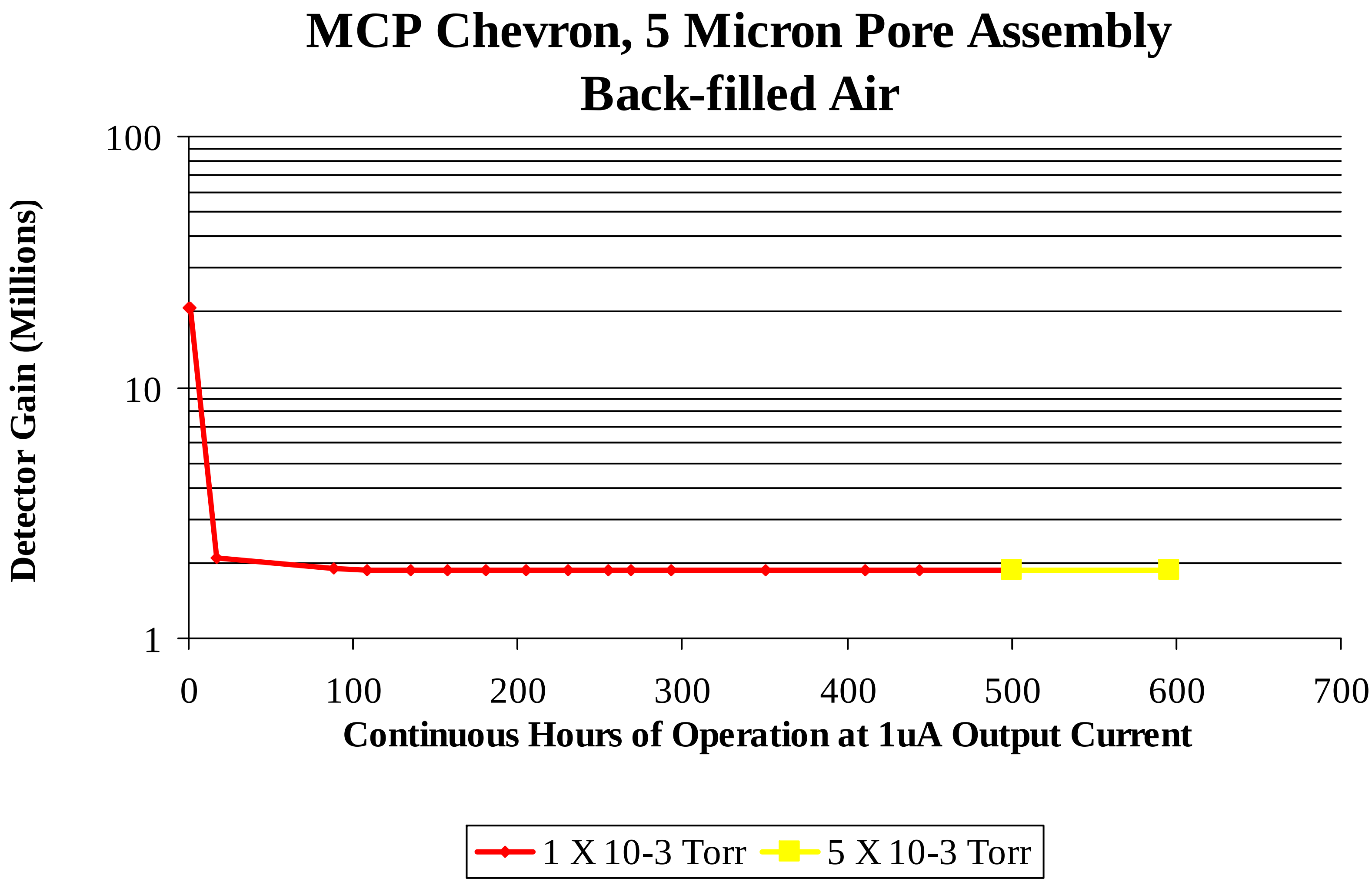




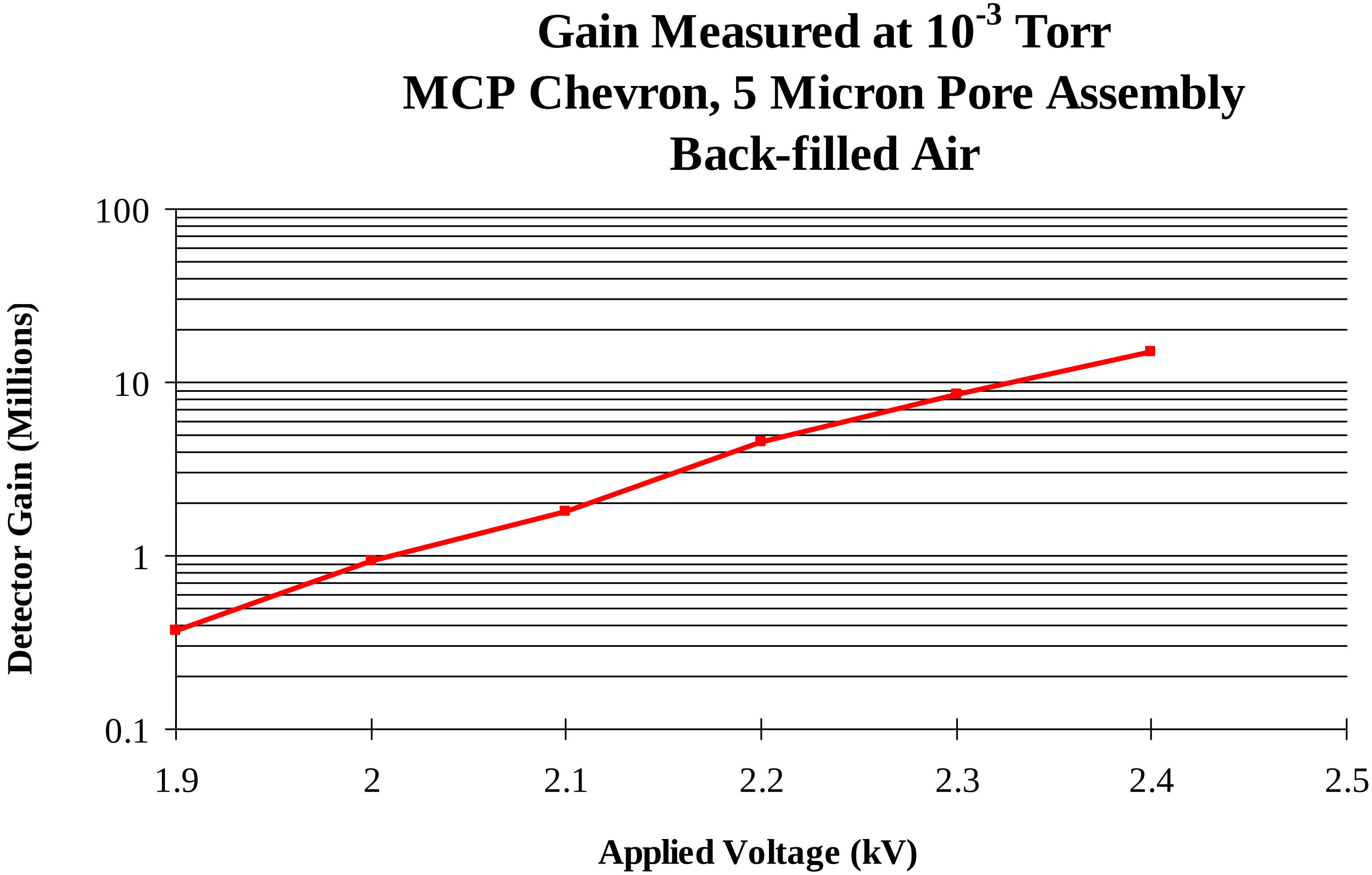
Lifetime at High Pressure:



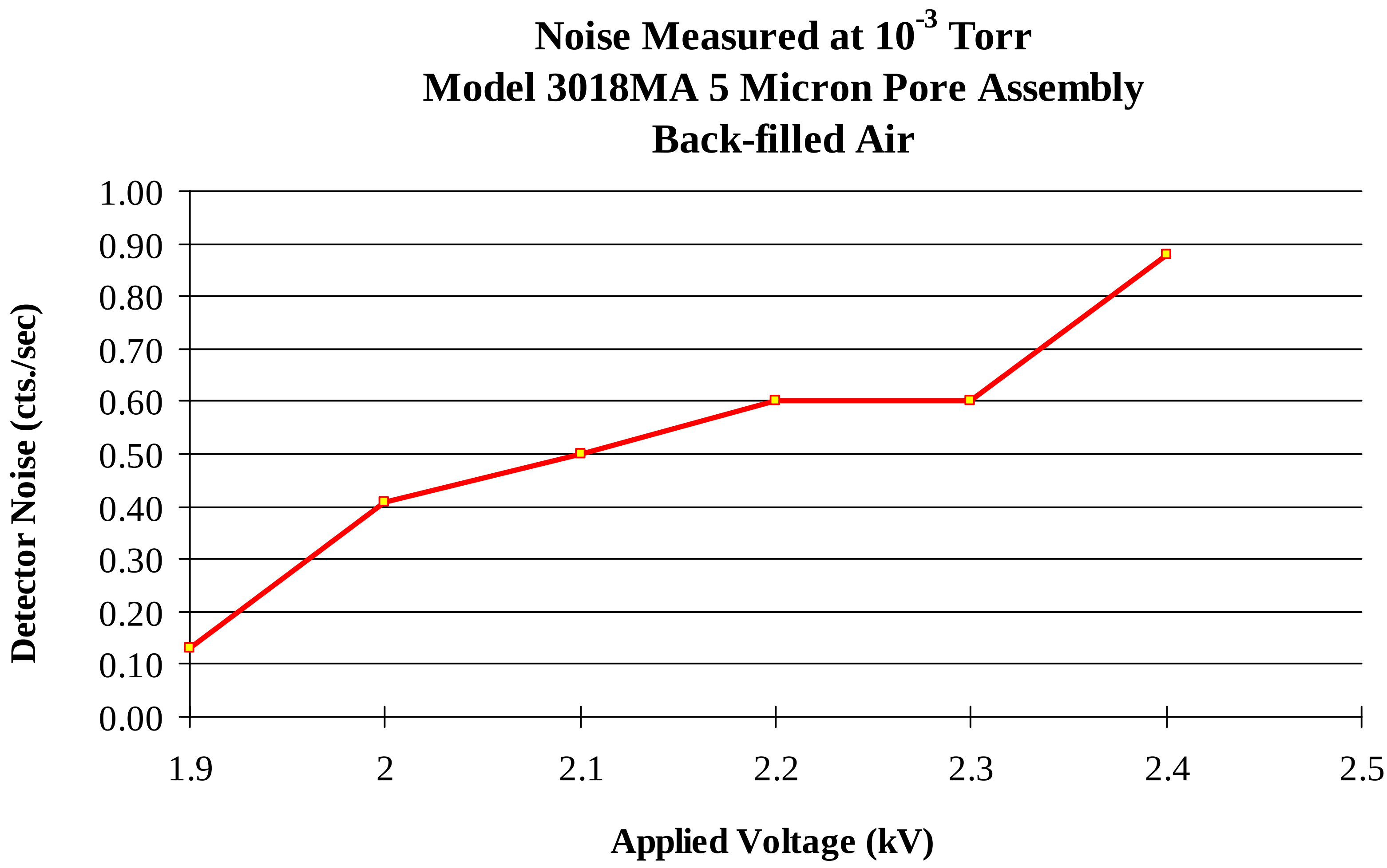
Lifetime at High Pressure:



Performance After 300 Hours:



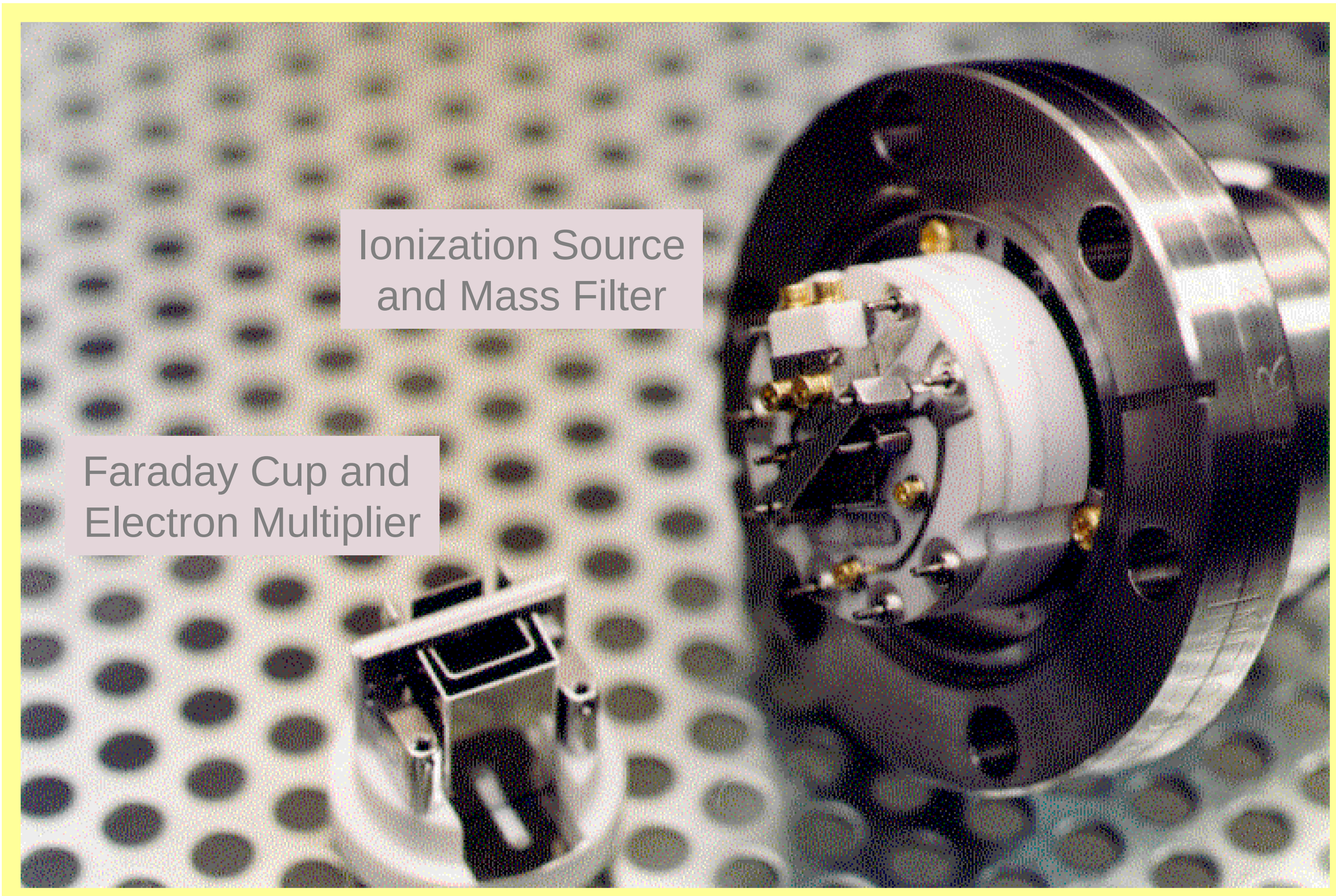
Performance After 300 Hours:



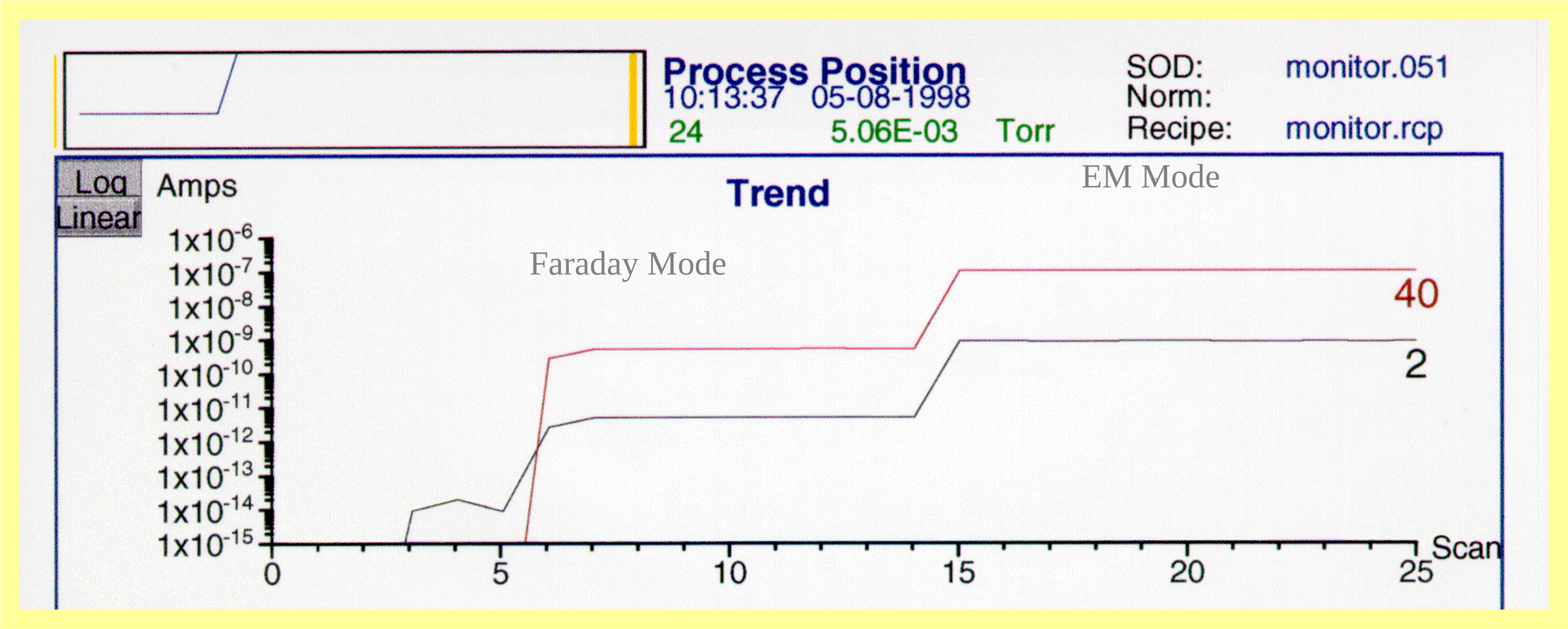
Experimental Apparatus

- The experimental apparatus consisted of an Inficon XPR-III Residual Gas Analyzer (0-100 AMU) utilizing a microchannel plate/faraday detector mounted to a turbo pumped vacuum chamber.
- Chamber pressure was modulated using a Granville Philips precision leak valve connected to choice backfill gases.
- Sensor pressure was monitored using a combination of calibrated Veeco ionization tubes and Granville Philips convectrons.

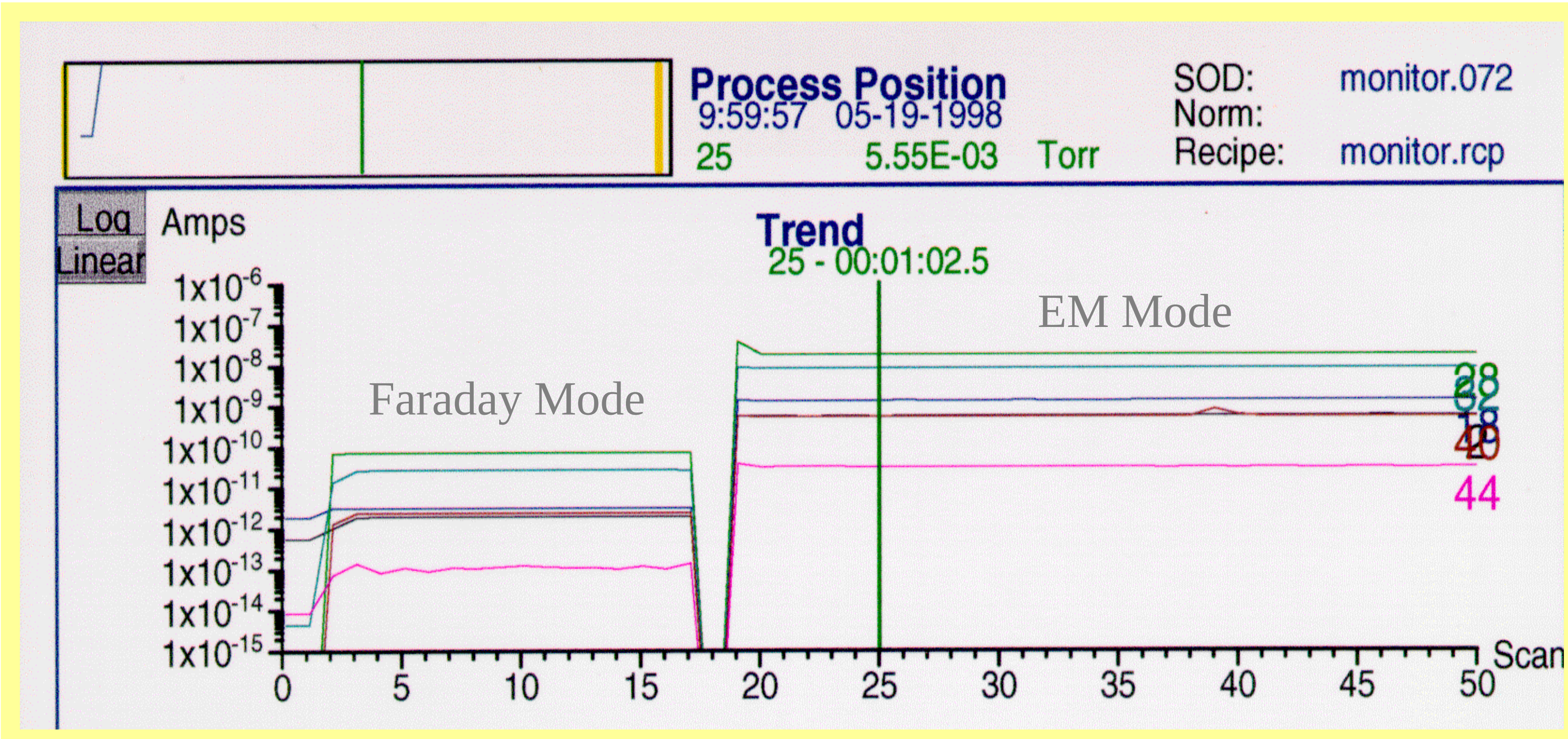
Miniature Mass Spectrometer and Electron Multiplier



Argon and Hydrogen at 5 milli-Torr, Utilizing a Microchannel Plate Based Electron Multiplier



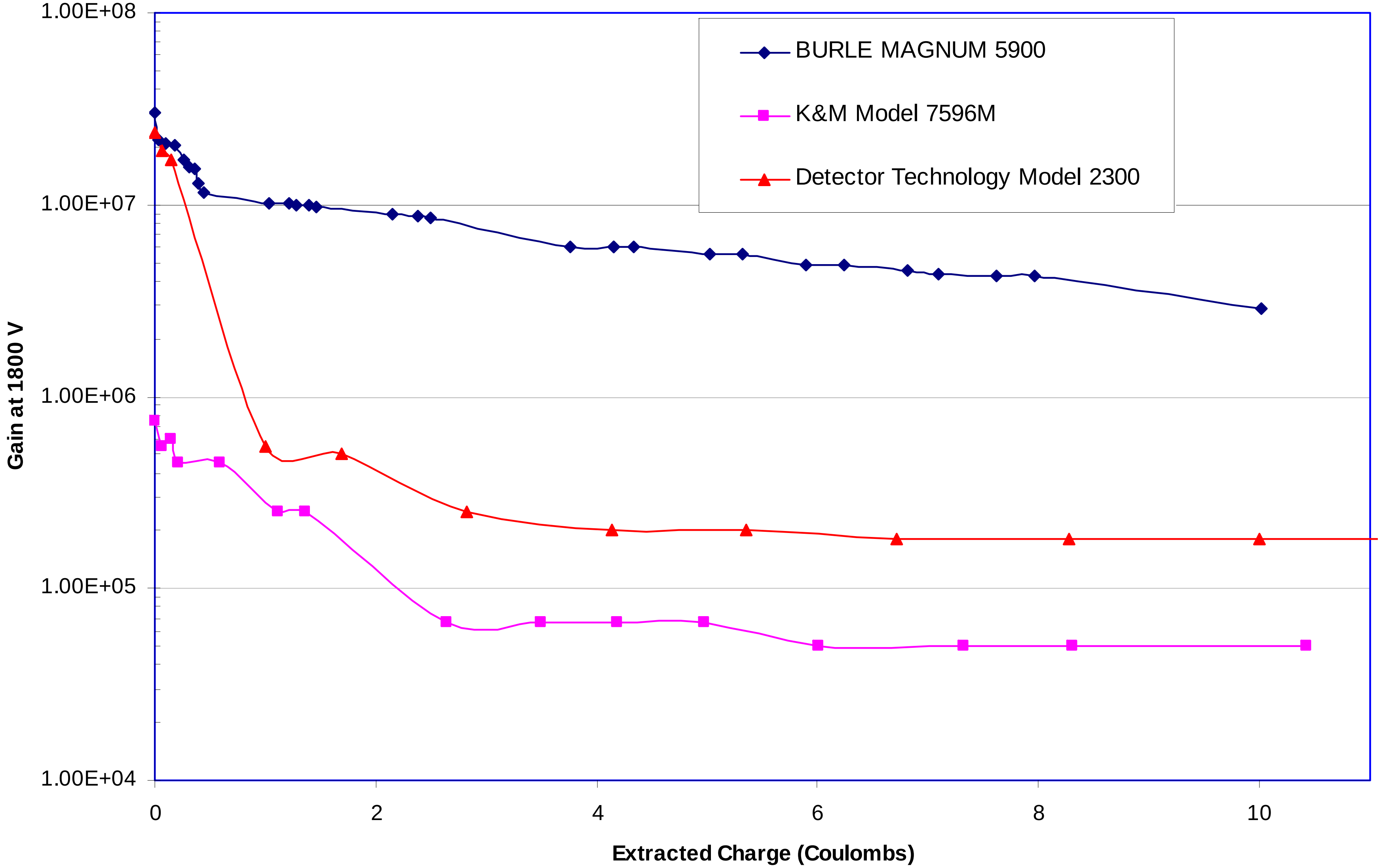
Lab Air Collected at 5.5 milli-Torr



Chemical Durability

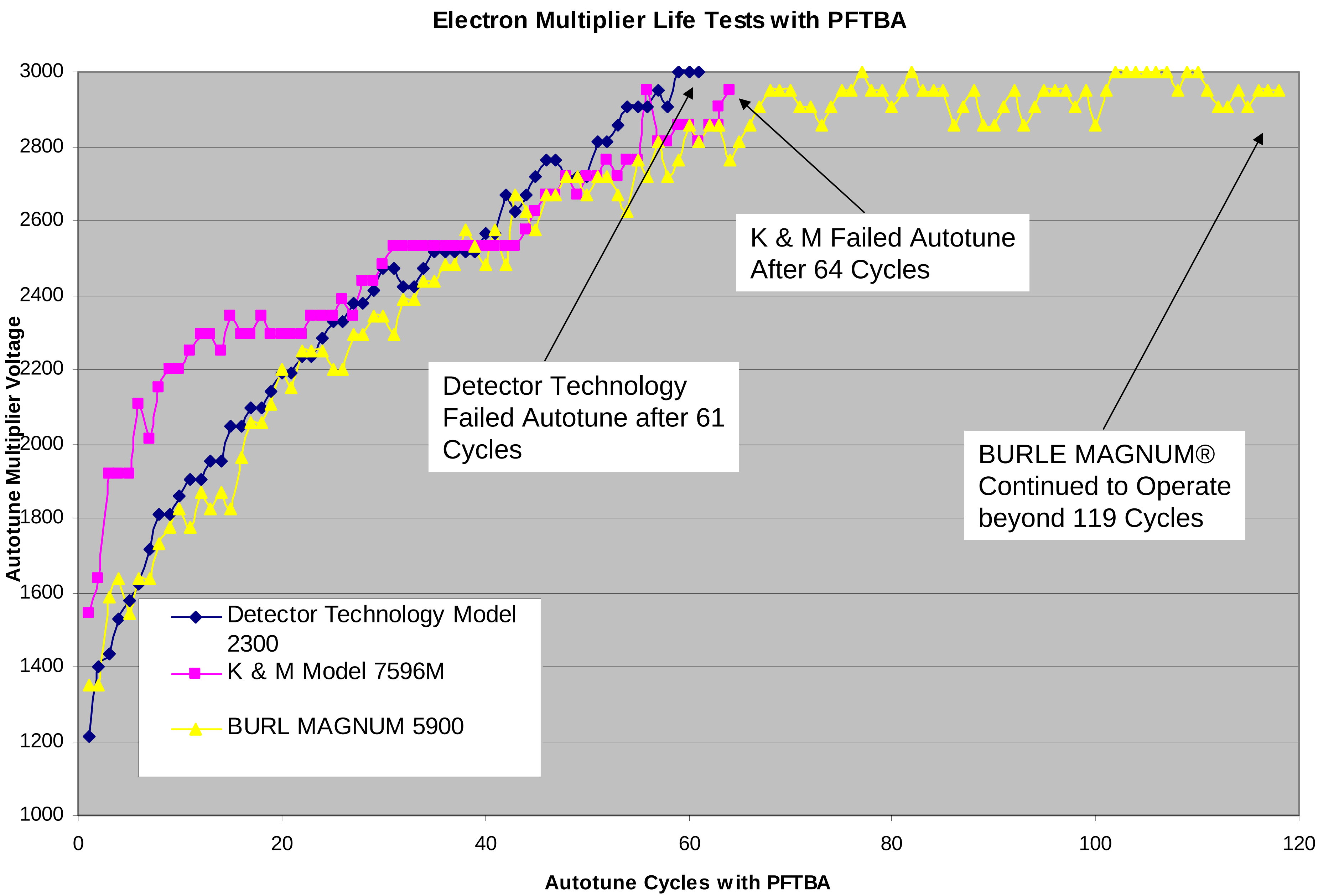
- The performance of an electron multiplier will degrade as a result of everyday operation. Ions from the mass filter impinge on cone of the multiplier and produce a cascading of secondary electrons, ultimately resulting in the signal used to produce the mass spectrum.
- The constant bombardment of ions on the cone can result in the development of a surface coating which will reduce the efficiency of the secondary electron emission process.
- Equivalent Electron Multipliers from three manufacturers were subjected to an extended life test.
- The multipliers were loaded in a demountable test stand and bombarded with ions created from residual gas molecules of the species typically encountered in Residual Gas Analysis (RGA) monitored systems

Gain Stability of Various Multipliers for Bench top GCMS Applications



Chemical Durability

- Multipliers from three manufacturers were tested for chemical durability in an Agilent 5971 GCMS Chemstation. The internal calibrant PFTBA was used to create ions ranging from mass 69 to mass 512. PFTBA is known to be an aggressive material which quickly degrades multiplier performance.
- The original instrument ion optics frame was used for this test with all multipliers.
- Each multiplier was subjected to repetitive test cycles consisting of a Maximum Sensitivity Auto tune, Gain and Linearity tests, then begin the cycle again. The instrument was not vented between cycles. The cycles were repeated until the instrument was no longer able to achieve the requirements of auto tune.
- Before each multiplier sequence began, the ion source was completely disassembled and cleaned.


Electron Multiplier Life Tests with PFTBA
Autotune Multiplier Voltage
Autotune Cycles with PFTBA
3000
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
0
20
40
60
80
100
120
K & M Failed Autotune After 64 Cycles
Detector Technology Failed Autotune after 61 Cycles
BURLE MAGNUM® Continued to Operate beyond 119 Cycles
Detector Technology Model 2300
K & M Model 7596M
BURL MAGNUM 5900

Conclusions

Discrete dynode multipliers develop ion feedback at pressures above 10^{-5} Torr

Single Channel Electron Multipliers Operate well at pressures into the mid 10^{-5} Torr Range.

SPIRALTRON™ and MAGNUM Electron Multipliers® operate well into the 10^{-4} Torr Range

- A specially designed Microchannel Plate-based Electron multiplier has been successfully operated for over 1200 continuous hours at elevated pressures in excess of 10 milli-Torr with good performance.

- A Mass Spectrometer (Inficon XPR-III) utilizing a very short (25mm) quadrupole mass filter and this microchannel plate electron multiplier has been commercialized for process monitoring in semiconductor manufacturing applications.

Multiplier lifetime testing, with low mass ions, for models manufactured by three companies highlighted the differences in gain performance.

Multiplier lifetime testing in a bench top GCMS using the internal standard PFTBA to create ions indicated that the 6 channel MAGNUM Electron Multiplier® utilizing SPIRALTRON™ Technology operated over 85% longer than the OEM multiplier.