METHODS OF HELIUM INJECTION AND REMOVAL FOR HEAT TRANSFER AUGMENTATION

Harlan Haight and Jeff Kegley
NASA Marshall Space Flight Center

Meghan Boudreaux
University of Alabama
NASA Undergraduate Student Research Program

ABSTRACT

While augmentation of heat transfer from a test article by helium gas at low pressures is well known, the method is rarely employed during space simulation testing because the test objectives usually involve simulation of an orbital thermal environment. Test objectives of cryogenic optical testing at Marshall Space Flight Center's X-ray Cryogenic Facility (XRCF) have typically not been constrained by orbital environment parameters. As a result, several methods of helium injection have been utilized at the XRCF since 1999 to decrease thermal transition times. A brief synopsis of these injection (and removal) methods including will be presented.

INTRODUCTION

Prior to commissioning of the 1999 cryogenic modifications, the XRCF team began investigating techniques to augment heat transfer from test articles. Physics dictates that relying solely upon radiative heat transfer at low temperature with small temperature differences will be painfully slow. Active cooling or conductively strapping optical test articles is not generally desirable due to the potential of inducing strains and/or vibrations. The possibility of using a gas to enhance heat transfer was considered and investigated. Although a "text book" technique, this did not seem to be commonly practiced by anyone in the space simulation field (the presence of a high concentration of gas in a typical space simulation test usually invalidates the simulation). Since the goal at the XRCF was to thermally equilibrate a test article with a low temperature environment so that its properties may be measured, it was decided to experiment with gas conductivity.

In the subsequent experiments injecting helium, the XRCF ran the test facility through the three flow regimes (molecular, transitional, and viscous) and measured the effect of helium gas heat transfer in each. Obviously, all three flow regimes can augment radiative heat transfer – the initial goal of the XRCF was to increase the chamber pressure with helium gas enough to make the free molecular heat transfer significant without approaching the viscous flow regime. It was feared that entering the viscous flow regime would couple the helium shroud to the ambient chamber environment sufficiently to overpower the refrigeration capacity; however, continued experiments determined that the chamber could operate into the viscous regime without compromising the helium refrigerator system's ability to maintain temperature. The results of these experiments yielded the optimum operating pressure for the XRCF which is in the upper transitional / lower viscous regime.

Experiments were also run to confirm the amount of time required to remove helium gas via our existing turbomolecular pumps.

The addition of helium to the test volume as a heat transfer mechanism is now routine operating procedure. It has been employed successfully in over 60 tests in both the large and small chamber. This technique is used with caution however, as large changes in test article temperature can occur as helium in injected into the test volume.

METHODS

Original Configuration

The original helium injection configuration is shown in Figure 1. A volume with a light spring seal was connected to a clean helium source to serve as an ambient pressure helium reservoir. A small volume (~ 1 cubic centimeter) was devised and connected between two vacuum valves. The 1cc volume was chosen because at the XRCF 1 standard cc of gas will raise the chamber pressure by ~ $1x10^{-6}$ Torr. Thus by connecting the fixed volume to the chamber and alternately opening it to the vacuum and the ambient helium source, the chamber pressure was increased in increments of $1x10^{-6}$ Torr. This method proved to be very precise and repeatable; however, increasing in the 10^{-5} Torr range proved to be an arduous process.

Generation 2

The second generation injection system built on the initial concept and is shown in Figure 2. The small 1cc volume was replaced with a larger 65cc volume. A gage capable of reading vacuum to 2 atmospheres was installed on the 65ccc volume. The vacuum valve between the helium reservoir and the 65cc volume was replaced with a metering valve. By cycling the vacuum valve and the metering valve, one could easily increase the chamber pressure in increments of 6.5×10^{-5} Torr. By partially filling the volume with helium as indicated on the gage, one could precisely tune the chamber pressure in increments of $1x10^{-6}$ Torr.

Generation 3

The third generation injection system deleted both the ambient pressure reservoir and the known volume. The helium source was connected directly to the metering valve. The vacuum valve remains open throughout the injection process. The metering valve is used to precisely tune the chamber pressure. It has been determined that a 10 psig helium source in combination with our metering valve is sufficient for controllable injection rates at XRCF. The risk of overshooting the target pressure is mitigated by having a turbomolecular pump standing by to remove excess helium if necessary. The third generation injection system is shown in Figure 3.

Generation 4 (Current)

The current (fourth generation) helium injection system is shown in Figure 4. The metering valve has been replaced with a mass flow controller (MFC) capable of tuning the chamber pressure accurately. The MFC was sized to be able to increase the chamber pressure into the 10^{-4} Torr range rapidly, yet still provide control precise enough for tuning the chamber pressure in 1×10^{-6} Torr increments. The vacuum valve remains to provide positive isolation from the vacuum chamber.

CONSIDERATIONS

Turbomolecular Pumps

The XRCF is equipped with two turbomolecular / molecular drag hybrid pumps. Each pump has a helium pumping speed of 1800 liters/second. These pumps individually produce “clean-up” times of approximately 1 hour from 1×10^{-4} Torr into the 10^{-7} Torr range.

It has been operationally demonstrated that the turbopumps can be used to maintain desired chamber pressure in the presence of unexpected small helium leaks from the refrigeration system. By simply placing one or both turbopumps on-line and tuning the helium injection system (in a continuous injection mode), the chamber pressure can be kept at the desired pressure for extended durations. This has proven to be a valuable technique in that the chamber was able to be kept in operation.

Cryogenic Pumps

The XRCF is equipped with six valved cryogenic pumps. Since the helium injection typically occurs at environment temperatures around 100 Kelvin, some number of cryogenic pumps is still required to actively maintain the chamber vacuum. Each of these pumps has a helium capacity of approximately 1 standard liter. Although intentionally dumping helium into a cryogenic pump may not be desired, experience has shown that the pumps can be saturated with helium, still maintain pumping capability (the cold head temperature remains less than 25K), and can be regenerated without detrimental effects.

Liquid Nitrogen Surfaces

The effects of increased chamber pressure when operating the liquid nitrogen shrouds in the XRCF was initially a concern. Fortunately, no measurable differences have been observed in the either the consumption of liquid nitrogen or in the performance of the nitrogen shrouds when operating with helium gas in the chamber.

MLI / Helium Refrigeration Capacity

The impact of the helium gas on the helium-cooled enclosure’s multi-layer insulation (MLI) was also a concern. While the helium gas must be thermally “shorting” the layers of the MLI, the refrigeration system has proven to be able to maintain temperature control as long as the pressure is not increased beyond the threshold value for the XRCF.

Corona

Prior to increasing the chamber pressure intentionally with helium gas, the possibility of corona discharge or gas breakdown voltage must be considered for individual test setups.

FIGURES

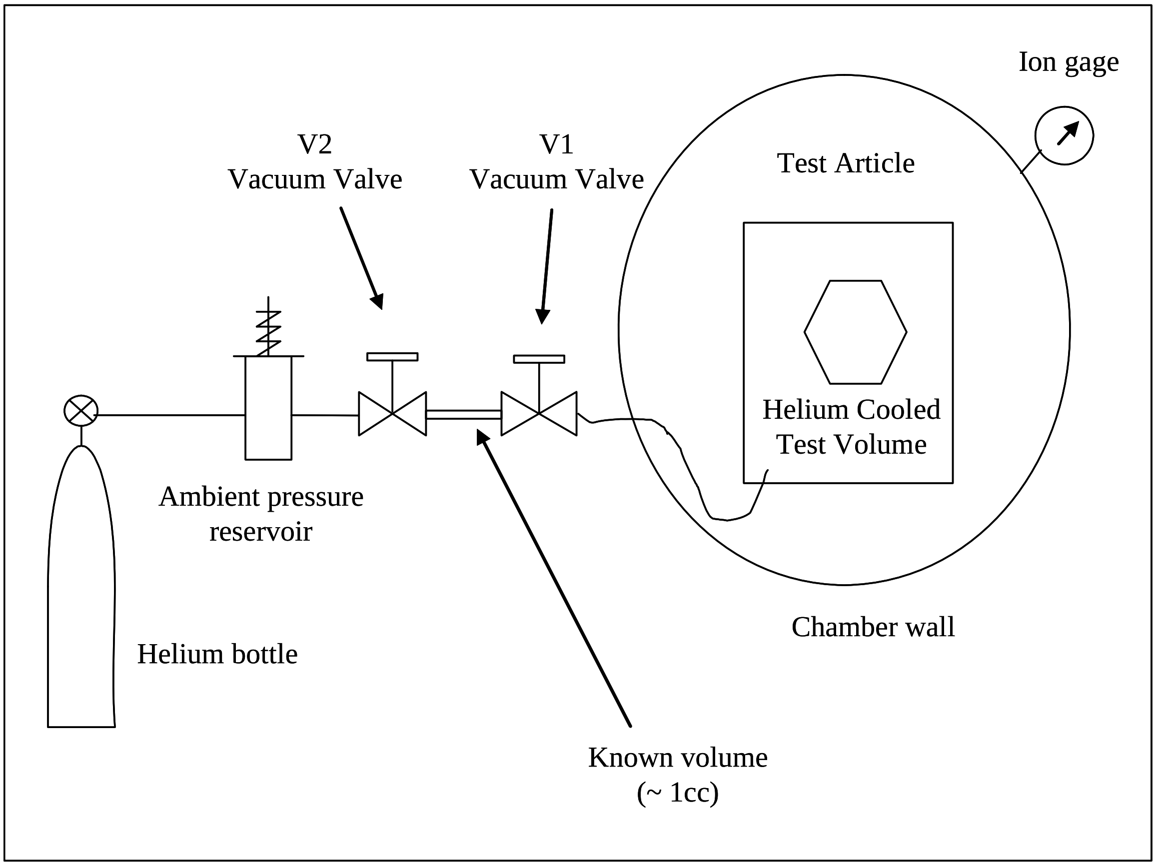

Figure 1: Helium Injection System - Original

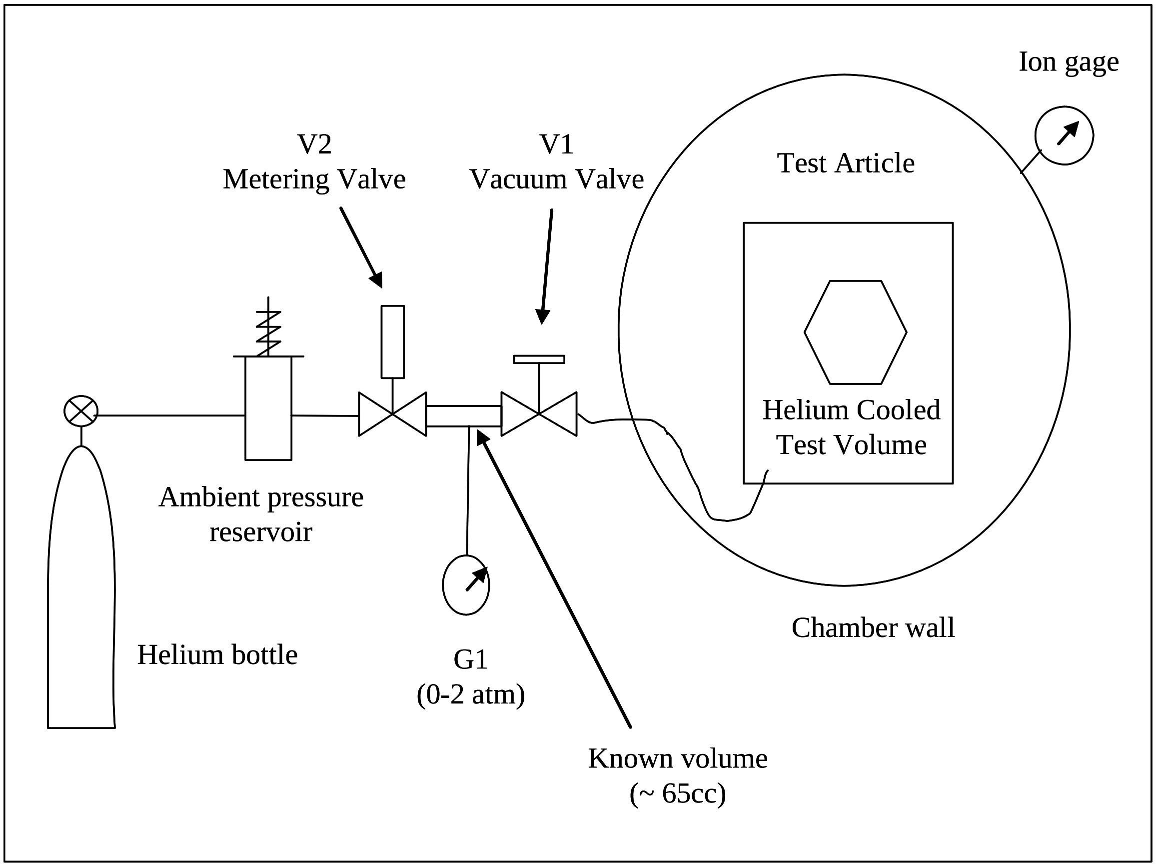

Figure 2: Helium Injection System – 2nd Generation

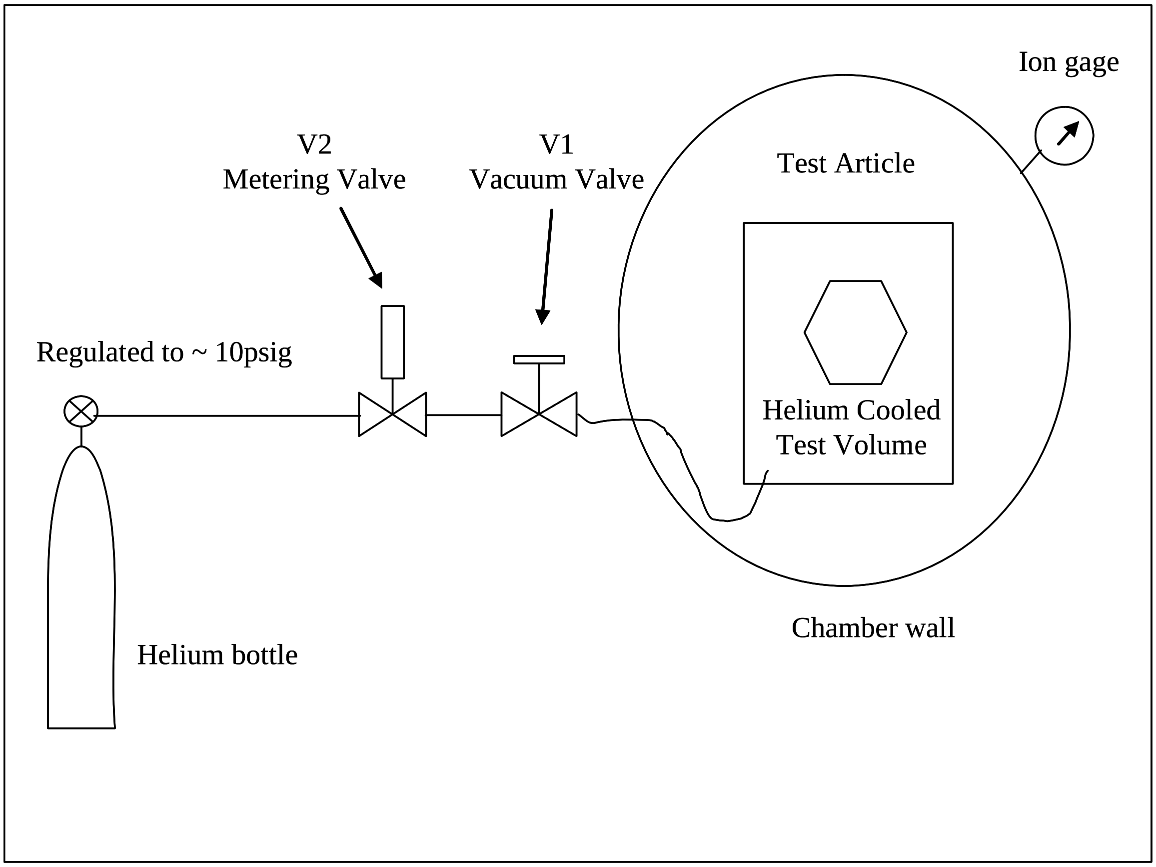

Figure 3: Helium Injection System – 3rd Generation

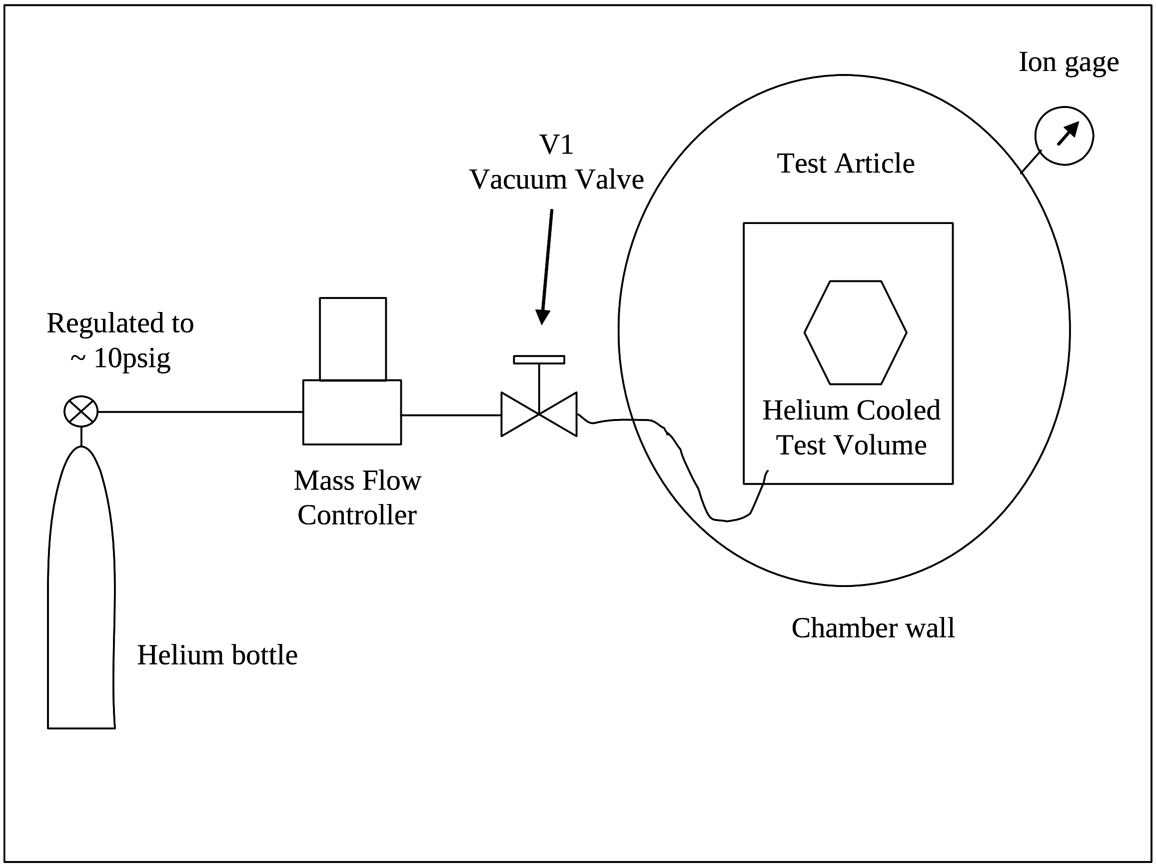

Figure 4: Helium Injection System - Current

REFERENCES

1. Kegley, J., et.al., "Cryogenic Test Capability at Marshall Space Flight Center's X-ray Cryogenic Facility", Space Simulation Conference, Annapolis, MD, 2006.

2. Boudreaux, M., "Modifications to Helium Injection System and Other Related Work Experience, Summer 2008", Undergraduate Student Research Program, August 2008.

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jeff.kegley@nasa.gov

256.544.2291

Original System Schematic

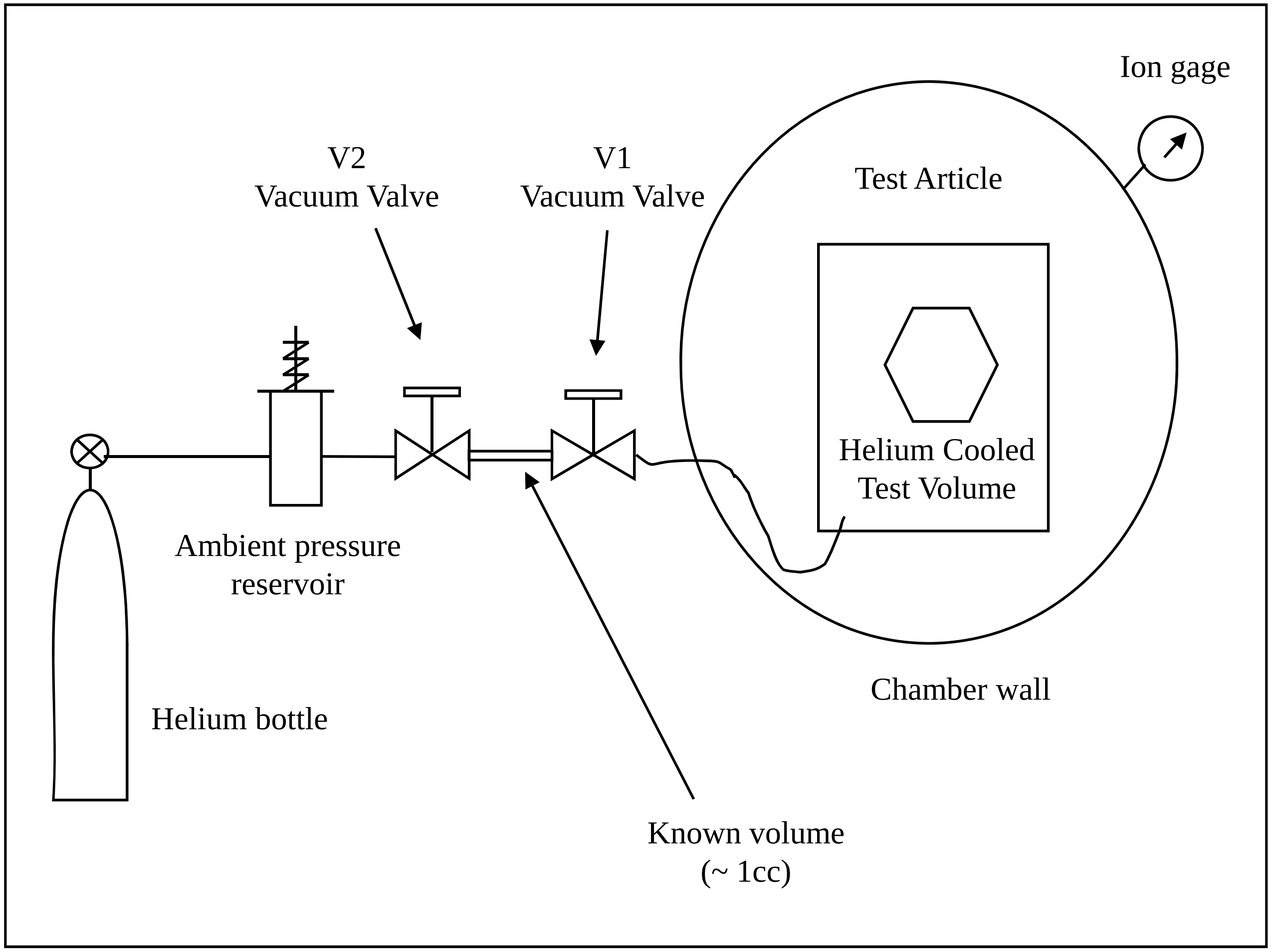

Figure 1: Helium Injection System - Original

Gen 2 System Schematic

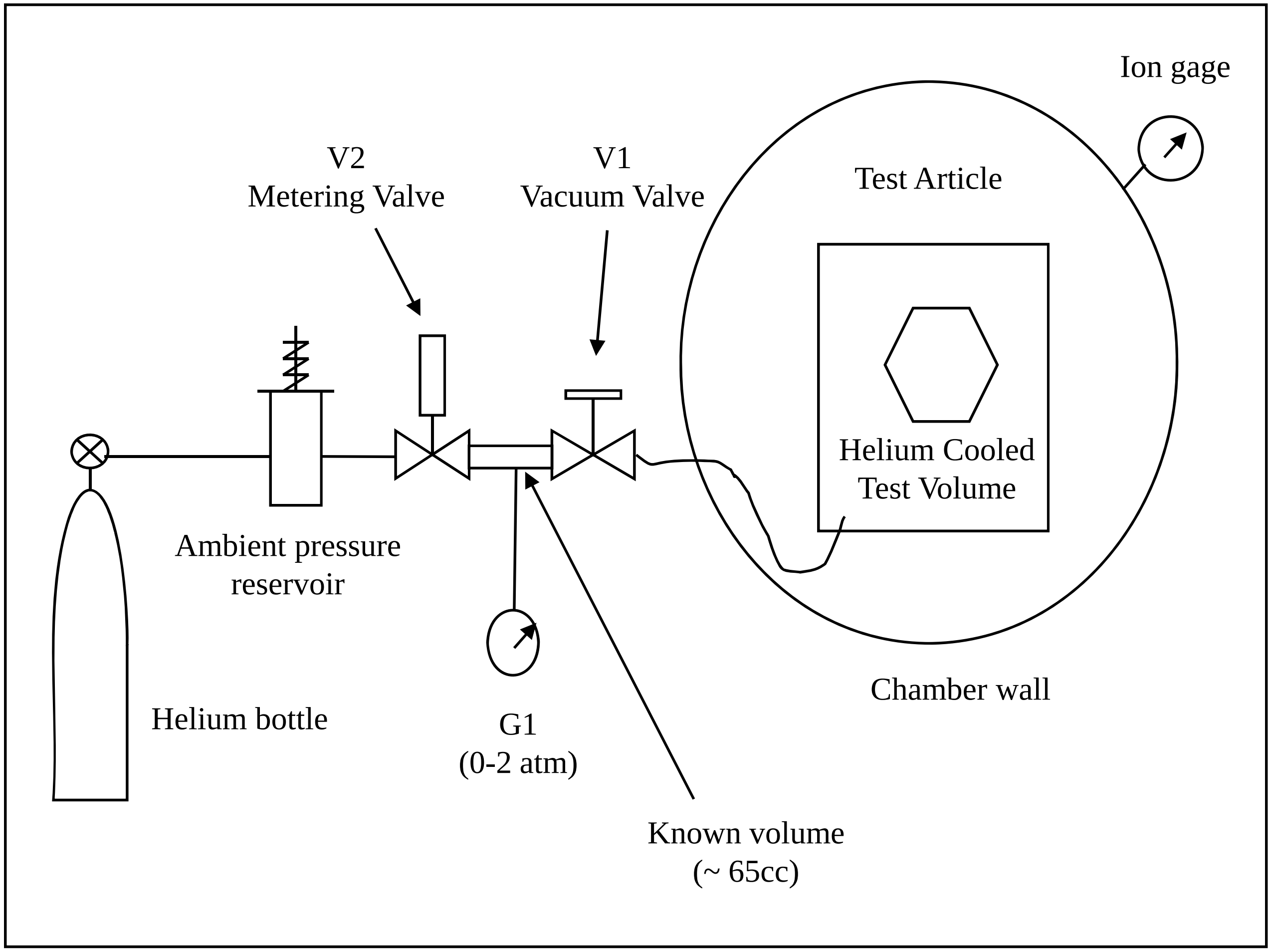

Figure 2: Helium Injection System – 2nd Generation

Gen 3 System Schematic

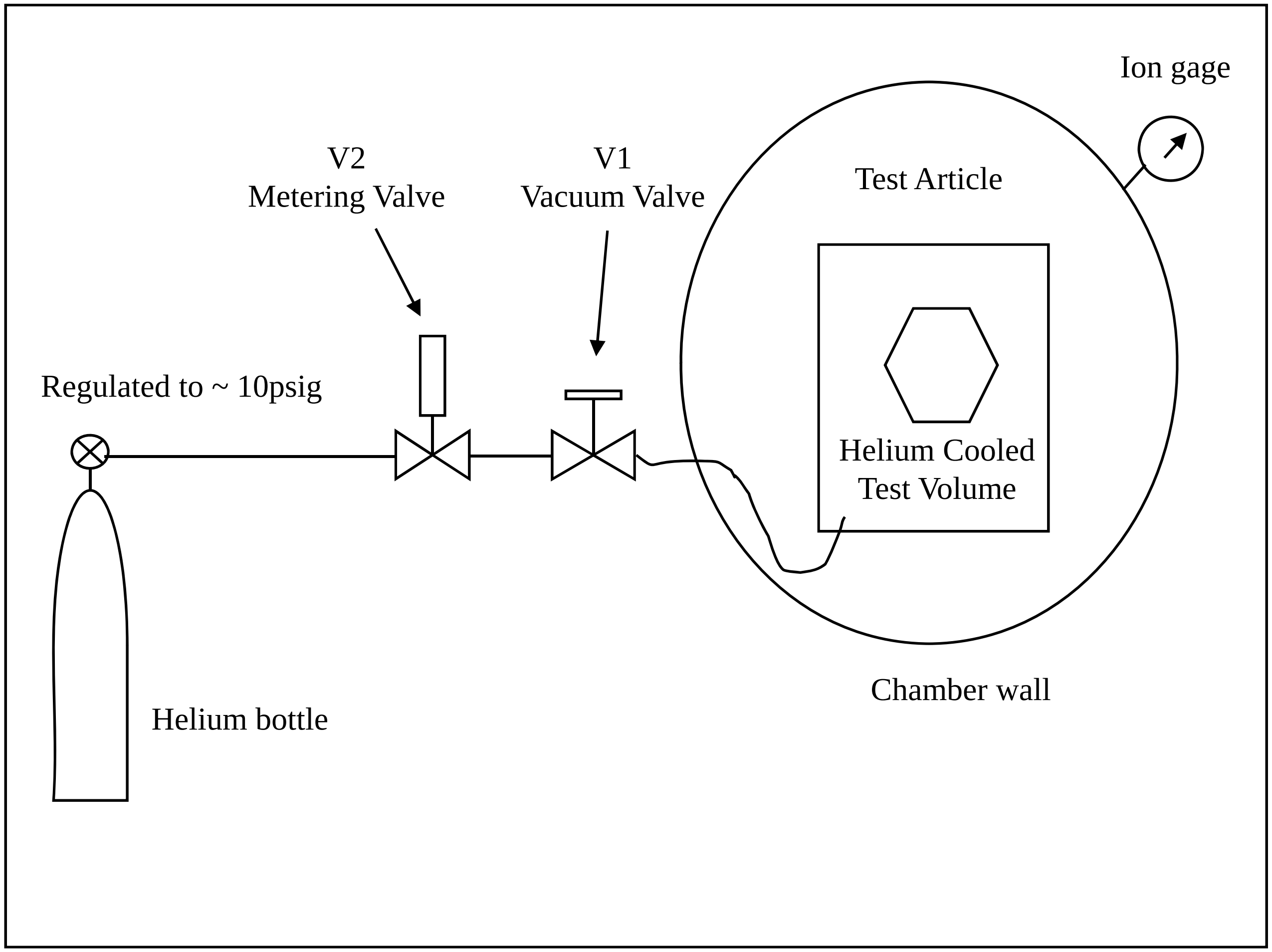

Figure 3: Helium Injection System – 3rd Generation

Gen 4 System Schematic

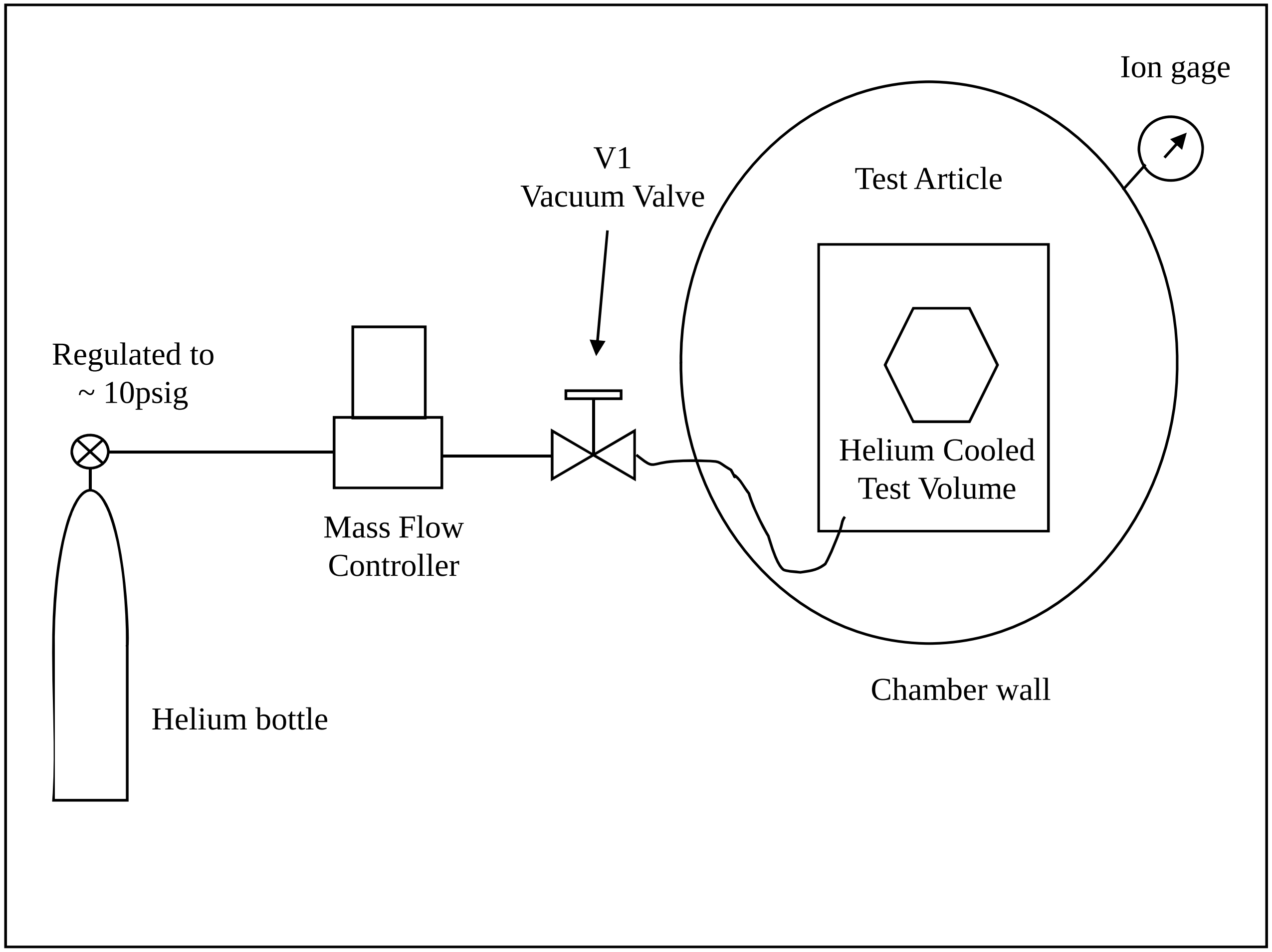

Figure 4: Helium Injection System - Current

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