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FITTING LEAK TEST REPORT

GROUND-BASED CRYOGENIC LEAK TEST OF FITTINGS FOR CRYOGENIC FLUID MANAGEMENT

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ABBREVIATIONS, ACRONYMS, AND SYMBOLS

Units of measure and some terms commonly understood within the subject disciplines have been abbreviated in the body of this document without callout but are included among the following.

ASTM	American Society for Testing and Materials
COTS	Comercial Off The Shelf
CTL	Cryogenics Test Laboratory
DAQ	Data Acquisition
GEVS	General Environmental Verification Standard
GHe	Gaseous Helium
H2	Hydrogen - gaseous
HLS	Human Landing System
K	Kelvin
LASSO	Laboratory Support Services and Operations
MOWP	Maximum Operating Working Pressure
Mpa	Megapascals
MSFC	Marshall Space Flight Center
NASA	National Aeronautics and Space Administration
Ni	Silver-plated Nickel
O2	Oxygen - gaseous
PRSD	Power Reactant and Storage Devices
psig	pounds per square inch gage
sccs	Standard Cubic Centimeter per-Seccond
SN	Serial Number
SST	Stainless Steel
TVAC	Thermal Vacuum Chamber
VCR	Vacuum Coupling Radiation

EXECUTIVE SUMMARY

Mechanically connected joints used in cryogenic fluid lines as part of space flight elements need to survive launch vibrations and remain leak-free to minimize the loss of on-board commodity and hazardous gas accumulation. In 2020, a cryogenic test apparatus was developed which can evaluate the leak performance of pressurized threaded fluid fittings. The fittings were mounted in the TVAC and cooled to cryogenic test temperature and pressurized with helium while the leak rate was measured using a calibrated GHe leak detector. The test articles for the initial proof of concept testing were ¼ and 1 inch Swagelok VCR fittings with three different types of seal rings copper, nickel, and Ni. Each fitting configuration (size/seal material) was subjected to two consecutive cryogenic thermal cycles, followed by exposure to a launch vibration profile at ambient temperature, after which two additional TVAC cycle tests were performed.

The testing reported here is a continuation of the 2020 tests with a statistically significant large number of samples and test runs. Three Swagelok VCR fitting sizes were tested ¼, ½ and 1 inch, and five (5) samples of each fitting size, each sample was tested with SST and Ni seal rings (Total of 30 unique test articles). Each test article was subjected to four (4) thermal cycles. Half of these cycles were performed before vibration testing and half were performed after vibration testing. The vibration testing was performed to evaluate the ability of the fittings to survive launch-type vibration profiles and remain leak-free. Leak checking of each fitting was completed at temperatures between 20K – 30K. The test procedure in Section 8.0 was designed to facilitate a qualification test program by allowing a higher test throughput rate coupled with repeatable test profiles.

Results were very positive and show that out of the 30 samples they all passed with leak rates a factor of 2-3 lower than the established 10^{-6}sccs GHe leak threshold. The result showed the Ni seals had lower leak rate, but the SST was more rugged. There were two deviations where damage to the Ni seal ring during assembly resulted in a leaky fitting, this is discussed in Section 10.7 Test Deviations. These fittings show great promise for space flight use and further testing is recommended to fully qualify the fittings per the ASTM F1387-19 and/or other relevant NASA specifications.

The test equipment hardware and software capability developed for this testing is generic and not restricted to VCR fittings. It can be employed to evaluate/qualify the leak performance of other types of fittings and a wide range of other cryogenic fluid components such as valves, gages, connectors, etc.

1.0 BACKGROUND

The Swagelok VCR fitting is widely used and trusted for ground testing in thermal vacuum environments which are highly sensitive to even minute leakage. A recent survey of NASA cryogenic users found that they are commonly used by every center that performs cryogenic thermal vacuum work. Based on the results of this survey, the VCR fittings, see **Figure 2** and **Figure 3**, were selected as good candidates for use on future flight vehicles.

This study was undertaken to evaluate the performance of the Swagelok VCR fittings under space flight conditions. This fitting is an alternative for flight systems employing other fluid fittings styles such as 37° flared fittings with copper crush washers, flared tubing, Dynatube, KC fittings, etc. which all have deficiencies some of which could be solved by the VCR fitting.

This report presents a follow on to the initial 2020 testing with more extensive testing of additional Swagelok VCR fitting samples. The purpose of this additional testing is to provide a statistically significant larger sample size and be able to evaluate the potential to qualify the VCR fitting for flight use. The Artemis Program will likely need flight qualified cryogenic fittings, and this testing will allow for development of qualification test set-ups and procedures. Additionally, this testing is designed to further demonstrate that VCR fittings, specifically, are good candidates for flight qualification. This testing followed American Society for Testing and Materials (ASTM) F1387-19 Standard Specification for Performance of Piping and Tubing Mechanically Attached Fittings, but it was only a partial subset of the specification. A full qualification was not in the scope of this project. This testing was focused on the space flight relevant portion of the ASTM Spec. Full qualification could be undertaken in the future based on the positive results obtained from this round of testing.

The remainder of this report details the test hardware test plans and procedures, test data and the results.

2.0 OBJECTIVES

The objective of this test was to evaluate if the VCR fittings can operate leak free under space flight conditions. The testing program included the following objectives:

1. Testing of three (3) different VCR fitting sizes: 1/4, 1/2, and 1 inch.

2. Five (5) samples of each fitting size

3. Two (2) different seal material types: SST and Ni. These materials were selected because they are the most compatible with the cryogenic space flight fluids.

4. Four (4) complete ambient (300K) to cryogenic (20-30K) thermal cycles in TVAC for each fitting size and seal material combination. Two (2) thermal cycles were performed before and two (2) cycles after vibration testing.

5. Vibration testing to relevant launch dynamic profile, see Section 9.1 Test Method.

6. Leak checking of fittings throughout the TVAC test sequence by pressurizing to 400-420 psi (27.5-29 bar) with GHe and monitoring the chamber background with a GHe mass spectrometer leak detector.

3.0 REQUIREMENTS

1. Fittings to Test: Swagelok VCR size ¼, ½ and 1 inch
2. Seal Rings: 316L Stainless Steel and Silver-Plated Nickel
3. Test Temperature: 295K to 20K-30K
4. Test Pressure: 400-420 psig, (27.5-29 bar)
5. Working Fluid: GHe
6. Leak Rate Threshold: 10^{-6} sccs GHe (See reference specifications NOTES 1 and 2)
7. Vibration Profile: General Environmental Verification Standard (GEVS)-SE Rev A,

   Table 2.4-4, Unpressurized and at Ambient Temperature (See Section 9.0 Vibration Test Apparatus)

NOTE 1: The leak rate threshold value was based on references to the following Kennedy Space Center (KSC) specifications for installed fittings and fitting assemblies:

KSC-SPEC-Z-0008 Revision D Change 2, FABRICATION AND INSTALLATION OF FLARED TUBE ASSEMBLIES AND INSTALLATION OF FITTINGS AND FITTING ASSEMBLIES, SPECIFICATION FOR

Section 3.5 Pressure/Temperature Requirements – Tubes and Fittings
3.5.4 Leak Checking
a) Fluid mechanical joints shall be leak checked in accordance with ASME B31.3 and **KSC-STD-Z-0005**

KSC-STD-Z-0005 Revision C, PNEUMATIC GROUND SYSTEMS DEVELOPMENT STANDARD
Section 5. PNEUMATIC SYSTEM REQUIREMENTS

5.14 Leak Test
d) All test points shall be bubble tight for a minimum of one minute after leak test solution is applied. Bubble tight is defined to be no greater than **1×10^{-4} sccs** of the leak test medium.

NOTE 2: The leak rate threshold value of 10^{-6} sccs is 2 orders of magnitude below that specified in KSC-STD-Z-0005 and is representative of more stringent flight hardware specifications. For example, The Space Shuttle Orbiter PRSD gaseous oxygen (O_2) and gaseous hydrogen (H_2) system allowable Leak Rate was 1×10^{-7} sccs.

4.0 HARDWARE ENHANCEMENTS

Based on the lessons learned from the initial proof of concept testing in 2020, hardware enhancements were implemented to enable the efficient execution of numerous tests. These focused on two areas: automation to enable a higher test rate and completion of several thermal cycles per day and enhancing the test hardware to minimize interruptions between tests.

A higher test rate allowed more comparative testing of fitting sizes and seal types. In addition, the faster test rate enhanced the ability to resolve hardware or sample issues and quickly retest fittings. A LabVIEW program was written and used to automate the test execution and monitoring. This program automated leak testing, solenoid valve operation, and error handling as well as data collection and reporting. The program effectively enabled a succession of fitting tests at a much higher rate than previously possible.

Hardware enhancements included: the addition of cup heaters to speed up the warm-up time, the fabrication of two separate fitting holding fixtures to aid in the rapid swap out of test samples, and the addition of Teflon ferules to the vacuum ports which sped up the sample installation process. A complete list of the hardware enhancements can be found in **<u>Appendix A. Hardware Enhancements</u>**.

A diagram of the original proof-of-concept hardware is shown in **<u>Figure 1</u>**. Hardware enhancements recommended in the December 2020 Final Report included the addition of solenoid-operated valves and an electronic pressure regulator to automatically control fitting pressurization, venting and vacuum system isolation. These enhancements were added to the system and are show*n in* **<u>Figure 1</u>** ***(red cir***cles). The complete fluid schematic of the updated VCR Test Hardware is shown in **<u>Figure 7.</u>**

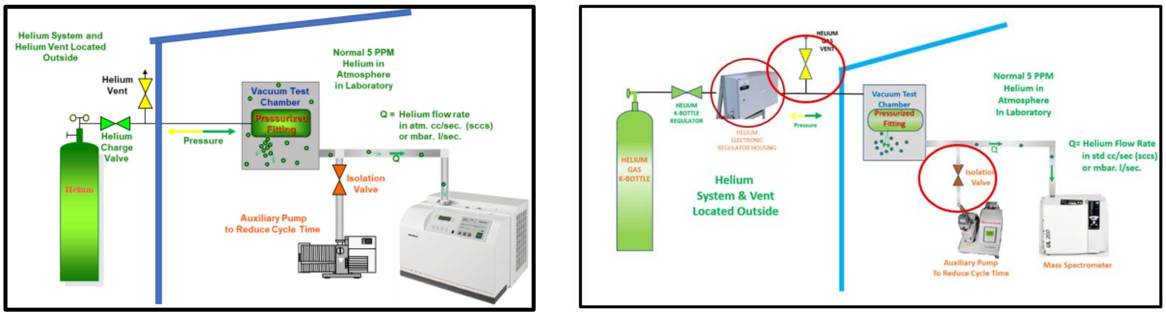


Figure 1. Test Hardware Setup – Initial (L) and with Automation Enhancements (R)

5.0 TEST ARTICLES

Each test article consisted of a single Swagelok VCR fitting joint with standard COTS parts and assembled per the manufacturer's instructions shown in **Appendix B. Swagelok Fitting Installation Instructions**. The joint is shown in **Figure 2** and is composed of a female nut, a "Blind" gland, a seal ring, a "Long Tube Butt Weld" gland and a male nut. The butt weld gland is welded to a reducer(s) which is then welded to a 10-foot length of 1/8" diameter tube to provide a very long thermal conduction path, see **Figure 3**. The tube is coiled within the vacuum chamber and then exits the chamber passing through a 1/8-inch Swagelok compression fitting. The end of the 1/8-inch tube is then mated to the GHe pressurization supply line using a threaded fluid fitting (Swagelok compression fitting), see ***Figure 4***.

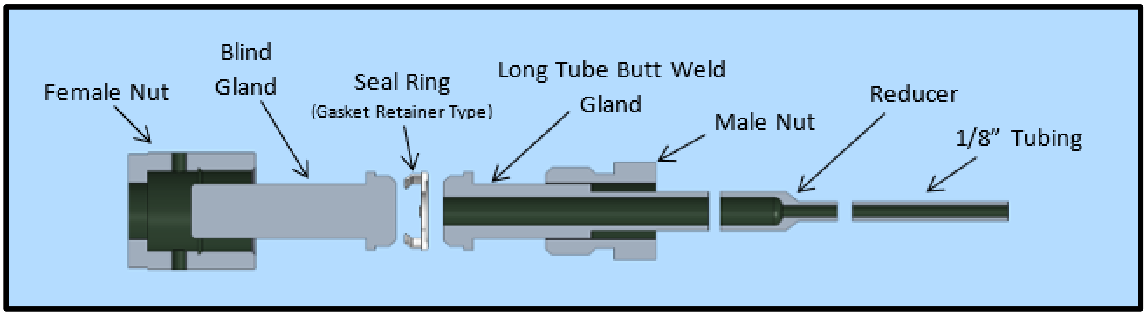


Figure 2. VCR Fitting Test – Typical Test Article Assembly

Several steps were involved in preparing a test article for testing. First, the welded gland, reducer(s) and 1/8-inch tube were joined using a Swagelok Automatic Orbital Welding machine to produce precise, consistent, quality welds that are leak-free.

The next step was to bend the 10-foot length of tubing into the coiled shape. Because the test article includes fabricated tubing it required a hydrostatic pressure test. With the assembly filled with water, both halves of the fitting are assembled per the Swagelok VCR assembly procedure in **Appendix B. Swagelok Fitting Installation Instructions**, using a copper seal ring, and then pressure tested to 750 psig (which is 150% of leak test system design pressure). The fitting assembly was then disassembled and dried using a nitrogen purge and the copper seal ring is discarded.

Finally, the fitting joint is assembled with the test-specific seal ring. A gross leak check is performed on the bench with helium at 400-500 psig as a final quality verification prior to installation into the vacuum chamber. A completed Swagelok VCR Fitting Assembly prior to installation for testing is shown in **Figure 3**.

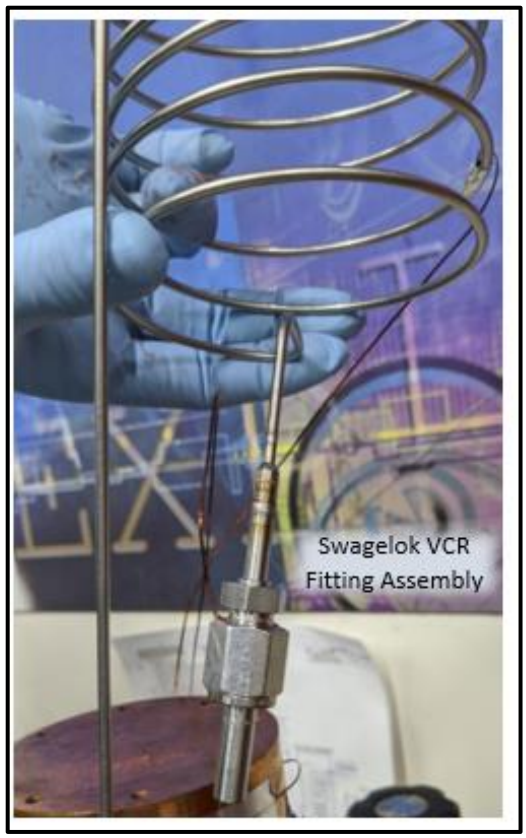


Figure 3. VCR Fitting Assembly prior to vacuum chamber installation

6.0 COLD LEAK MEASUREMENT TEST APPARATUS

Testing of the fittings took place inside a purpose built TVAC chamber. A cut-away of the vacuum test chamber is shown in **Figure 4**. The chamber was designed to be quickly opened and samples removed/installed in an efficient manner. The sample fittings were mounted on top of the cryocooler cold tip inside an aluminum cup with copper fastenings to achieve good thermal contact. Heat leakage was minimized by the aluminum cup and coiled tube. Flexible Kapton heaters were added to the cold head to speed up the warmup time, which was one of the lessons learned from the initial test runs in 2020. Several ports on the chamber were used for connecting the vacuum pump, the leak detector and pressure gages.

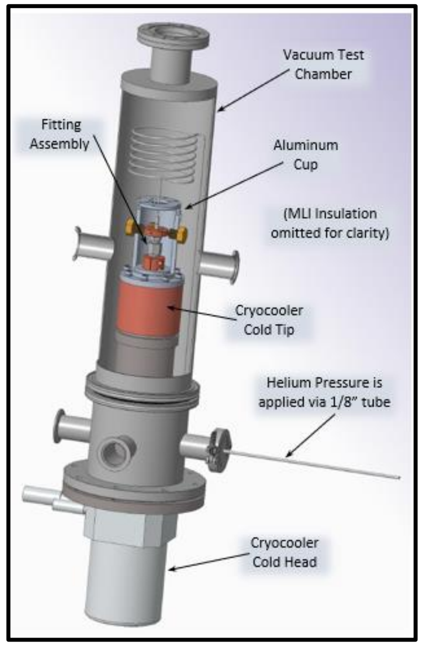


Figure 4. VCR Fitting TVAC Chamber Cutaway

The Test Setup inside the CTL high bay is shown in **Figure 5**. The Cryomech AL325 cryocooler is used to attain the 20-30K cold test temperature required. The INFICON UL 200 Mass Spectrometer Helium Leak Detector measures the GHe background inside the vacuum chamber during the TVAC cycles. An Edwards TIC Vacuum Pumping station is used to evacuate the vacuum chamber surrounding the fitting. The DAQ System monitors fitting pressure, vacuum chamber pressure, and temperature transducer values during each test. A LabVIEW software program controls valves and can automatically terminate any test if the measured leak rate of any fitting is above a predetermined ceiling value.

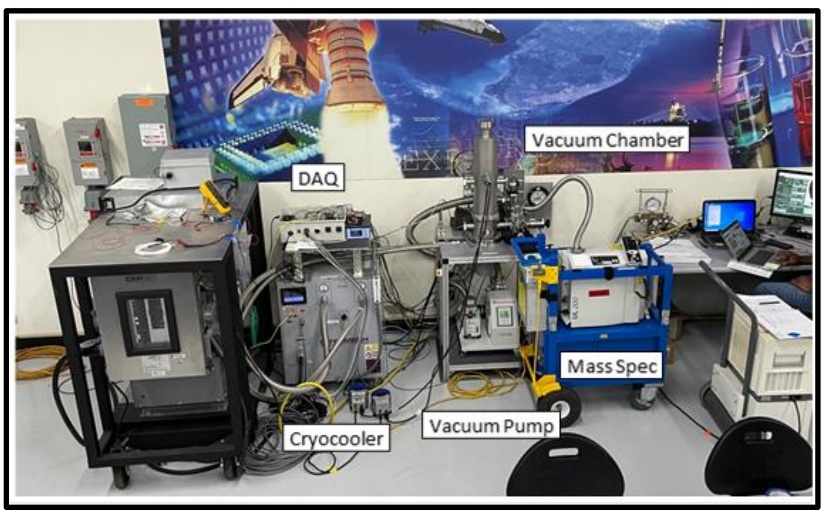


Figure 5. VCR Fitting Test Setup (Internal - CTL Highbay**)**

The other components of the test setup are shown in **Figure 6**. Including the chiller for the cryocooler, the GHe K-Bottle, and Tescom auto regulator. They are located outside on the North side of the CTL building to minimize helium accumulation around the leak-check hardware and to avoid excessive noise in the lab. The TESCOM model ER5000 electropneumatic motor actuated regulator connected to the GHe K-bottle is controlled by the LabVIEW program. When in the OPEN configuration the test fitting is pressurized with GHe.

Figure 6. VCR Fitting Test Setup (External – Outside CTL)

6.1 Test Method

The "inside-out" method of leak measurement method was used for all testing. The fittings were placed inside of an evacuated chamber and pressurized with GHe. Any leakage of the GHe from the test article into the evacuated chamber was measured by the leak detector. This method of leak measurement is ideal for this application because the fitting is pressurized internally and exposed to the same stresses that it would be in its intended application. It is a reliable, quantitative method that is highly sensitive and capable of measuring a wide range of leak rates. In these tests, the leak measurement technique is augmented with the fittings being thermal cycled from ambient to cryogenic temperature under vacuum conditions while pressurized.

During testing, temperature is monitored at three primary locations within the test chamber using silicon diodes: the cryocooler cold tip temperature (T1), the aluminum cup temperature (T2), and the fitting assembly temperature (T3). The fitting assembly temperature diode is attached to the wrench flats of the male or female nut. The reducer temperature (T4) is monitored as a secondary fitting temperature. In comparison, the fitting pressure (P1) is monitored as a primary measurement for the leak test. The mass spectrometer indicates the GHe leak rate and inlet pressure (vacuum). The pressure in the vacuum test chamber (P2 and P3) is monitored as a guide for performing various stages of the test. The locations of the silicon diodes (T1, T2, T3, T4) and pressure transducers (P1, P2, P3) are called out in **Figure 7**.

6.2 Electrical Schematics

The overall electrical schematic for the VCR Fitting Tests is shown in **Figure 8**. National Instruments cDAQ CompactDAQ/RIO components (NI 9477, 9219, 9201, and 9265) were utilized to measure temperature and pressure during the tests and to power solenoid valves based on LabVIEW software control. The control box schematic is shown in **Figure 9** and the connector pinouts are shown in **Figure 10**.

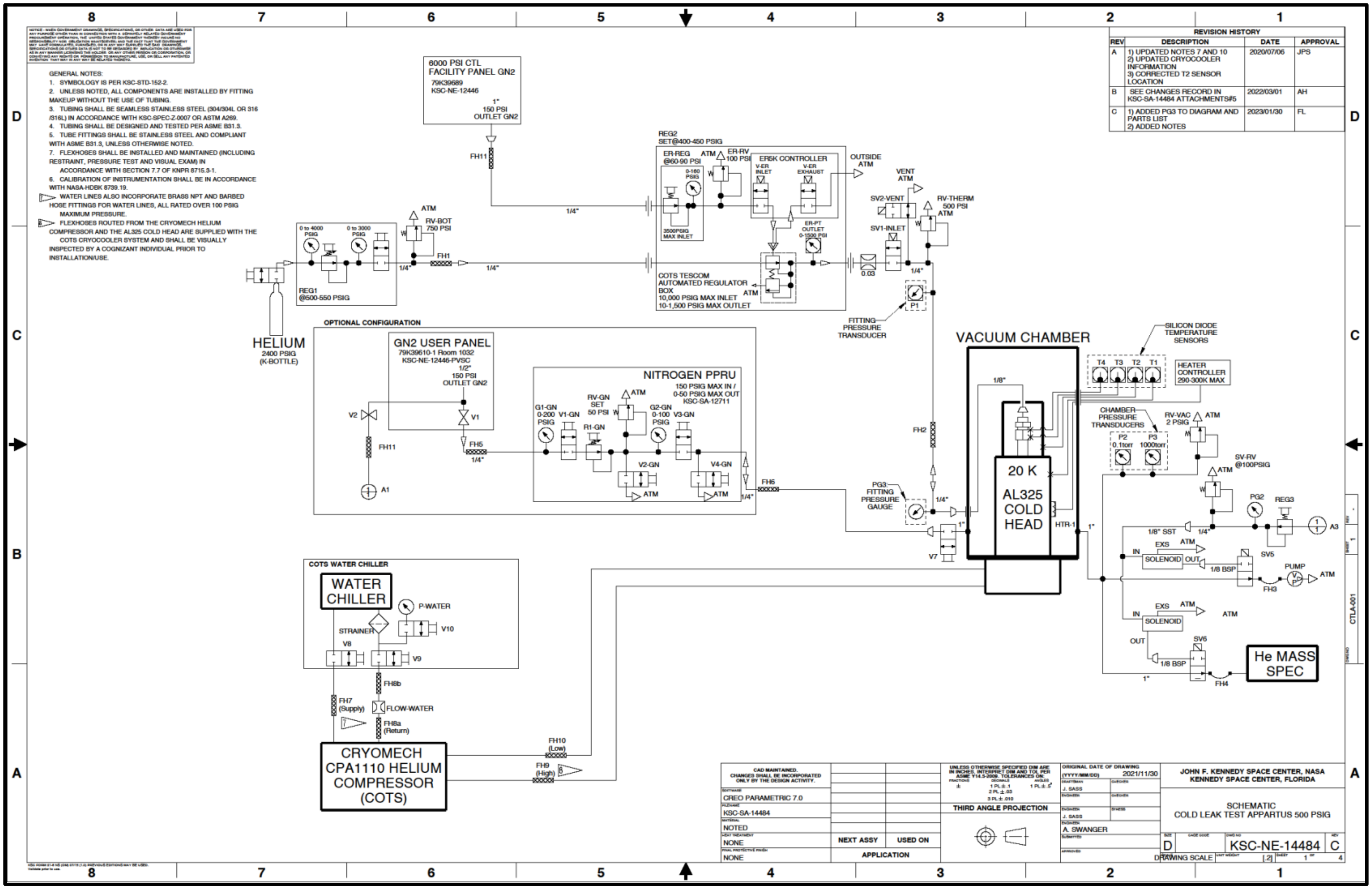


Figure 7. Cold Leak Test Fixture Fluid Schematic

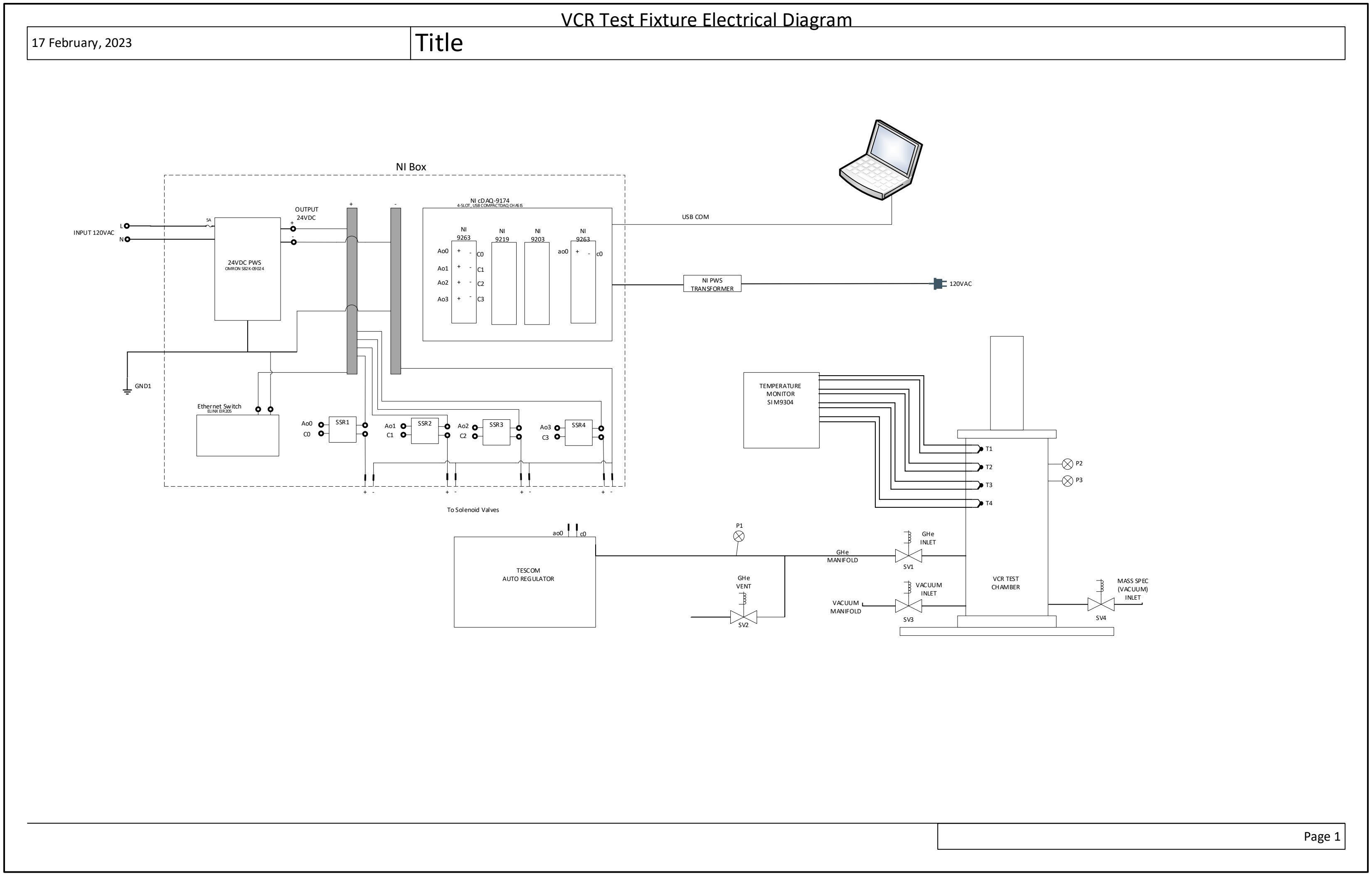


Figure 8. VCR Fitting Test Fixture Electrical Schematic (overall)

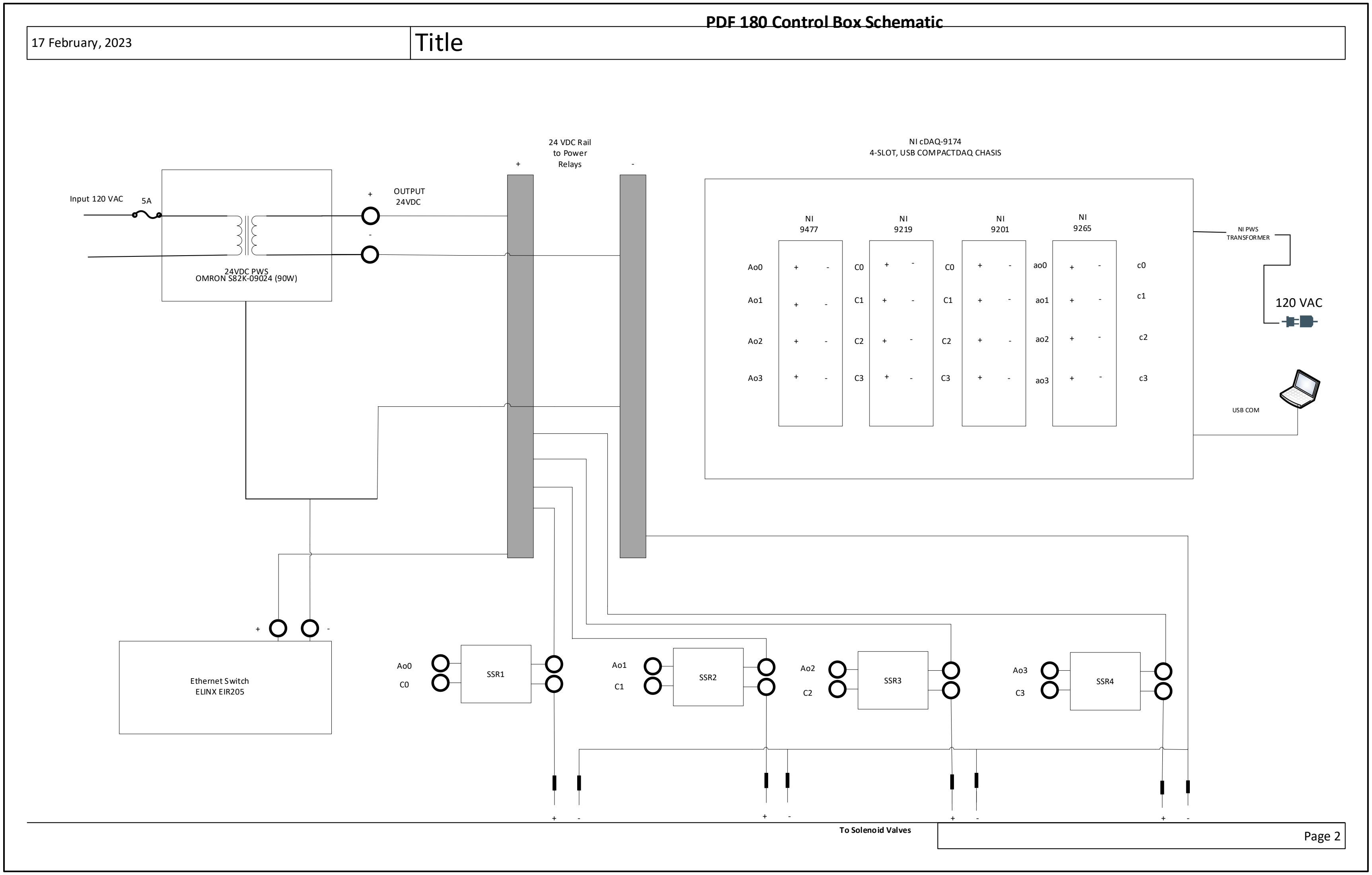


Figure 9 VCR Fitting Test Electrical Control Box Schematic

	19 Pin Connector		
DO1	A-SV-1	White	24 VDC
DO5	B-SV-1	Black	24 VDC
DO2	C-SV-2	White	24 VDC
DO6	D-SV-2	Black	24 VDC
DO3	E-SV-5	White	24 VDC
DO3	F-SV-5	Black	24 VDC
DO4	G-SV-6	White	24 VDC
DO4	H-SV-6	Black	24 VDC
CH0	J-P1-4-20MA	White	24 VDC
CH0	K-P1-Return	Black	24 VDC
CH1	L-P2-10 VDC	Red	10 VDC
CH1	M-P2-10 VDC	Black	10 VDC
CH2	N-P3-10 VDC	Red	10 VDC
CH2	P-P3-10 VDC	Black	10 VDC
AO0	R-Setpoint Sig	Red	10 VDC
COM	S-Setpt Sig Ret	Black	10 VDC
9219 CH3	T-Analog Output	Red	10 VDC
CH3 COM	U-Analog Sig Ret	Black	10 VDC
	Heater Circuit 2-Pin		
DO0	to 24 VDC Ret for Heater	Black	24 VDC
CH3	120 VAC Neutral	White	120 VAC
Pin A	120 VAC Line Pwr fr Heater	Black	24 VDC
Pin B	120 VAC Neutral	White	120 VAC

Figure 10. Connector Pinouts

6.3. Software Logic Schematic

To automate the test execution a LabVIEW application was developed. This application executed an automated series of leak measurement tests, cycling the test article from ambient to cryo and back to ambient. A condensed version of the software logic flow for the LabVIEW application is shown in **Figure 11**. The complete logic flow can be found in **Appendix C. Software Flow Logic (Complete).**

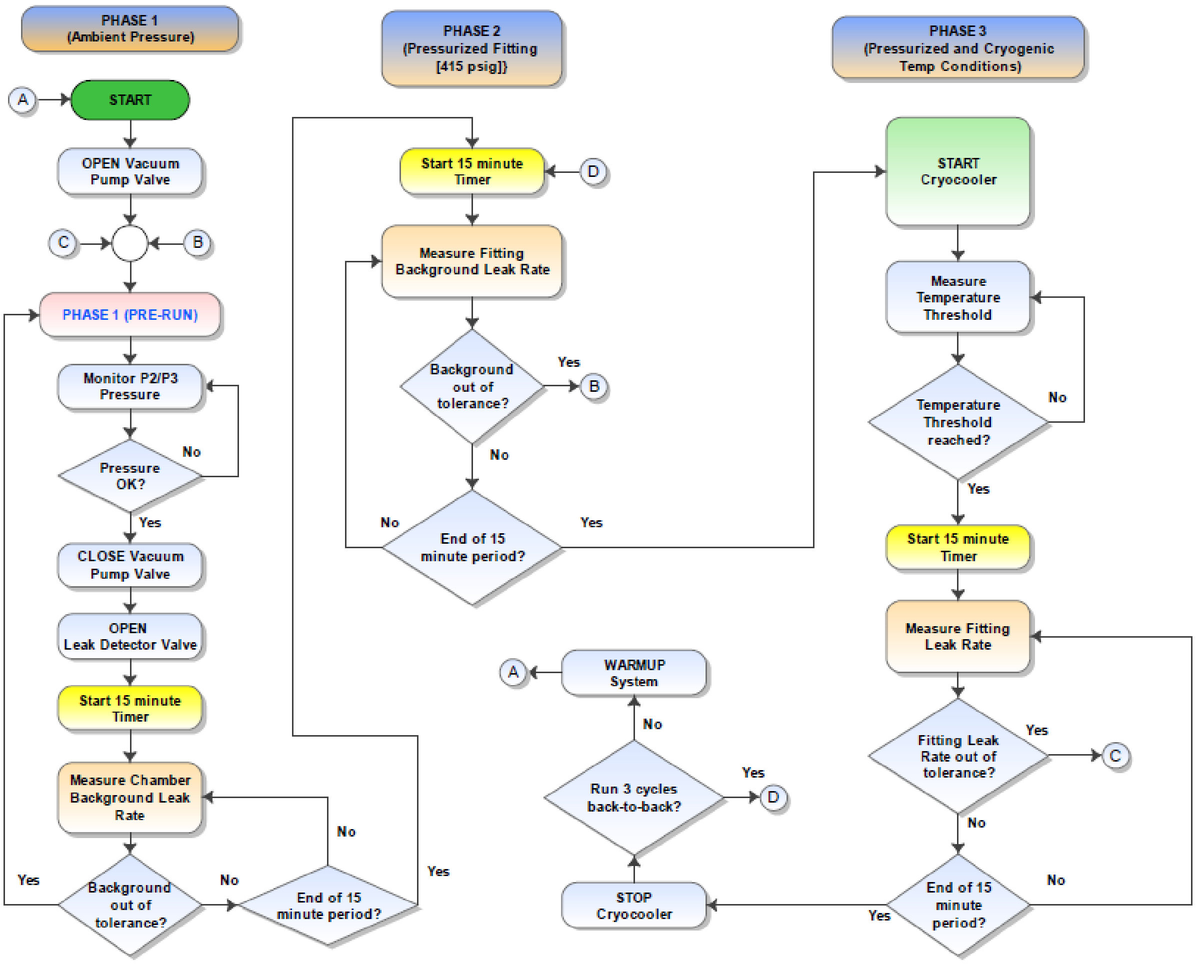


Figure 11. VCR Fitting Test Software Logic Schematic (Condensed)

7.0 MATRIX OF VCR FITTING TESTS

The matrix of VCR fitting tests performed as part of this report is shown in **Table 1**. In all, three (3) unique fitting sizes (¼, ½, and 1 inch) and two (2) different seal types (Silver-plated Nickel, 316L Stainless Steel) were tested. Five (5) samples of each fitting size were tested to ensure that a statistically sufficient sample size of each fitting size/seal combination was included. Data from two (2) pre-vibration and two (2) post-TVAC cycles were compared to evaluate whether vibrations simulating a launch environment had any effect on the sealing capability of each fitting size/seal pair.

Table 1. Matrix of VCR Fitting Tests

Seal Material (Silver-plated Nickel)																
Fitting Size	¼ inch VCR					½ inch VCR					1 inch VCR					**Total Cycles**
Fitting Sample #	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	
# of Pre-Vibe TVAC Cycles	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	
Vibe Cycles	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15
# of Post-Vibe TVAC Cycles	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	
TVAC cycles/fitting	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	60
Seal Material (Stainless Steel)																
Fitting Size	¼ inch VCR					½ inch VCR					1 inch VCR					**Total Cycles**
Fitting Sample #	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	
# of Pre-Vibe TVAC Cycles	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	
Vibe Cycles	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15
# of Post-Vibe TVAC Cycles	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	
Total thermal cycles/fitting	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	60

8.0 TEST PROCEDURE

This section provides a discussion of the test procedure and order of test events, these are shown in **Table 2.** This procedure was performed for each fitting size/seal material combination. An example of the automated TVAC test cycle is shown in **Figure 12.**

8.1 Order of Test Events

Table 2. Test Procedure Event Order

Test Action	**Description**
Install VCR Fitting Test Article	Install test article per procedure CTL-TP-082
Evacuate Vacuum Chamber	Evacuate to less than 1 millitorr prior to measuring the GHe background.
Measure Helium Background	This serves as the baseline helium background prior to pressurizing the fitting with helium. A high helium background at this stage of the test should be investigated further and may indicate a leak in the vacuum chamber.
Pressurize VCR Fitting Test Article to Test Pressure	For the initial leak measurement test after installation, air must be removed from the fitting and tubing. This can be accomplished either by evacuation or by performing several pressure/vent cycles.
Monitor Helium Leakage Until Fitting is De-Pressurized Post-Test	This serves as an ambient temperature helium leak measurement test.
Start Cryocooler, Chill Down test fitting	Helium leak measurement continues to be monitored throughout the chill down transient. The cold tip chills down in approximately 20-30 minutes. The fitting chill down to the range of 20K to 30K typically takes approximately one hour.

Test Action	Description
Hold Period for Cold Leak Measurement	Hold for at least 15 minutes after the fitting is cooled to between 20K to 30K.
Stop Cryocooler, Begin Warm Up	This is the end of the cold leak measurement test. The fitting can continue to be monitored for leakage during the warmup transient. Heaters are turned on to expedite the warmup process.
End Leak Measurement Test	The mass spec must be switched to standby prior to proceeding to the next step.
Break Vacuum with Nitrogen	There will be rapid warming and likely nitrogen condensation inside the chamber if any temperatures are < 77K.
Hold Until All Temperatures > 285K	Everything in the chamber should be as close to ambient temperature as practical to minimize condensation when the chamber is opened.
Remove VCR Fitting Test Article	Remove test article per procedure CTL-TP-082.

8.2 Automated TVAC Cycle Test Example

An example of an automated TVAC test sequence is shown in **Figure 12.** For clarity, pressurization of the fitting, valves opening/closing, and operational cycling of the cryocooler, have been widely separated on the graph to prevent overlap and allow a clearer picture of the hardware actions that typically take place during a VCR fitting test. The three test phases in this figure and nominal actions within each phase are listed below. A more detailed picture of the associated software flow can be found in **Appendix C. Software Flow Logic (Complete).**

Phase 1
Install fitting assembly and pump down vacuum chamber.
Collect data on pressure, temperature, and background leak rate for reference.

Phase 2
Close vacuum pump valve
Pressurize fitting assembly
Open Leak detector valve (Mass Spectrometer)

Phase 3
Start Cryocooler: Monitor fitting pressure, temperature, and leak rate
Warmup Phase: turn on heaters for warm-up phase, turn off Cryocooler**,** reopen vacuum pump valve

Most VCR fitting tests data files contained a single thermal vacuum cycle. When two thermal vacuum cycles were run back-to-back (e.g. **Figure 12**), the ambient temperature unpressurized fitting phase of the test is not repeated during the 2nd thermal vacuum cycle. The reason for this is, since the vacuum chamber is leak checked during the 1st cycle it does not need to be rechecked during the 2nd cycle.

The Leak Rate Data (Green line) shows some leakage of the fitting approximately 30 minutes into the chill-down cycle that dissipates and reaches a steady state after 45-60 minutes. There does not appear to be any other noticeable leakage throughout the remainder of the test cycle. The momentary spikes in the leak rate during testing may be attributed to the effects of electrical DAQ noise, mechanical system vibrations or resulting from valves opening/closing during testing. More of these fluctuations seems to occur during fitting chill-down cycles and can be seen in the data presented in Section 10.

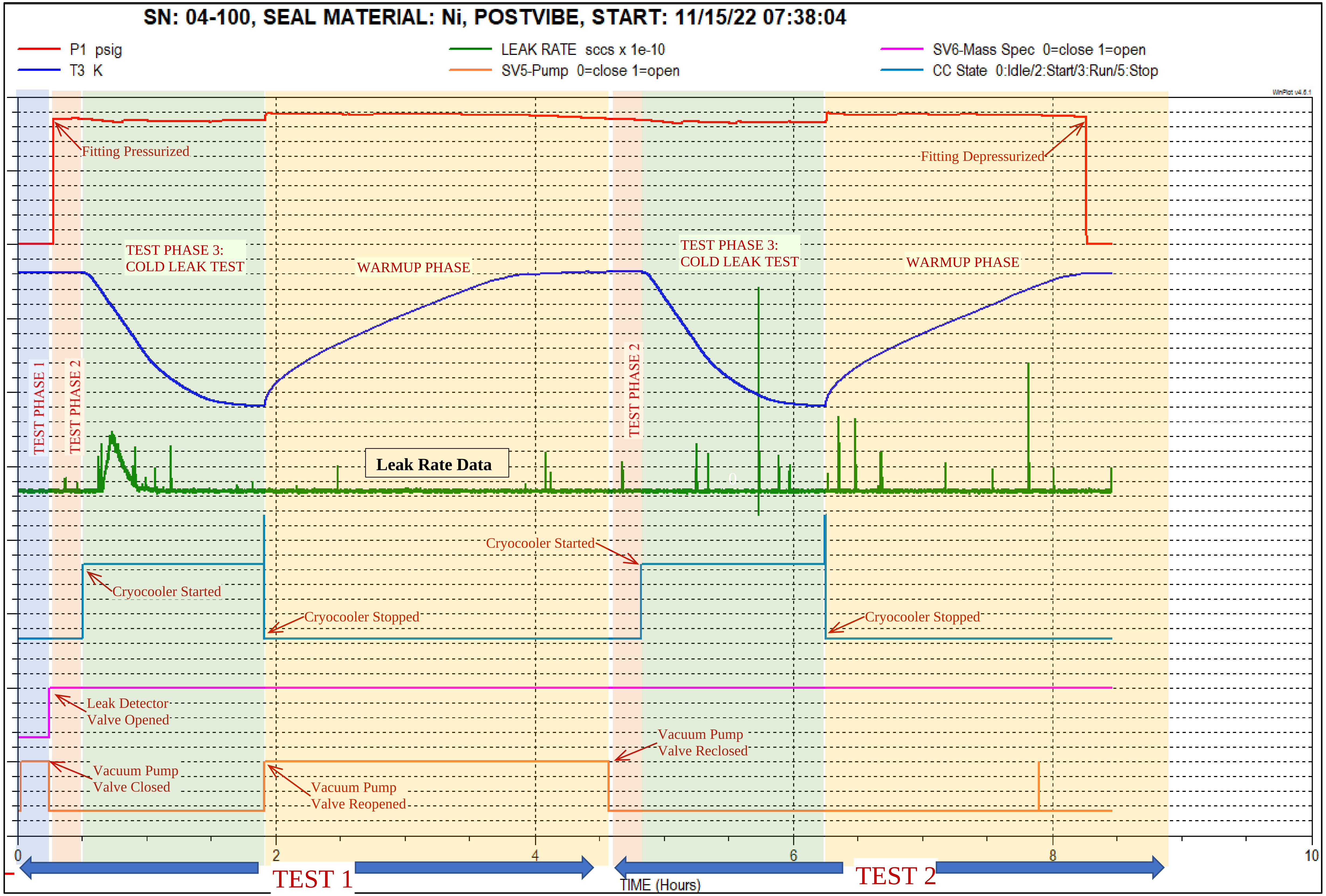


Figure 12. Example of an automated thermal vacuum cycle (2 tests in total cycle)

9.0 VIBRATION TESTING

9.1 Test Method

Vibration testing of the VCR fittings was utilized to expose each fitting to launch-like conditions and ascertain whether the sealing capability of any fitting was compromised due to vibration loads.

All vibration testing was performed on an Unholtz Dickey vibration shaker table, located at the KSC Vibration Test Laboratory. The vibration test profile used for the testing a is per flight standard vibration profile (Reference General Environmental Verification Standard (GEVS) Table 2.4-3, *GSFC-STD-7000B Goddard Space Flight Center Approved: 04-28-2021 Greenbelt, MD 20771 Revalidation Date: 04-28-2026 Superseding GSFC-STD-7000A* for GSFC Flight Programs and Projects) and is shown in **Figure 13**.

VIBROACOUSTICS VIBROACOUSTICS

Table 2.4-3
Generalized Random Vibration Test Levels
Components (ELV)
22.7-kg (50-lb) or less

Frequency (Hz)	ASD Level (g^2/Hz) Qualification	Acceptance
20	0.026	0.013
20-50	+6 dB/oct	+6 dB/oct
50-800	0.16	0.08
800-2000	-6 dB/oct	-6 dB/oct
2000	0.026	0.013
Overall	14.1 G_{rms}	10.0 G_{rms}

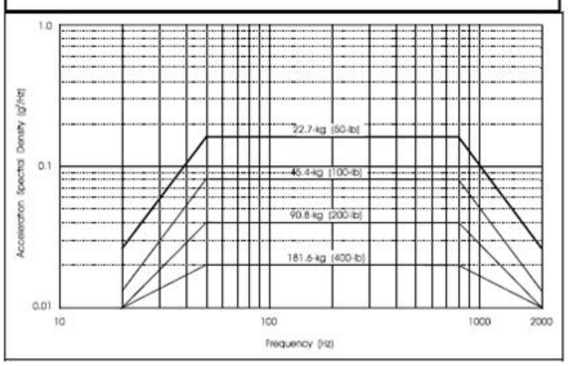
The acceleration spectral density level may be reduced for components weighing more than 22.7-kg (50 lb) according to:

	Weight in kg	Weight in lb	
dB reduction	= 10 log(W/22.7)	10 log(W/50)	
$ASD_{(50\text{-}800\ Hz)}$	= 0.16•(22.7/W)	0.16•(50/W)	for protoflight
$ASD_{(50\text{-}800\ Hz)}$	= 0.08•(22.7/W)	0.08•(50/W)	for acceptance

Where W = component weight.

The slopes shall be maintained at + and - 6dB/oct for components weighing up to 59-kg (130-lb). Above that weight, the slopes shall be adjusted to maintain an ASD level of 0.01 g^2/Hz at 20 and 2000 Hz.

For components weighing over 182-kg (400-lb), the test specification will be maintained at the level for 182-kg (400 pounds).



Check the GSFC Technical Standards Program website at http://standards.gsfc.nasa.gov or contact the Executive Secretary for the GSFC Technical Standards Program to verify that this is the correct version prior to use.

Figure 13. GEVS Vibration Test Profile

The testing procedure and attachment fixture (**Figure 14**) are based on ASTM F1387-19 S8 specifications except for the spacing of the supports which is not possible with the geometry constrains of the test specimens which were designed to fit the TVAC leak testing setup.

The mated fitting joint along with an adapter were securely mounted to the vibration shaker table test cube and the tubing restrained to minimize any excessive movement (**Figure 14**).

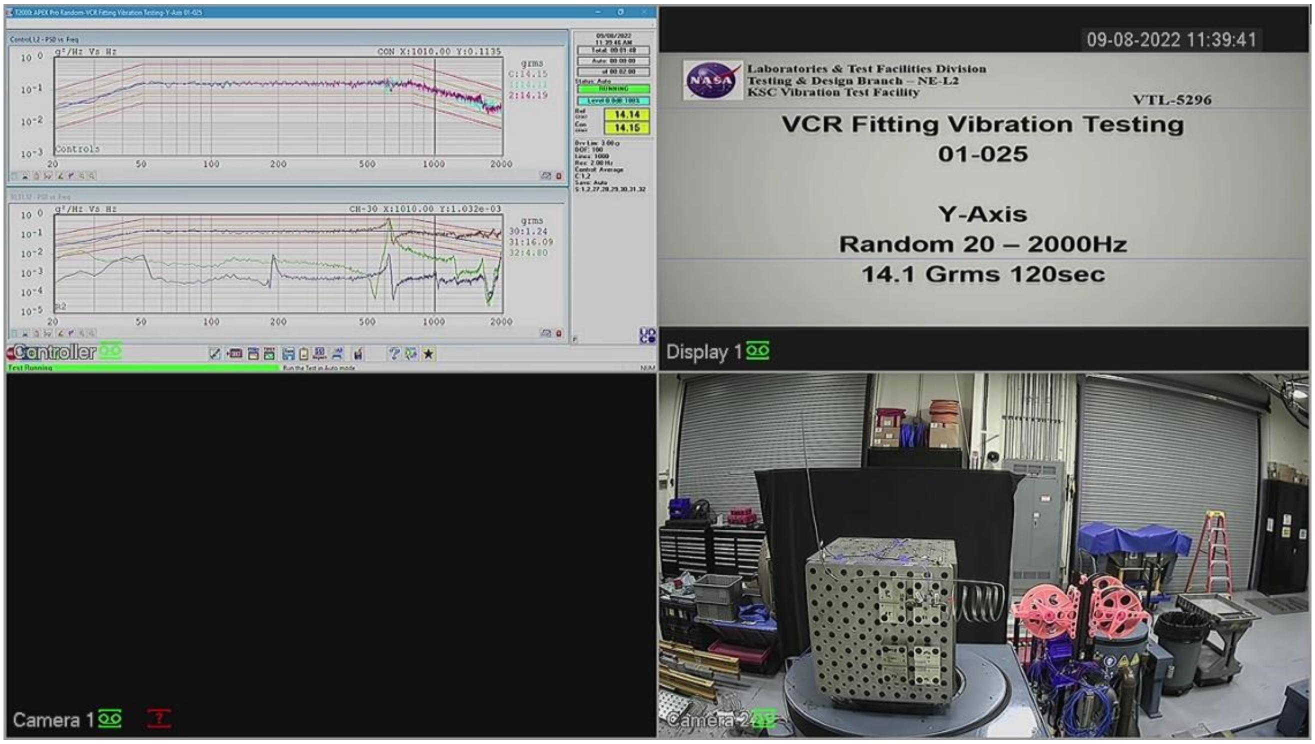


Figure 14. Testing Procedure and Attachment Fixture

The vibration testing was performed at ambient temperature and with the fitting unpressurized. For reference, **Figure 15** shows the addition of the attached accelerometer used for the collection of vibration responses.

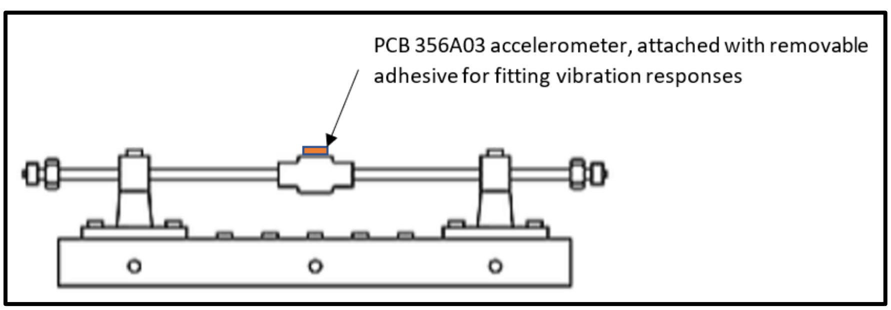
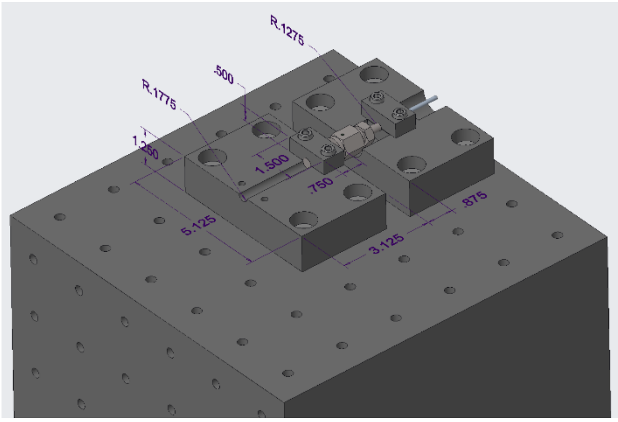
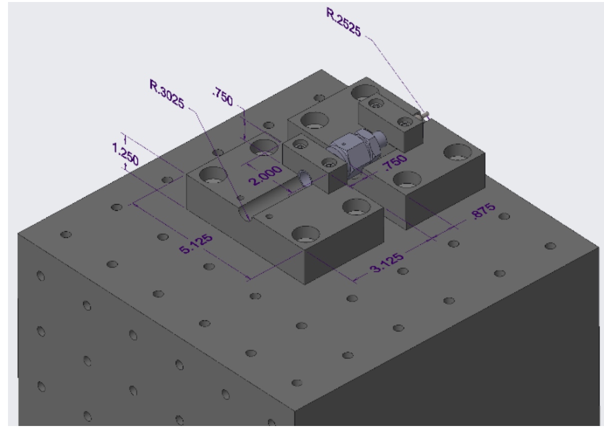


Figure 15: Schematic of the vibration fixture and attachment of the fitting hardware (form the ASTM F1387-19 S8 specifications)

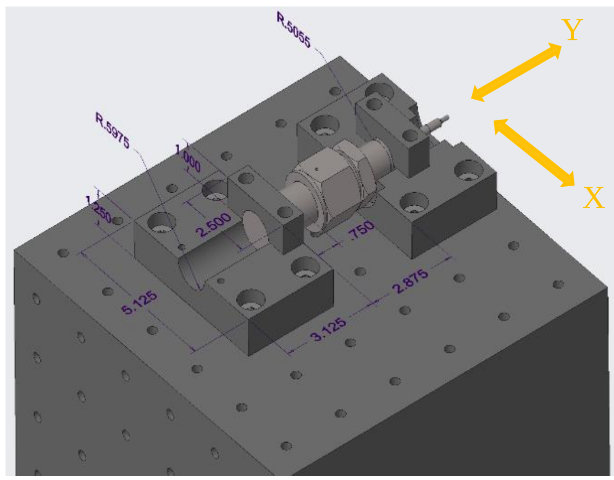
Due to geometry constraints the VCR fittings were mounted as shown in **Figure 16**. They were held by the tube ends with the fitting portion free as per the ASTM spec, but the tube ends were shorter due to the limitations of the size of the TVAC.



1/4-inch VCR fitting on vibration test fixture



1/2-inch VCR fitting on vibration test fixture



1 inch VCR fitting on vibration test fixture

Figure 16. Vibration Test Fixture

This overall shaker table/adapter/VCR fitting assembly shown in **Figure 17** was used during all vibration tests. Test Fixtures and test specimens mounted to the fixture cube are shown with the 1/8-inch coil extending over the edge of the test cube. Because the shaker table produces a linear acceleration in a single direction, each fitting assembly was subjected to two separate tests to evaluate both axial and radial vibration loads, with the fitting rotated 90 degrees on the table between tests. Photos of a typical X and Y fitting orientation are shown in **Figure 18** and **Figure 19**, respectively. Additionally, since the fitting is symmetrical, tests were only required on 2 of 3 axes.

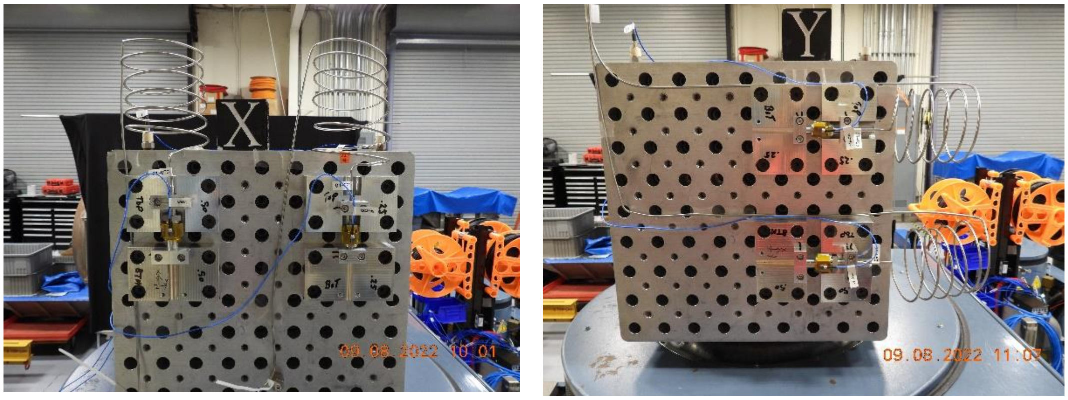


Figure 17: Vibration Test and Shaker Table Fitting Assembly

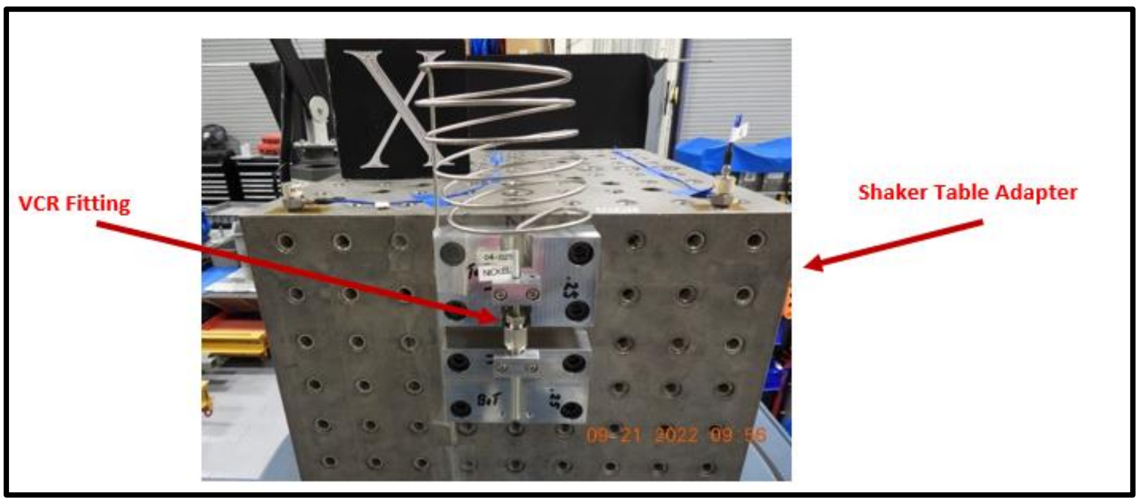


Figure 18. ¼" Fitting #4, Ni seal, Vibration Test Setup, X-Axis

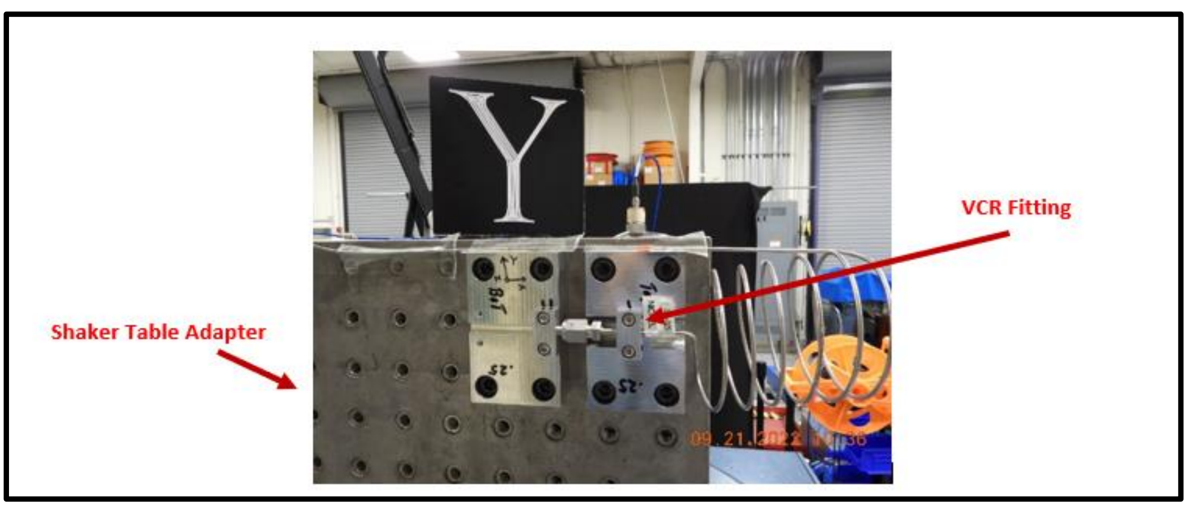


Figure 19. ¼" Fitting #4, Ni seal, Vibration Test Setup, Y-Axis

A vibration test report was generated for each fitting/seal pair tested. The graphical test profile from a representative report is shown in **Figure *20*.** A copy of the entire report for related fitting/seal pairs **(X-Axes 01-025 and 01-050 Nickel)** can be found in **Appendix D. VCR Fitting Vibration Test Report**.

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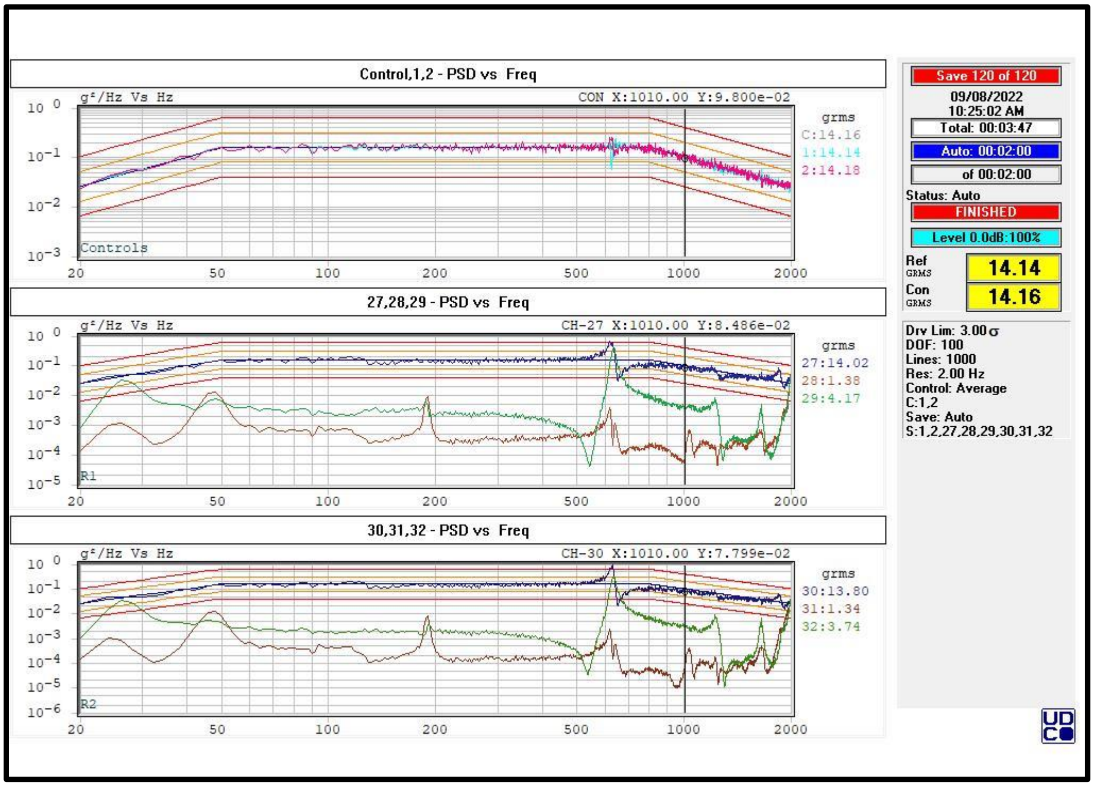


Figure 20. VCR Fitting Test – Representative Vibration Test Profile

10.0 TEST RESULTS

10.1 Representative Test Runs

Representative single data runs for each of the fitting sizes are shown in **Figure 21** thru- **Figure 23**. Each graph shows the fitting pressure (P1- red), fitting temperature (T3 - purple) and leak rate (green).

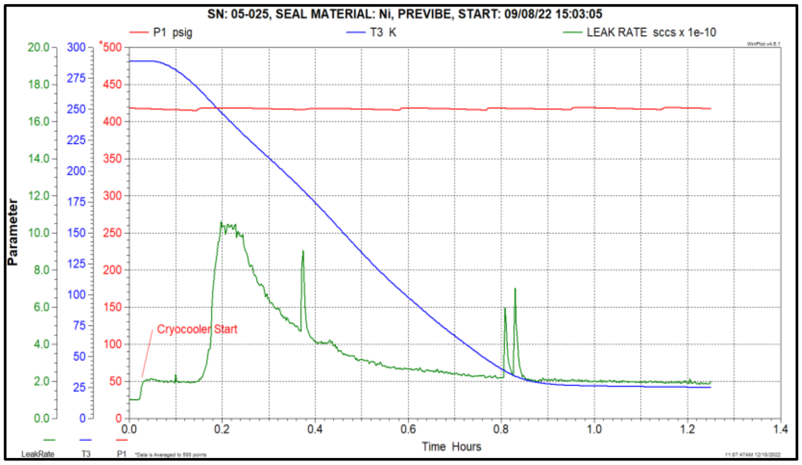


Figure 21. Representative Graph of ¼ inch Swagelok fittings

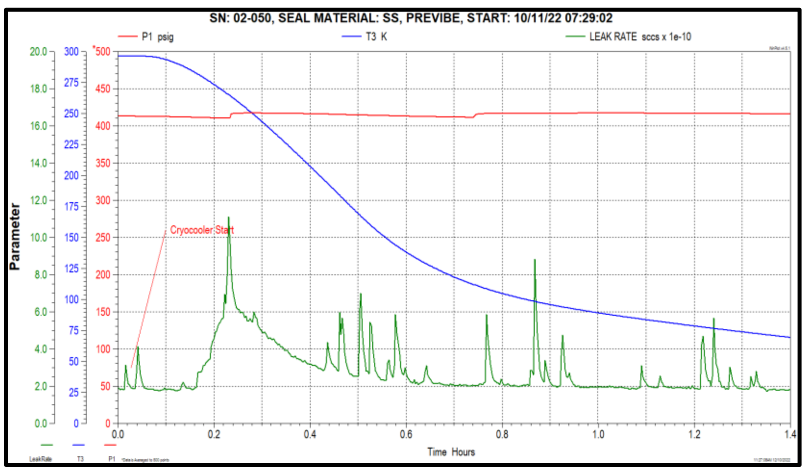


Figure 22. Representative Graph of ½ inch Swagelok fittings

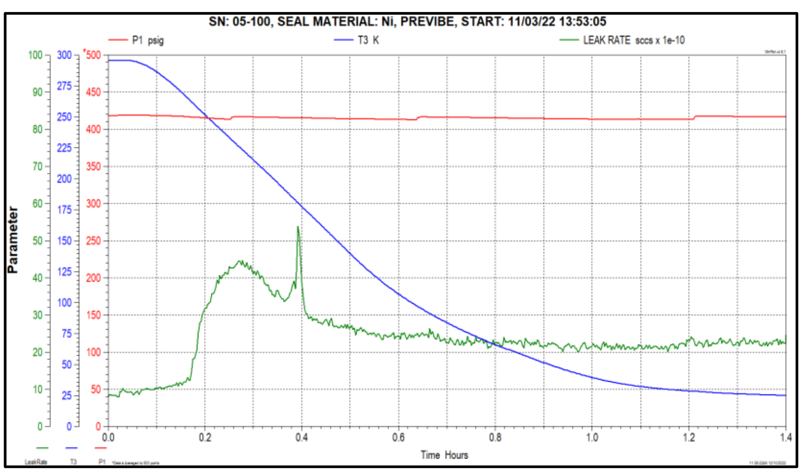


Figure 23. Representative Graph of 1 inch Swagelok fittings

The data graphs presented in Sections 10.2 – 10.4 compare the leak rate results from the Pre-Vibe and Post-Vibe tests on ¼, ½, and 1 inch VCR fittings. All fittings passed the leak rate criteria (maximum allowable rate of 10^{-6} sccs). Measured leak rates were, at a minimum, 2-3 orders of magnitude below this value. For reference, the limits of the leak detector measuring range are 1 x 10^{-1} to 5 x 10^{-11} sccs, and most of the test were at the lower end of this range around 10^{-10}. For clarity, the GHe pressure has been omitted, since it stays constant throughout all tests, see representative graphs in **Figure *21*** thru **Figure *23***. Each of graphs in Sections 10.2 – 10.4 includes a Temperature Profile curve for reference. When leaks in the range of 10^{-9}-10^{-10} sccs are noticed they seem to consistently occur between 10 – 30 minutes in the chill-down cycle and over a corresponding temperature range of 250K – 100K. This observed leak rate may be due to the "settling" of fitting/seal pairs during chill-down. The fact that some fitting/seal pairs do not exhibit detectable leaks may be due to smoother sealing surfaces or minor differences in component assembly. Note that **Figure 25**, **Figure 27**, **Figure 28**, and **Figure 29** each contain two (2) data sets for the same fitting/seal pair. The data sets were run on different days and are notated as such.

A reference guide on the data plots has been included in this report in **Appendix E. How to read the VCR Fitting Data plots.** The guide explains the scaling of leak rate data, date formatting, and data averaging parameters.

A list of the data files and their fitting size, fitting number, and seal material can be found in **Appendix F. Complete VCR Data File List.**

Data for individual fitting/seal pairs can be found in **Appendices G-I**.

10.2 ¼" Pre-Vibe and Post-Vibe Fittings (Comparison of Fittings)

STAINLESS STEEL SEAL (PRE-VIBE)

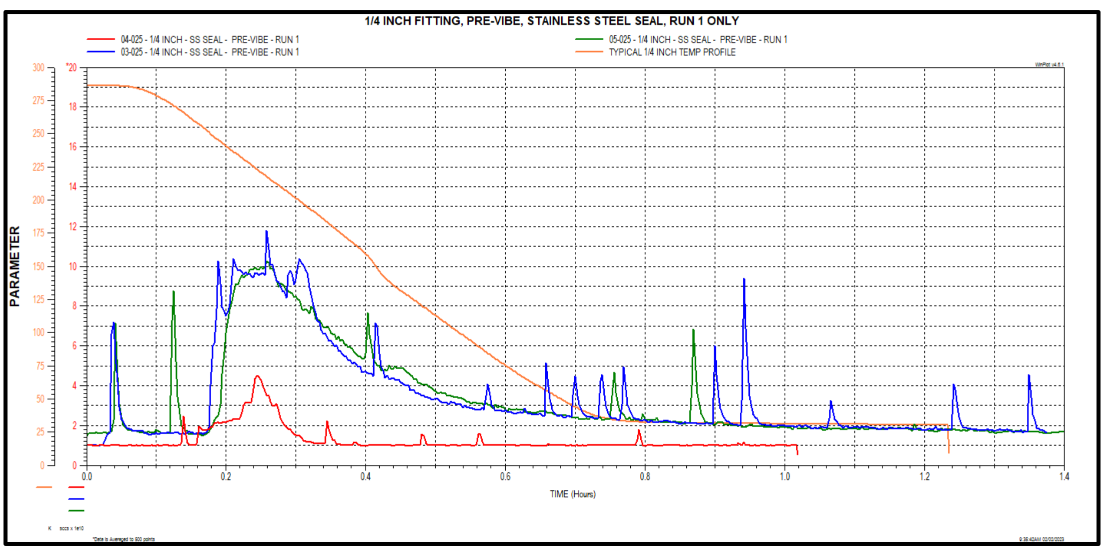


Figure 24. ¼ inch Stainless Steel Pre-Vibe fittings plotted together for comparison

STAINLESS STEEL SEAL (POST-VIBE)

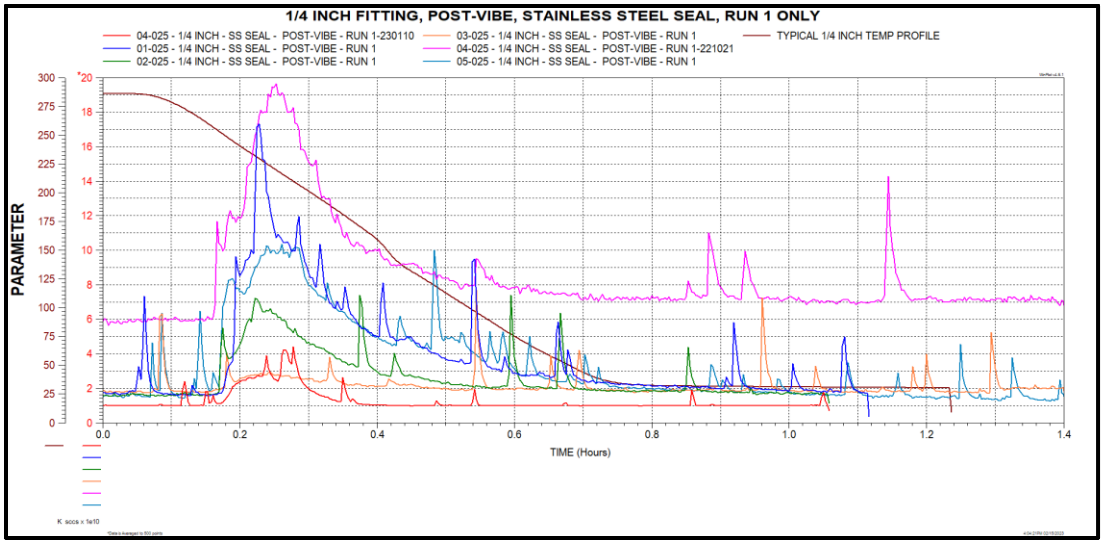


Figure 25. ¼ inch Stainless Steel Post-Vibe fittings plotted together for comparison

SILVER PLATED NICKEL SEAL (PRE-VIBE)

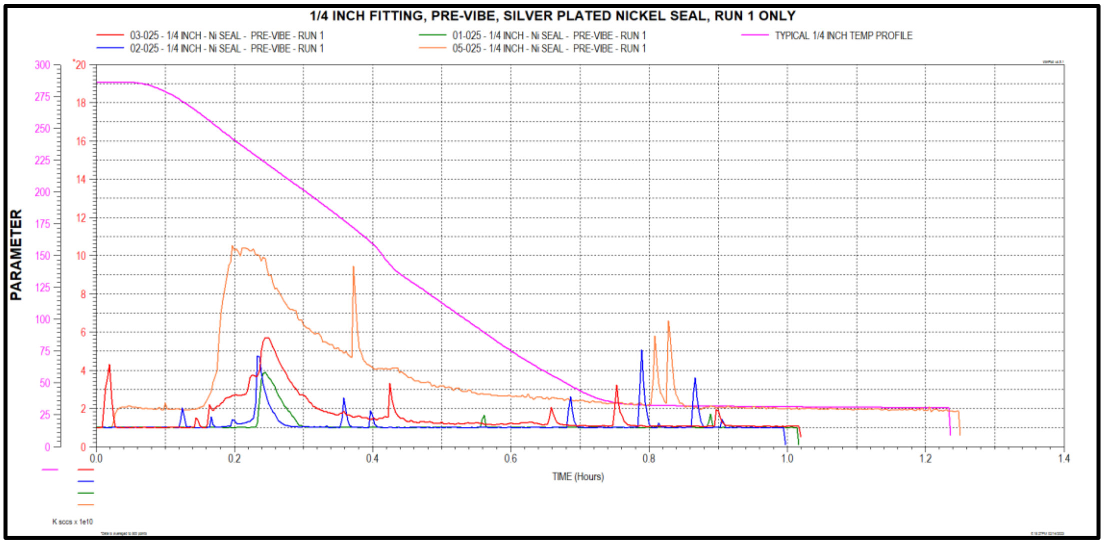


Figure 26. ¼ inch Silver plated Nickel Pre-Vibe fittings plotted together for comparison

SILVER PLATED NICKEL SEAL (POST-VIBE)

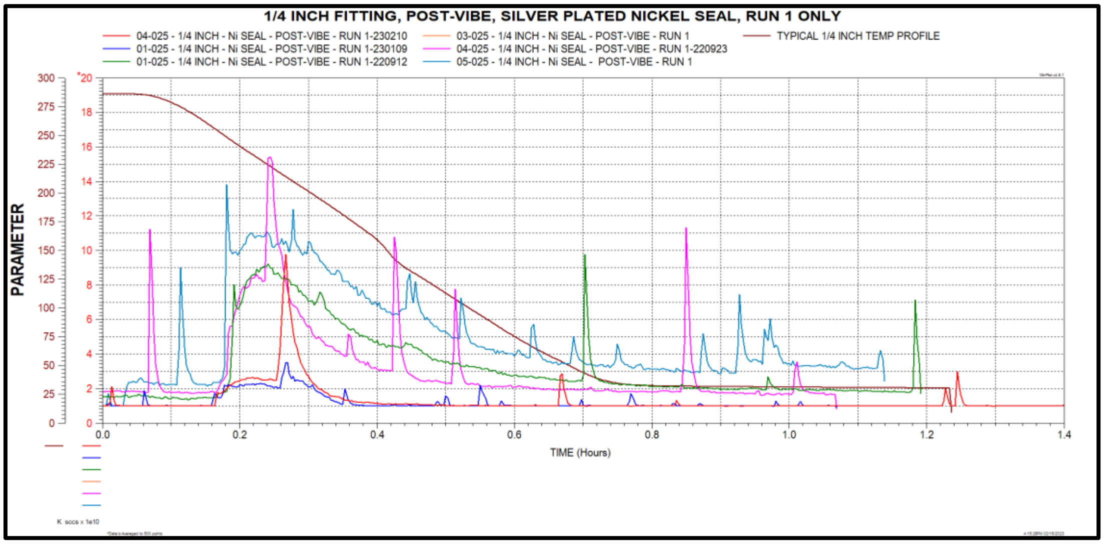


Figure 27. ¼ inch Silver plated Nickel Post-Vibe fittings plotted together for comparison

10.3 ½" Pre-Vibe and Post-Vibe Fittings (Comparison of Fittings)

STAINLESS STEEL SEAL (PRE-VIBE)

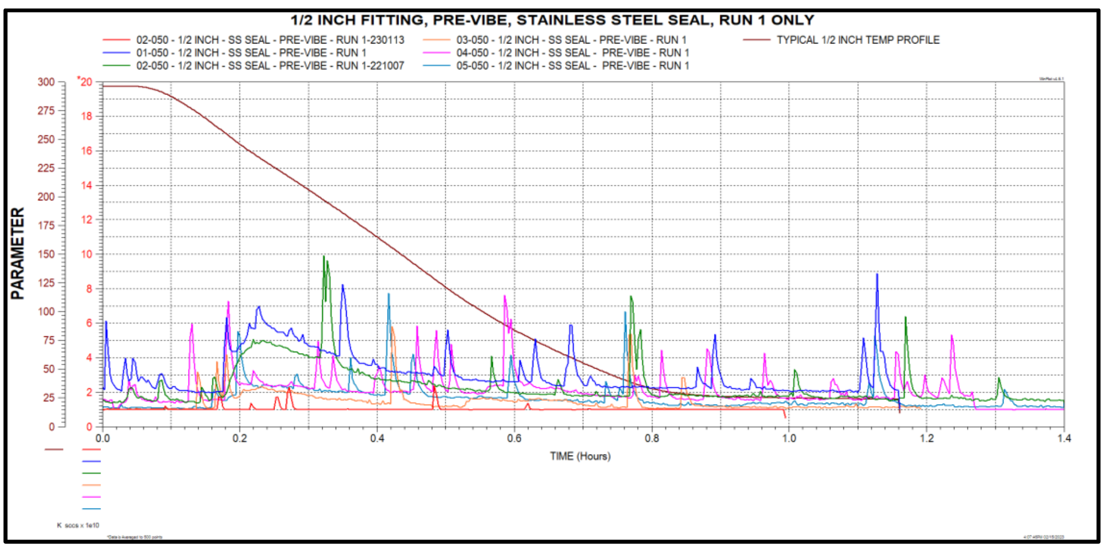


Figure 28. ½ inch Stainless Steel Pre-Vibe fittings plotted together for comparison

STAINLESS STEEL SEAL (POST-VIBE)

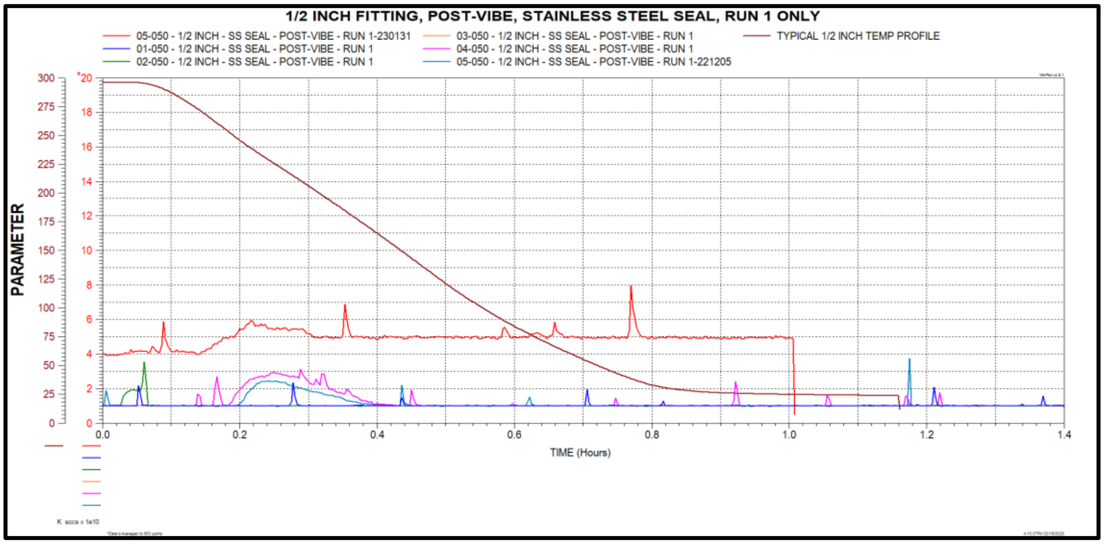


Figure 29. ½ inch Stainless Steel Post Vibe fittings plotted together for comparison

SILVER PLATED NICKEL SEAL (PRE-VIBE).

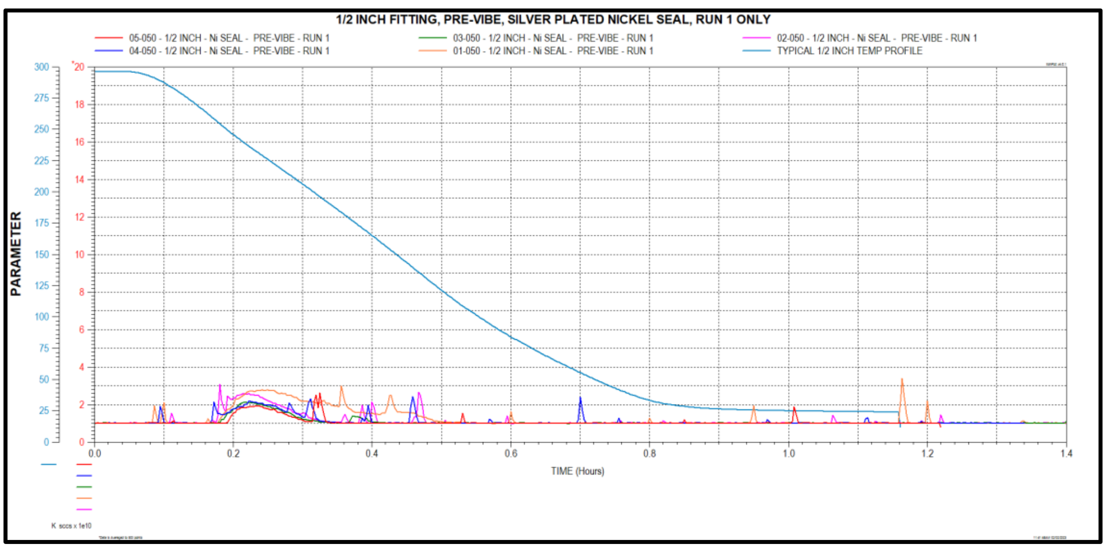


Figure 30. ½ inch Silver plated Nickel Pre-Vibe fittings plotted together for comparison

SILVER PLATED NICKEL SEAL (POST-VIBE)

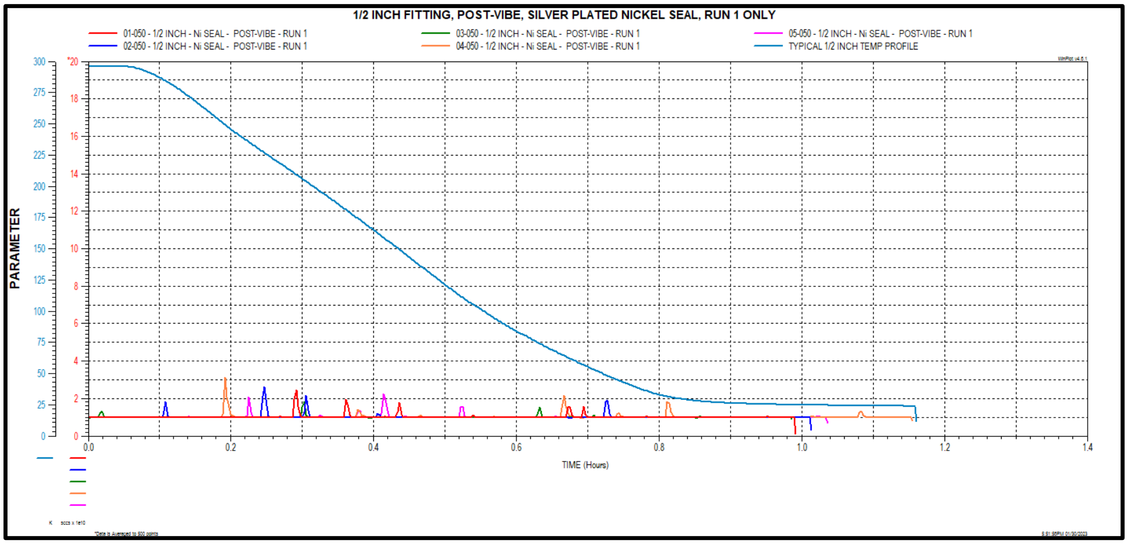


Figure 31. ½ inch Silver plated Nickel Post-Vibe fittings plotted together for comparison

10.4 1″ Pre-Vibe and Post-Vibe Fittings (Comparison of Fittings)

STAINLESS STEEL SEAL (PRE-VIBE)

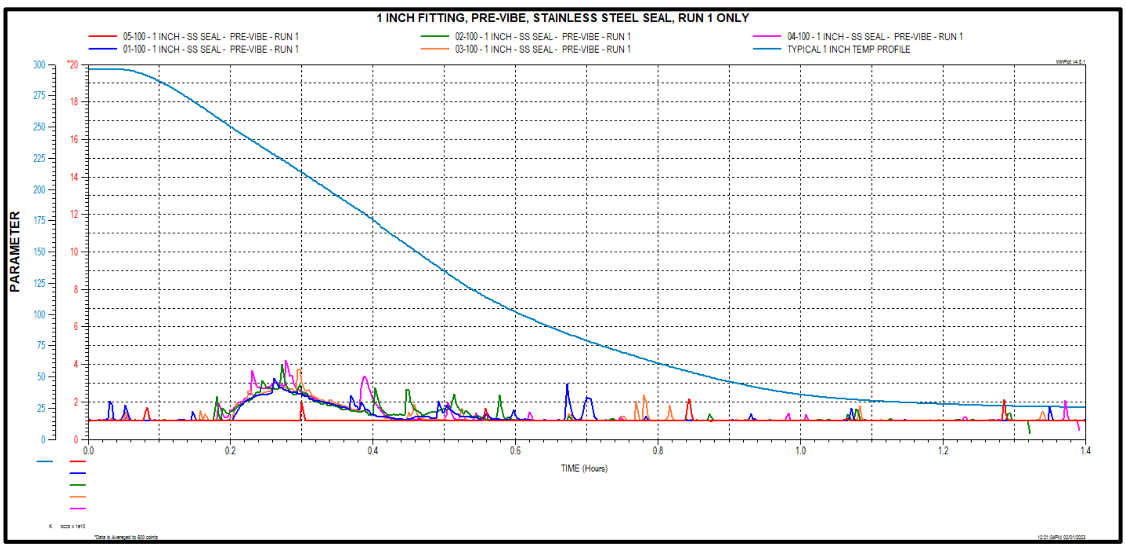


Figure 32. 1-inch Stainless Steel Pre-Vibe fittings plotted together for comparison

STAINLESS STEEL SEAL (POST-VIBE)

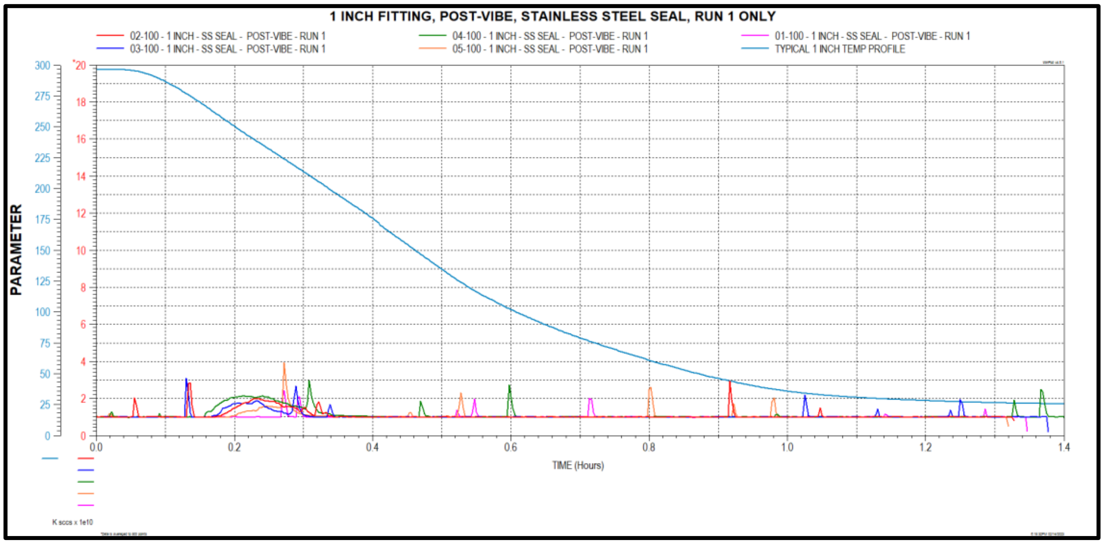


Figure 33. 1-inch Stainless Steel Post Vibe fittings plotted together for comparison

SILVER PLATED NICKEL SEAL (PRE-VIBE)

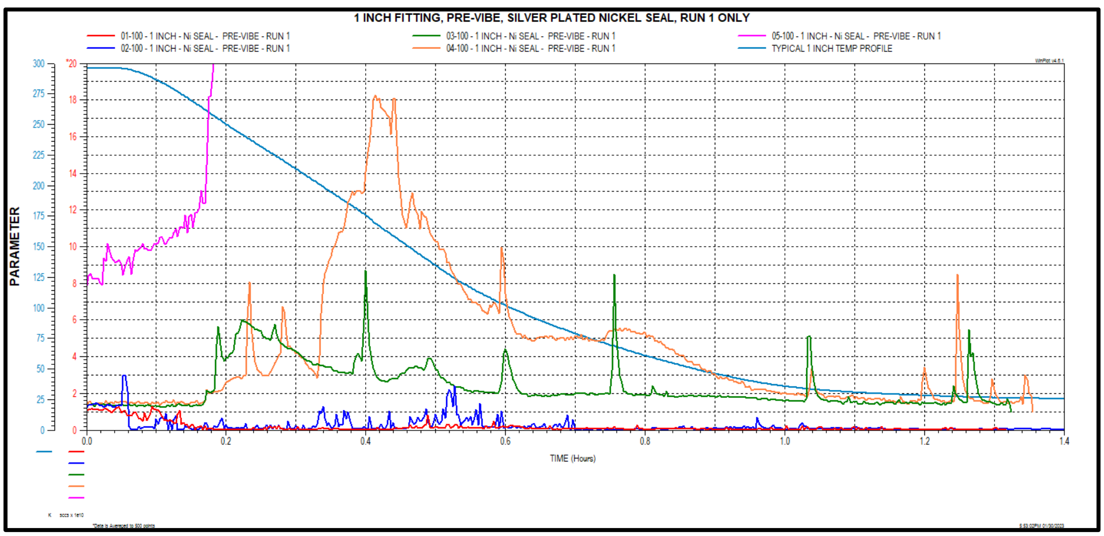


Figure 34. 1-inch Silver plated Nickel Pre-Vibe fittings plotted together for comparison

The data from **Figure *34*** is replotted in **Figure *35*** with an expanded Y-axis to show the complete leak rate curve for sample 05-100 (Pink Line). The leak rate for this fitting is higher than the other fitting values, but still well below the threshold of 10^{-6} sccs. The higher overall leak rate during the testing of this fitting may be due to seal material imperfections or a loosening of the fitting during assembly or chill down.

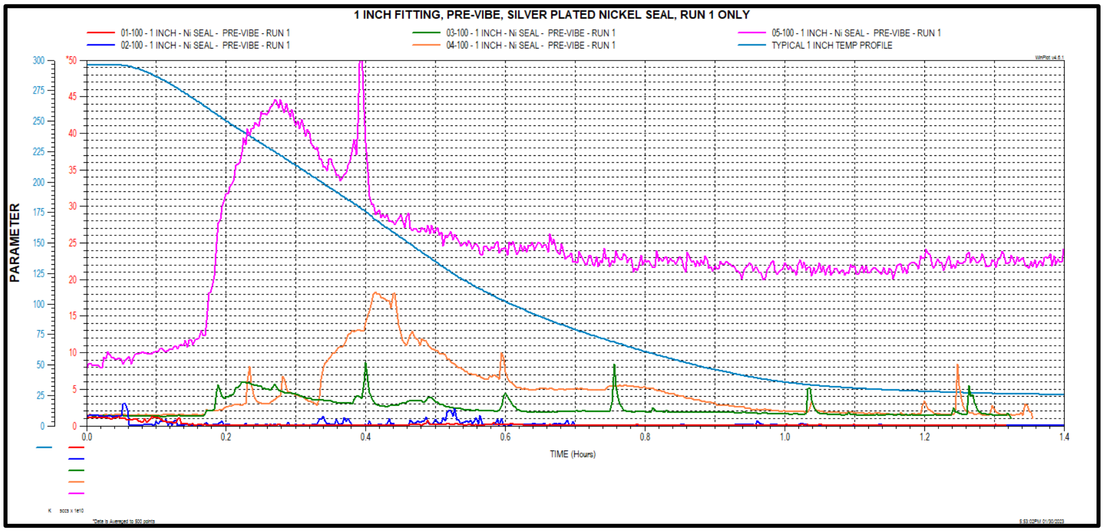


Figure 35. 1-inch Silver plated Nickel Pre-Vibe fittings (replotted from Figure 34)

SILVER PLATED NICKEL SEAL (POST-VIBE)

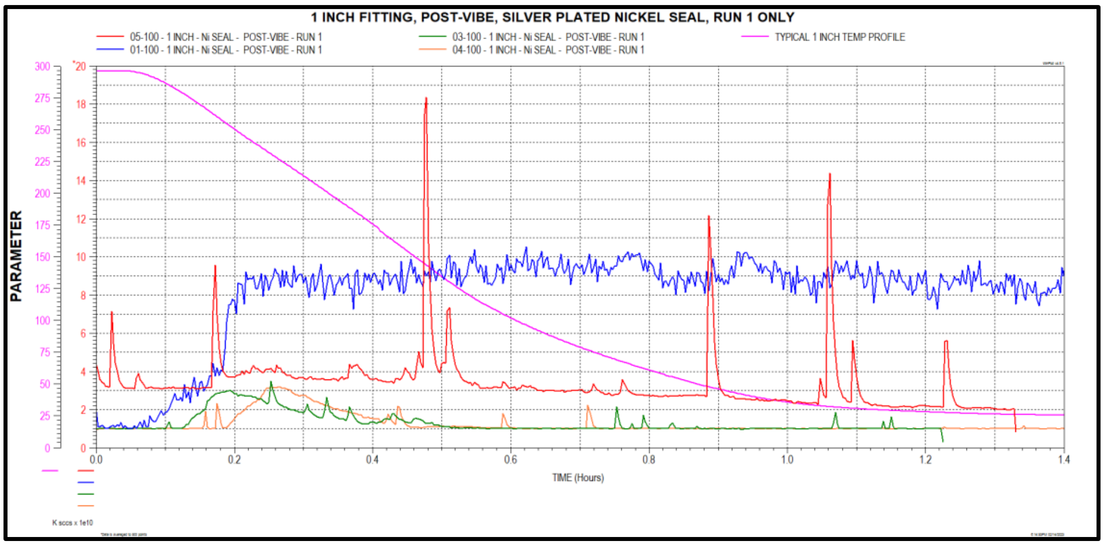


Figure 36. 1-inch Silver plated Nickel Post-Vibe fittings plotted together for comparison

10.5 Average Helium Leak Rate Comparisons

The data in this section is representative on the average helium leak rate across all five (5) serial numbers for a unique fitting/seal pair. Note that the leak rates for both the Pre-Vibe and Post-Vibe averages are comparable and well below the allowable maximum leak rate of 10^{-6} sccs. The "peaks" in the leak rate date are visible between 10-30 minutes after the start of the chill-down cycle (T=0). This corresponds to the observed peaks in graphs shown in Sections 10.2 – 10.4

1/4" FITTINGS

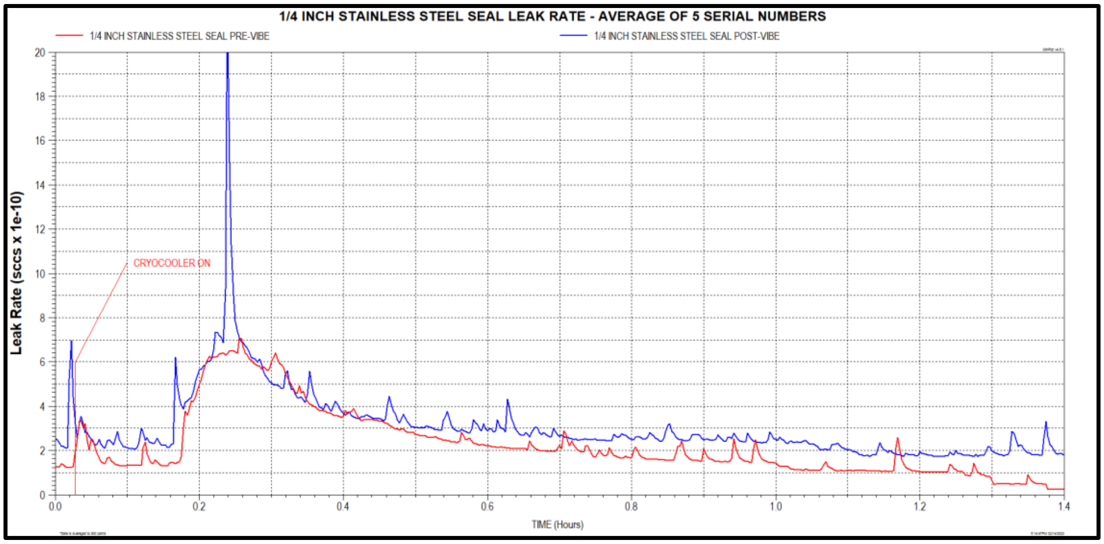


Figure 37. Graph of ¼" Swagelok VCR (Stainless Steel seal) Average Helium Leak Rate (sccs)

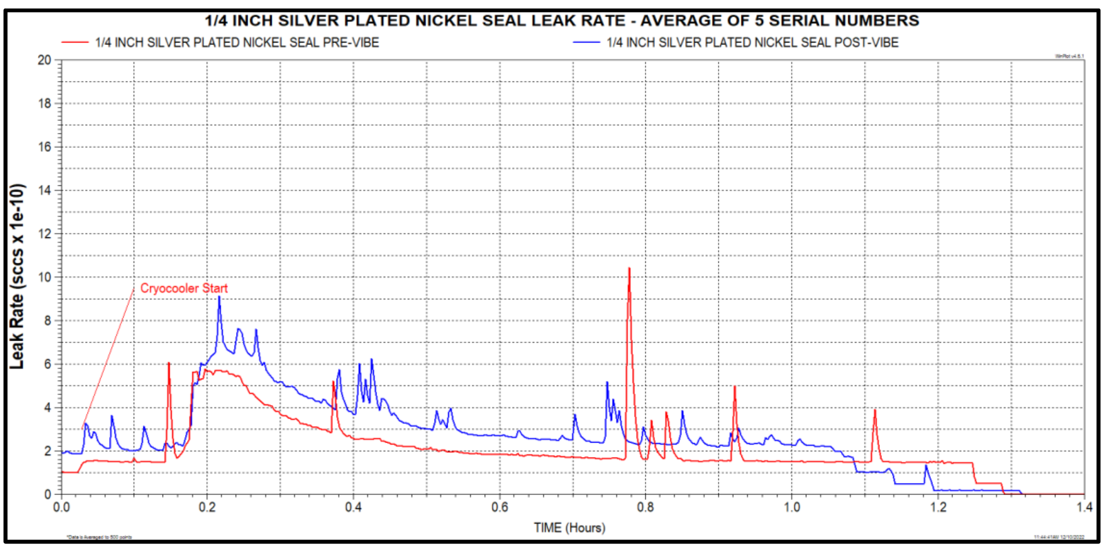


Figure 38. Graph of ¼" Swagelok VCR (Silver plated Nickel seal) Average Helium Leak Rate (sccs)

1/2” FITTINGS

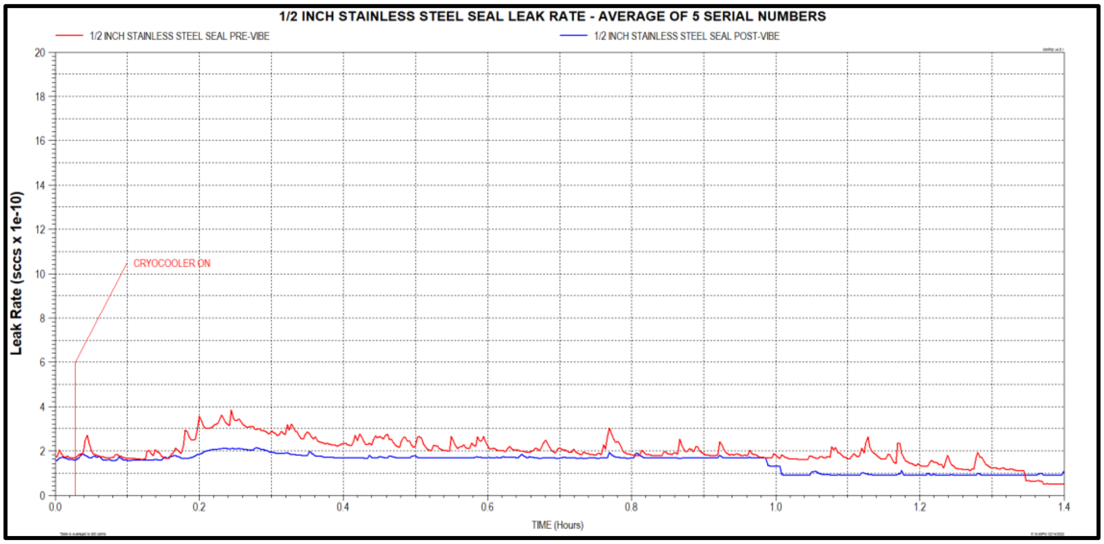


Figure 39. Graph of ½” Swagelok VCR (Stainless Steel seal) Average Helium Leak Rate (sccs)

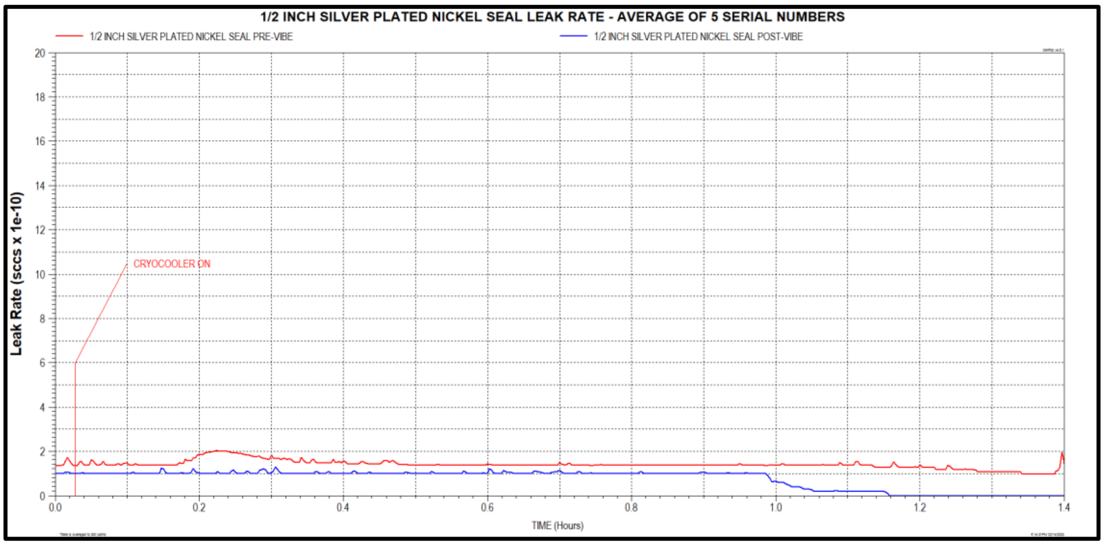


Figure 40. Graph of ½” Swagelok VCR (Silver plated Nickel seal) Average Helium Leak Rate (sccs)

1 INCH FITTINGS

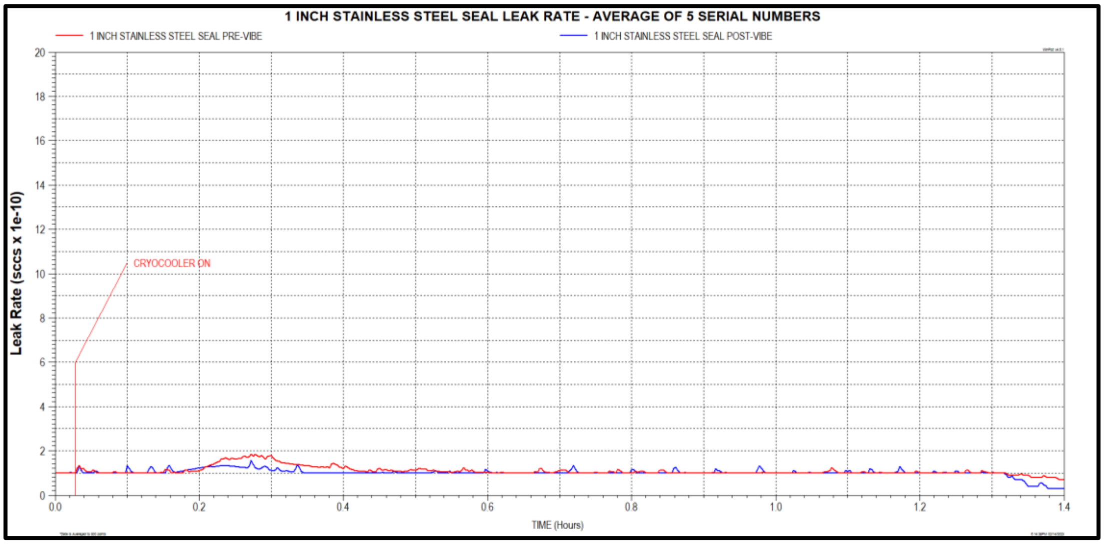


Figure 41. Graph of 1" Swagelok VCR (Stainless Steel seal) <u>Average</u> Helium Leak Rate (sccs)

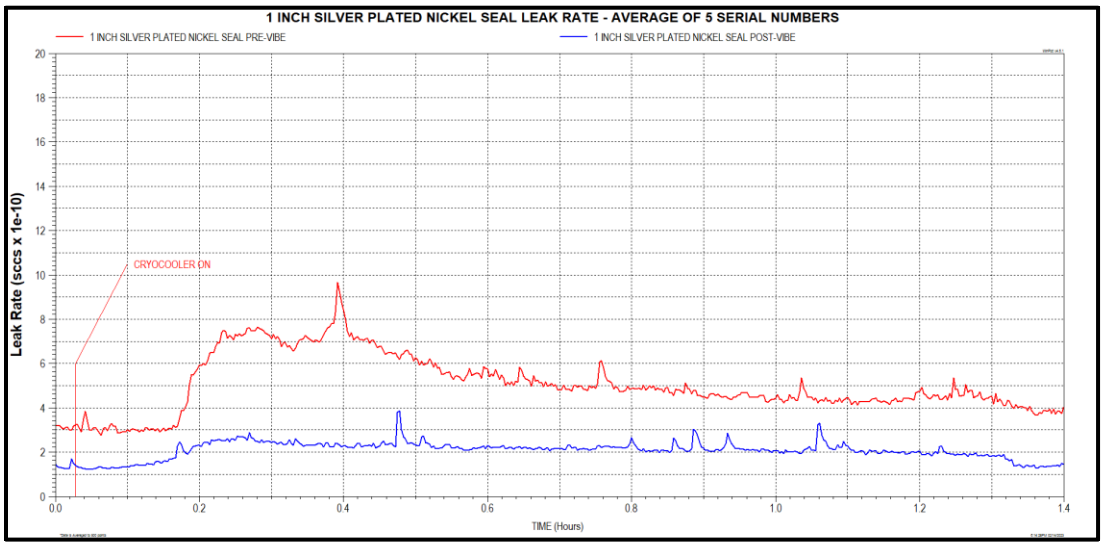


Figure 42. Graph of 1" Swagelok VCR (Silver plated Nickel seal) <u>Average</u> Helium Leak Rate (sccs)

10.6 Maximum Helium Leak Rate Comparisons

The graphs in this section compare the **<u>maximum</u>** measured leak rates of the ¼", ½" and 1" fittings. Each plotted leak rate is the average of the maximum leak rate for four (4) tests: pre-Vibe (2) and post-Vibe (2). The observed leak rates across all tested fitting sizes, seal materials, and fitting serial numbers were 3-4 orders of magnitude BELOW the maximum allowable leak rate of 10^{-6} sccs. On the average, the leak rates for ¼" and ½" SST seals are higher than those for the Ni. In comparison, the Ni seals show a higher average leak rate for the 1-inch fittings. These results are comparable to data previously presented in the 2020 report.

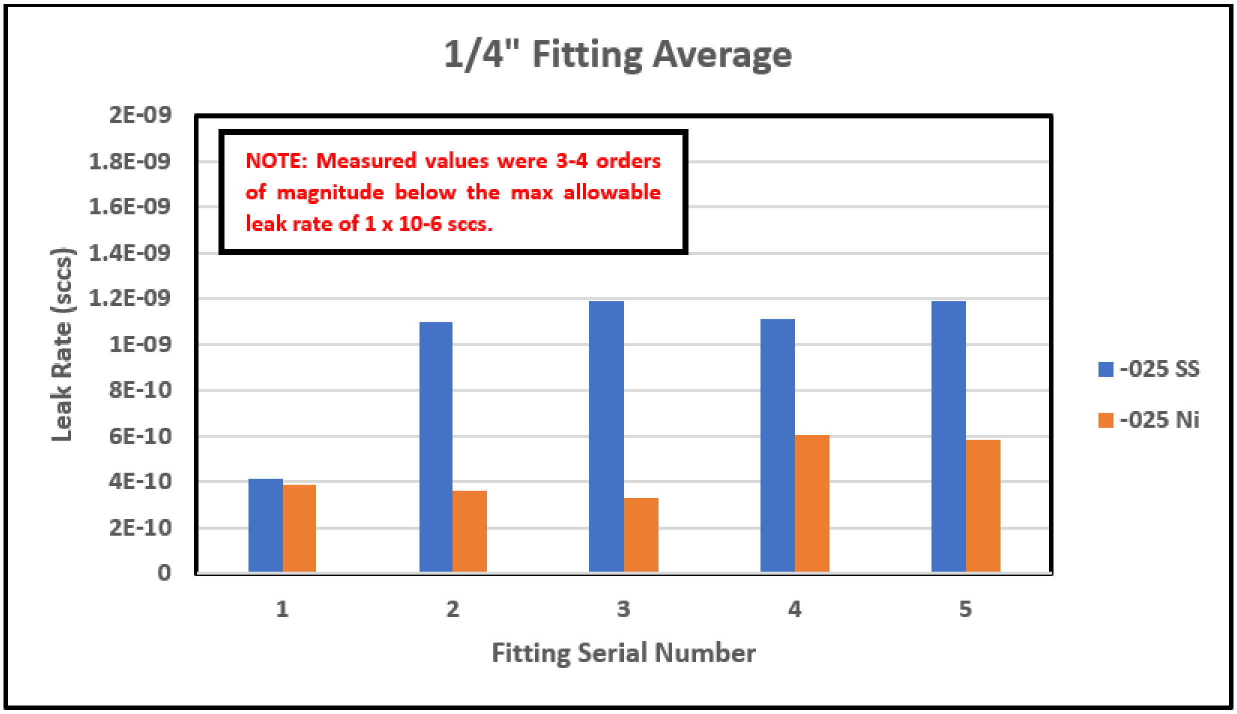


Figure 43. Maximum Helium Leak Rate Comparisons (1/4" fittings)

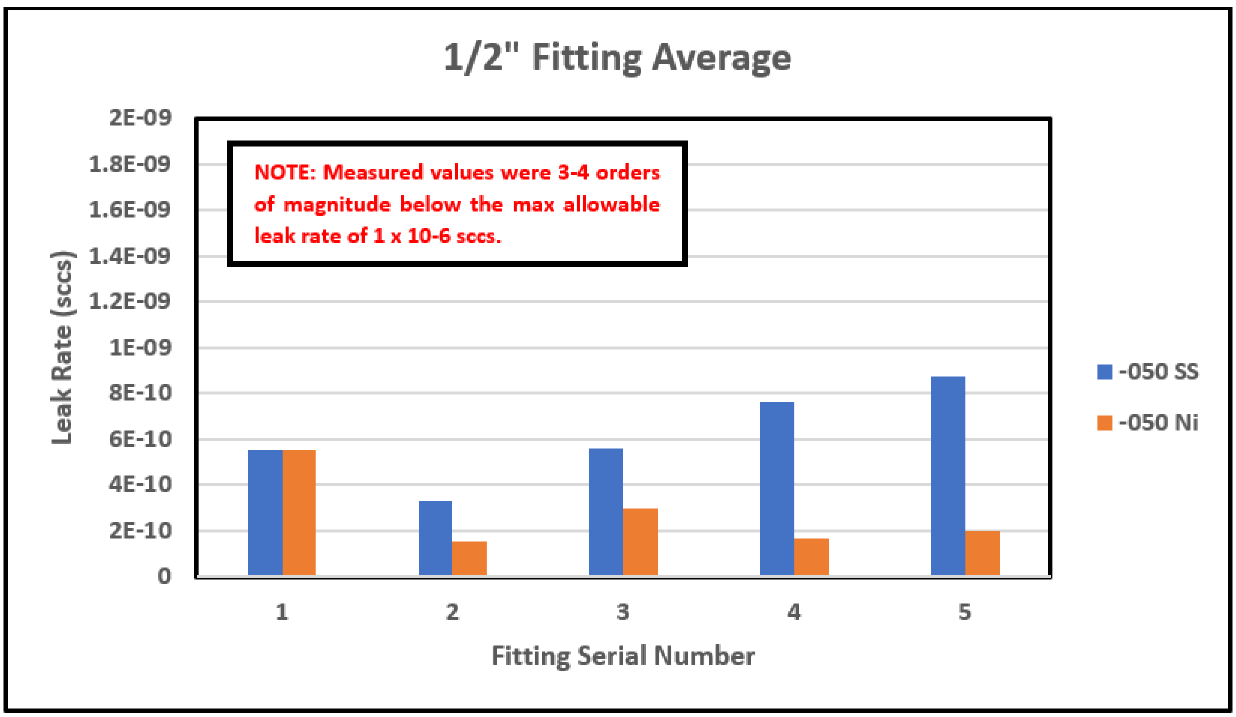


Figure 44. Maximum Helium Leak Rate Comparisons (1/2" fittings)

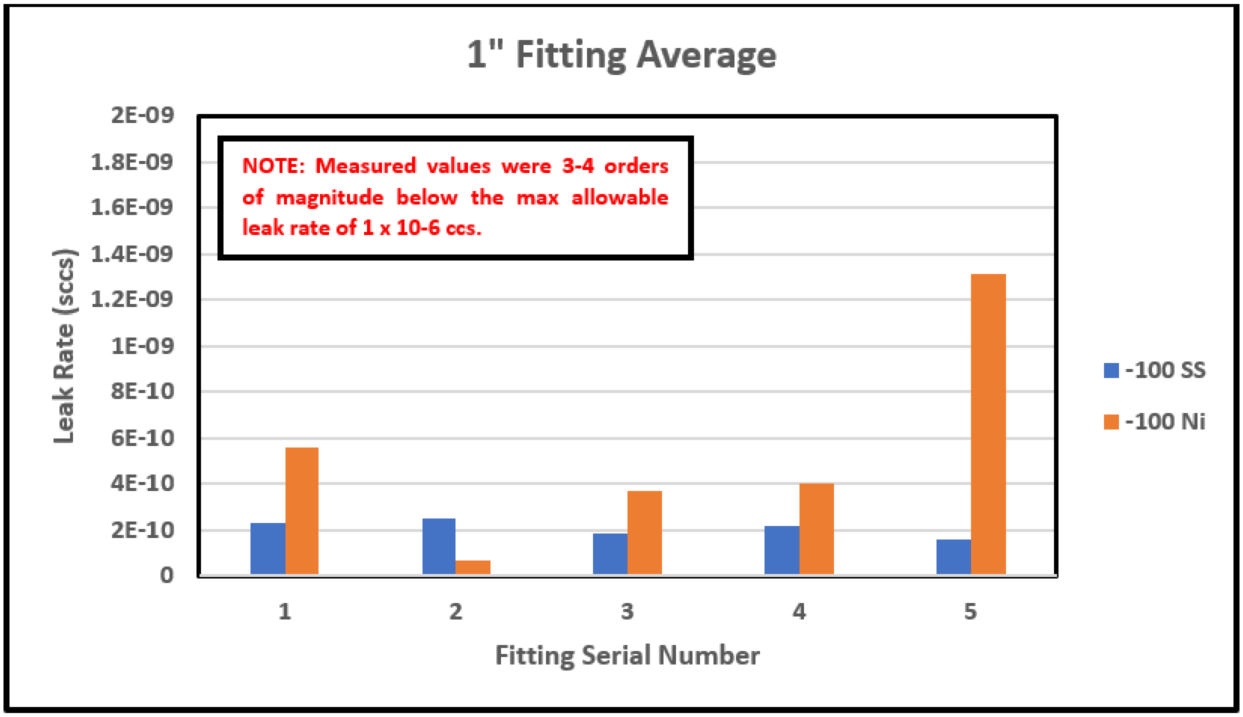


Figure 45. Maximum Helium Leak Rate Comparisons (1-inch fittings)

10.7 Test Deviations

This section discusses several deviations that were noted during VCR Fitting tests. The incidents are mentioned to highlight the types of deviations that can occur when running many tests over an extended period.

1. Pen and Inked (P/I'd) Step 04-70 in the procedure (CTL-TP-082) to add a Not Perform (NP) option to the GHe K-bottle change out with a GN_2 K-bottle after the initial run. There is no need to repeat GN_2 leak checks after the initial run. Also, P/i'd procedural steps 04-100, 110, and 150, to change GN_2 to GHe.

2. During automated testing, after pump-down to the background leak rate measurement, but prior to the start of data logging, there were several occurrences where some back pressure or feedback within the vacuum chamber was observed. This may have been due to the helium leak detector turbo pump being overwhelmed by the secondary Edwards vacuum pump system. To mitigate this circumstance, vacuum was pulled on the system by briefly opening the vacuum pump valve (SV-5) while the background was still being established. This anomaly is discussed in Section 12, Lessons Learned along with suggestions for mitigating the anomaly in the future.

3. The test data for two (2) fitting/seal pairs: ½ inch Ni (**Figure 46**) and 1 inch Ni (**Figure 47**) were inconsistent. Upon further examination it was found that both seals contained scratches and imperfections that may explain the inconsistencies in the test data. One of the recommendations listed in Lessons Learned (Section 12) is to visually inspect all fittings/seals under high magnification prior to installation as a way of mitigating inconsistent test results.

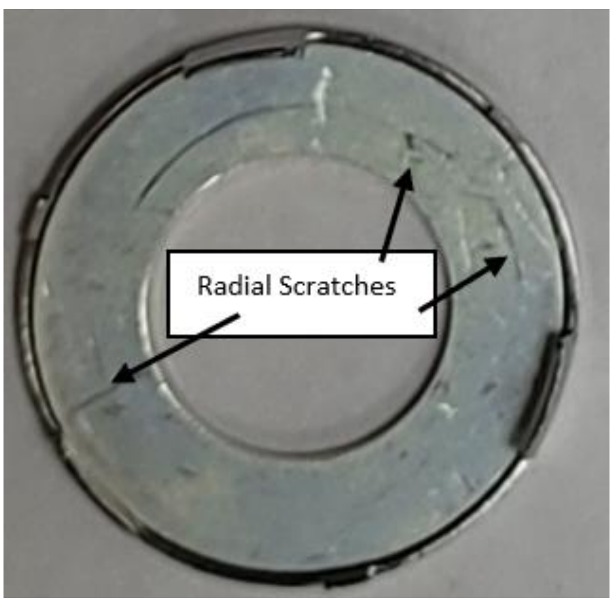


Figure 46. ½" Silver Plated Nickel Seal

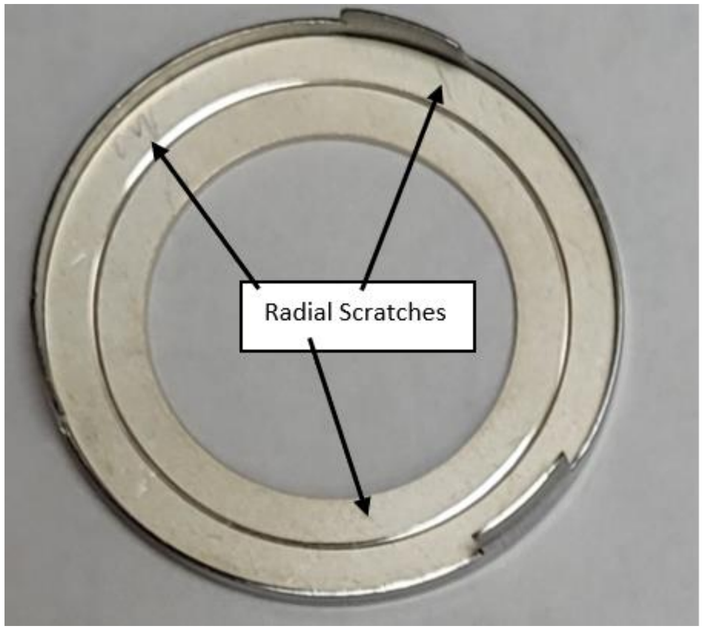


Figure 47. 1” Silver Plated Nickel Seal

11.0 MASS SPECTROMETER CONFIDENCE RUN

The GHe Mass Spectrometer Leak Detector can detect leaks as low as 1 x 10^{-11} sccs. A test was conducted to validate the sensitivity of the detector by installing a ½ inch VCR fitting with a SST seal, hand-tightening the fitting, but not tightening the additional 1/8 of a turn per Swagelok recommendations prior to installation of the fitting into the vacuum test chamber. The fitting test was run at ambient temperature with the test set up described in Section 6.0. The TVAC was then closed, and pump down initiated per procedure (CTL-TP-082). With the GHe mass spec isolated, the background reading was in the 1 X 10^{-9} sccs range. At that point, the external vacuum pump was opened, and TVAC background measured at 1 X 10^{-8} sccs. Subsequently, the mass spec Turbo Pump was isolated and the TVAC background measured 1 X 10^{-6} sccs. When the Auto regulator was set up to a fitting GHe pressure of 1 psig, the mass spec indicated a leak rate of 1 X 10^{-2} sccs. This test sequence is shown in **Figure 48**.

CONCLUSION: GHe Mass Spec leak detector is very sensitive and quickly detects a GHe leak, and High level of confidence exists in its use.

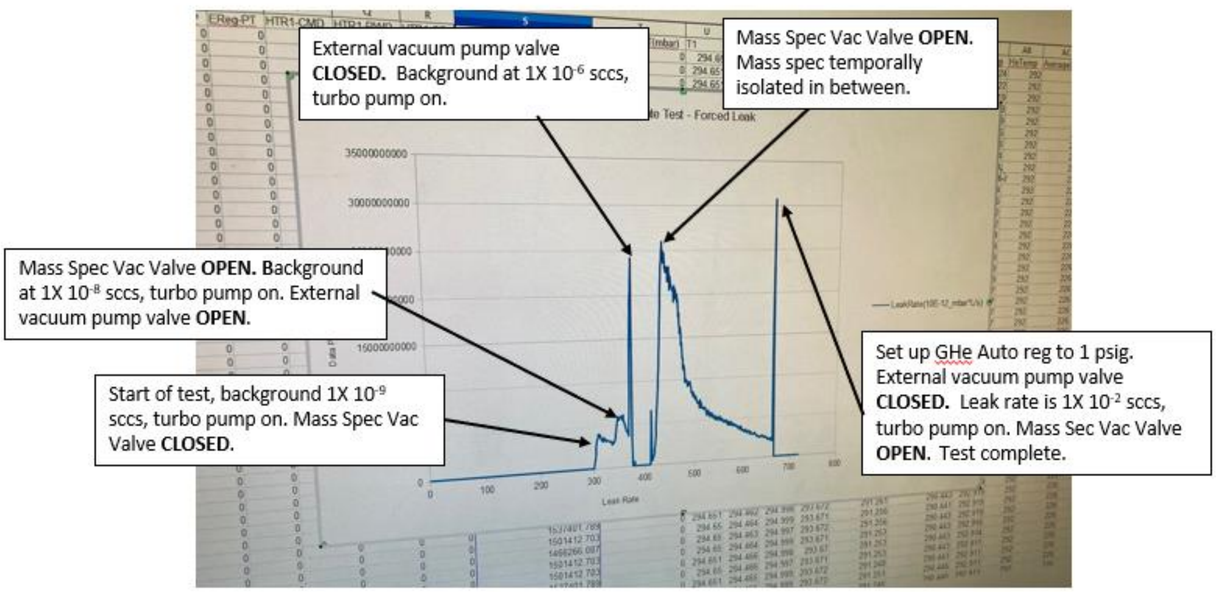


Figure 48. GHe Leak Detector Confidence Run

12.0 LESSONS LEARNED

This section presents some of the lessons learned during the VCR Fitting test program. The information is broken down into the following categories: hardware, electrical, software, data processing and general. Items within each category are presented with a Lesson Learned (aka – recommendation) and an explanation.

HARDWARE SETUP

Re-evaluate the method for attachment of the silicone diode thermocouples to the cold head.
During both the setup and testing phases of the project the diodes continuously kept falling off the cold head and were not reading correctly.

Develop the test platform using a GN_2 K-Bottle.
The test platform was checked out and de-bugged several times to make sure it was performing correctly prior to the actual testing. The use of GHe for system pressurization during this check-out instead of GN_2 unnecessarily wasted a lot of GHe commodity. A GN_2 bottle for check-out would be the better more economical approach, and once the test platform is verified then switch to GHe would be the recommended approach.

Use Teflon Ferrules on 1/8" tubing
Teflon ferrules on the 1/8" tubing worked out much better than the stainless ferrules and did not deform the tubing. Stainless ferrules deformed the tubing and required the ferrule to be cut off for every test.

Add GHe pressure gage to indoor system
The addition of a GHe pressure gage to the indoor system allowed personnel to monitor pressure of outdoor GHe K-bottle without interruption.

Visually inspect seals under high magnification prior to installation
Scratched surfaces on fittings and imperfections on seals may cause fitting/seal pairs to fail as discussed in Section 10.7 Test Deviations. All fittings and seals should be inspected prior to installation and discarded if imperfections are found.

Match pumping capabilities of helium leak detector turbo pump and secondary vacuum pump system
During automated testing, after the pump-down to the required background vacuum and before the start of data logging, there were several occurrences where some back pressure or feedback within the vacuum chamber was observed. This may have been due to the helium leak detector turbo pump being overwhelmed by the secondary Edwards vacuum pump system. Matching the pumping capabilities of these two systems would help to minimize the pressure feedback within the system.

ELECTRICAL SETUP

Protect RTD wiring
The wiring for the RTD's connected to the test article need to have a protective wrap or cover on them to prevent chaffing and cracking of the shielding from repetitive use.

Re-evaluate heater requirements prior to procurement
The heaters procured for the application were constantly burning out causing delays. Although spares were available, it was a struggle to keep the heaters working. Good conductive thermal contact is required between the heaters and the cold head. Due to thermal expansion the heaters were prone to delamination and should be mechanically clamped to the surface. The adhesives and tape used did not perform well in the TVAC to maintain heater contact which resulted in heaters separating and creating hot spots, i.e. burned out.

Minimize modifications to the test setup as much as possible

The test setup should be discussed as much as possible prior to initiation of the testing to minimize modifications. Due to the changes in setup during testing, some of the electrical connections had to be modified on-the-fly. This introduced delays in testing.

If possible, ensure that backups for important components such as the GHe leak detector and secondary vacuum pump are available

In the middle of the test cycles the helium mass spectrometer was inoperative due to a failure of an internal component. This caused a pause in the testing until a replacement unit or part could be located. The software was initially coded based on the requirements of the first mass spectrometer. When another unit became available a new electrical connection had to be created along with a software modification to allow data collection from the second mass spectrometer. This took time and caused delays in testing. Having operational backups for important components can save both test time and limit the amount of addition hardware or software modifications that need to be made.

SOFTWARE SETUP

Identify and agree upon the needs of software development at the beginning of the project

Any expectations concerning the software should be vetted prior to the start of program development. The needs of the project should be clearly defined early in the process to prevent constant development of the software during testing.

Develop software that goes hand on hand with system hardware.

Ensure, as much as possible, that the hardware functionality is explicitly understood. During test operations, some of this functionality had to researched, tested, and methods developed to better understand the fluid phenomena with the gases in a vacuum that kept interrupting the testing operations. Some delays in understanding new phenomena can be expected, but lessons learned from previous similar testing should be reviewed for additional knowledge.

Build in sufficient project time to develop the software

The software took some time due to the automation and complexity of the conditions to be met to achieve the results of the test.

Add a text input field on the LabVIEW software GUI

The addition of this text field would allow the user to enter the sample description (i.e. sample serial number) so that it can be logged into the test data file. At present, this information had to be manually recorded in the project logbook by the user.

DATA PROCESSING

Decisions on recording, post-processing, and other specifications should be completed and agreed upon prior to any testing.

Requests of this nature were made when testing had already been initiated and eventually slowed down data processing. Initially, the software was developed based on assumptions regarding data requirements. Delays were realized when modifications to data processing were made after project inception.

Restructure datafile formatting to facilitate locating specific test data

Sample #, Fitting size, Seal Material and Pre/Post Vibe indications are the important pieces of information that identify unique test samples

The original datafile formatting and naming convention shown here makes sorting data difficult.

A	B	C	D	E	F	G	H	I
20230111	**13-34**	**01-050**	**Ni**	**Y**	**R**	**6**	**P**	**DP**

Where:

A Date (YYYYMMDD)
B Time (HH-MM)
C Sample # (01-05)-Fitting Size (025=1/4",050=1/2",100=1-inch)
D Seal Material (SS – Stainless, Ni – Silver Plated Nickel)
E Pre-Vibe(N), Post-Vibe(Y)
F Run (R)
G Run #
H Pass (P), Fail (F)
I Test Conductor Initials

A new proposed formatting shown below ensures that the date and time are properly recorded but are not the main sort parameters. In this way, one could easily find all the SS or Ni seals of a certain size. The updated formatting would also make it easier for project personnel to ascertain whether files were missing from all the data sets.

C	D	E	F	G	H	A	B	I
01-050	**Ni**	**Y**	**R**	**6**	**P**	**20230111**	**13-34**	**DP**

Post processing of the data should be done as soon as possible after the completion of individual tests. Processing acquired data as soon as possible allows the test team to re-assess assumptions regarding formatting, data rates, and the like. Corrections to data processing can then be done in a timely manner and facilitate quicker turnaround and evaluation of future results along with minimizing test delays. Some data processing was not completed until 1 month after the tests were run. This resulted in delays and several tests having to be re-run because the data files were corrupted or lost.

Evaluate previous software versions thoroughly prior to use

The idea of "using the previous software and modifying it a little for this test" does not always work. The previous software utilized in 2020 was designed to meet very simple, manual testing criteria. Some of the previous features were used, but new architecture had to be developed that allowed operators to perform fully automated testing cycles back-to-back without intervention. These changes required additional time to develop and validate.

GENERAL

Implement better project structure

Prior to the start of any testing a clear state of the project and what help is needed should be defined with the project team. In addition, a better structure of the project, expectations, and planning will mitigate delays and ensure that the entire project team is aware of the project flow.

13. SUMMARY

This report presents the development of a TVAC test apparatus for cryogenic leak testing and qualification of the Swagelok VCR style fittings under limited space flight environmental conditions. The test was to evaluate if these types of fittings can survive launch vibrations and remain leak-free under extreme thermal cycling.

Three Swagelok VCR fitting sizes were tested ¼, ½ and 1 inch, and five (5) samples of each fitting size, each sample was tested with SST and Ni seal rings (Total of 30 unique test articles). Each test article was subjected to four (4) thermal cycles. Half of these cycles were performed before vibration testing and half were performed after vibration testing.

The results of this testing programs showed that the fittings remain leak tight at cryogenic temperature (20K- 30K). All fittings passed the requirement that a measured leak rate not exceed 10^{-6} sccs. Measured leak rates for the 30 fitting/seal pairs were typically in the range of 10^{-9} -10^{-10} sccs during both Pre-Vibe and Post-Vibe thermal vacuum cycles.

This report also contains additional detailed information about the design and operation of the test apparatus, test procedures, data files, upgrades, and lessons learned during the project. With slight modifications to the TVAC fixturing, this automated test apparatus could also be useful for future projects with similar goals of qualifying cryogenic fluid components for space flight, such as valves, couplings, instrumentation, and other types of fitting.

14.0 APPENDICES

Appendix A. Hardware Enhancements

This appendix contains a listing of the hardware enhancements that were recommended in the Final Report of the VCR Proof of Concept Testing (Reference: VCR Fitting Leak Test Report Public Release - Dec 2020). The enhancements are divided into two sections: 1) Enhancements to enable a higher test rate and 2) Enhancements to facilitate progression through the test plan with minimal interruptions or downtime between tests and to widen the applicability of the test results. Each proposed enhancement and its implementation are discussed.

SECTION 1 - REASON FOR ENHANCMENTS:
TO ENABLE A HIGHER TEST RATE

Enhancement:
Proposed: Program a LabView application to execute an automated series of leak measurement tests with full ambient-cryo-ambient thermal cycles after installation of a test article. The cryocooler, mass spectrometer, auxiliary vacuum pump and water chiller are already configured to be controlled automatically.
Implementation: This enhancement was implemented and is automated. These devices are turned on manually but operate based on automated control and data acquisition.
Enhancement:
Proposed: Add solenoid-operated valves and an electronic pressure regulator to automatically control fitting pressurization and venting and vacuum system isolation.
Implementation: This enhancement was implemented and is automated. **(Reference: Figure 1**)
Enhancement:
Proposed: Run several leak tests in rapid succession and unattended after initial set up.
Implementation: This enhancement was implemented. Two pre vibe tests, and two post-vibe tests are run back-to-back in an automated sequence.
Enhancement:
Proposed: Implement error handling of problems such as vacuum leak, high helium background, inadequate helium pressure, etc. to interrupt testing and await operator input.
Implementation: This enhancement was implemented through the LabView control system.
Enhancement
Proposed: Automated data collection and reporting.
Implementation: This enhancement was implemented.
Enhancement
Proposed: Incorporate cartridge heaters into the aluminum cup to accelerate warmup at a pre-determined ramp rate (e.g., 1-hour linear ramp). This will allow the vacuum test chamber to remain at vacuum pressure throughout test cycles, further minimizing test cycle time and allowing leak measurement over the entire warm up duration.
Implementation: Heaters were added to the cup to decrease the warmup period.

SECTION 2 - REASON FOR ENHANCEMENTS: TO FACILITATE PROGRESSION THROUGH THE TEST PLAN WITH MINIMAL INTERRUPTIONS OR DOWNTIME BETWEEN TESTS AND TO WIDEN THE APPLICABILITY OF THE TEST RESULTS

Enhancement

Proposed: Implement the following minor modifications and enhancements to improve the ease and repeatability of setting up a test.

Use a non-permanent-type ferrule for the 1/8" tube vacuum feed-through so that it will not require cutting the tube each time a fitting is installed.

Implementation: Teflon ferrules are used for the vacuum feed-through.

Fabricate MLI insulation blankets/boots that are easy to install and remove.

Implementation: Easily removable and reusable MLI insulating sleeves are used.

Improve the silicon diode attachment method to provide as easier and more reliable installation.

Implementation: Adhesive copper tape is used to attach the diodes.

Incorporate molex connectors on the wires for the silicon diodes on the fitting so that they can be installed on the fitting on the bench prior to installing the fitting in the vacuum test chamber.

Implementation: All the wires are routed to one feedthrough which does not need to be removed when changing samples.

Proposed: Fabricate or procure additional or spare parts.

Fabricate additional copper anchors so that fittings can be prepared for installation prior to removal of the previous fitting under test.

Implementation: Two (2) sets of fixture parts are on-hand so that one can be assembled while another is being tested.

Procure additional silicon diodes as spares and so that fittings can be prepared for installation prior to removal of fitting under test.

Implementation: Spare diodes have been purchased.

Fabricate spare aluminum cup and other hardware in case bolt threads become damaged.

Implementation: A spare aluminum cup and other hardware have been fabricated to be used if bolt threads become damaged or the cup becomes dented or scratched.

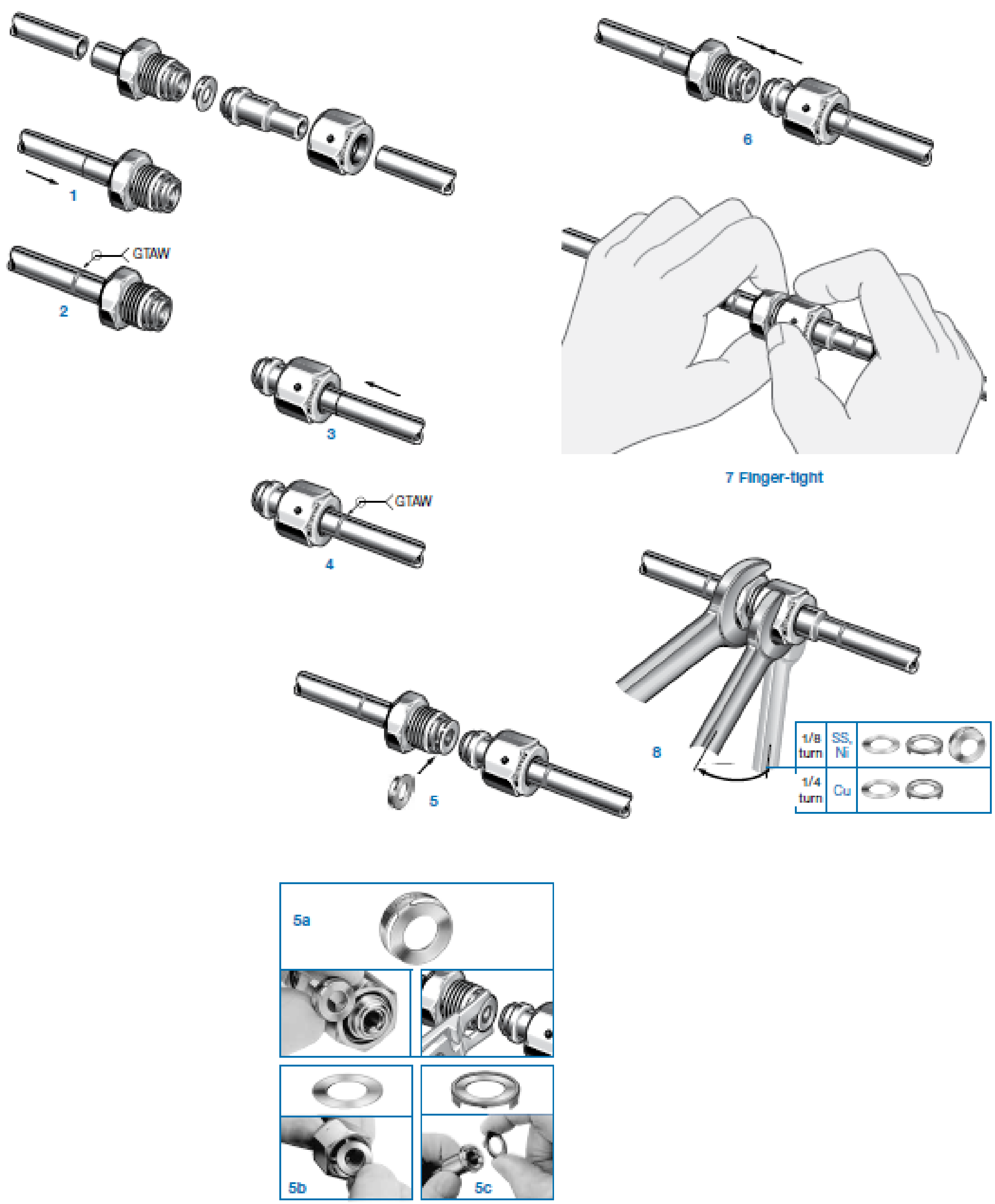
Enhancement

Proposed: Perform cold leak measurement testing at higher pressure, potentially at the fitting design pressure. This would require a high-pressure source of helium or incorporation of a helium intensifier to achieve test pressures above the maximum k-bottle pressure of 2400 psig.

Implementation: This enhancement was **NOT** implemented because it was not deemed to be a significant benefit. It would have been a significant complication to the test program and increased cost due to lack of high pressure GHe. The fittings were all hydro tested after welding to 1.5 Maximum Operating Working Pressure (MOWP), and leak tested at 450 psig fitting pressure.

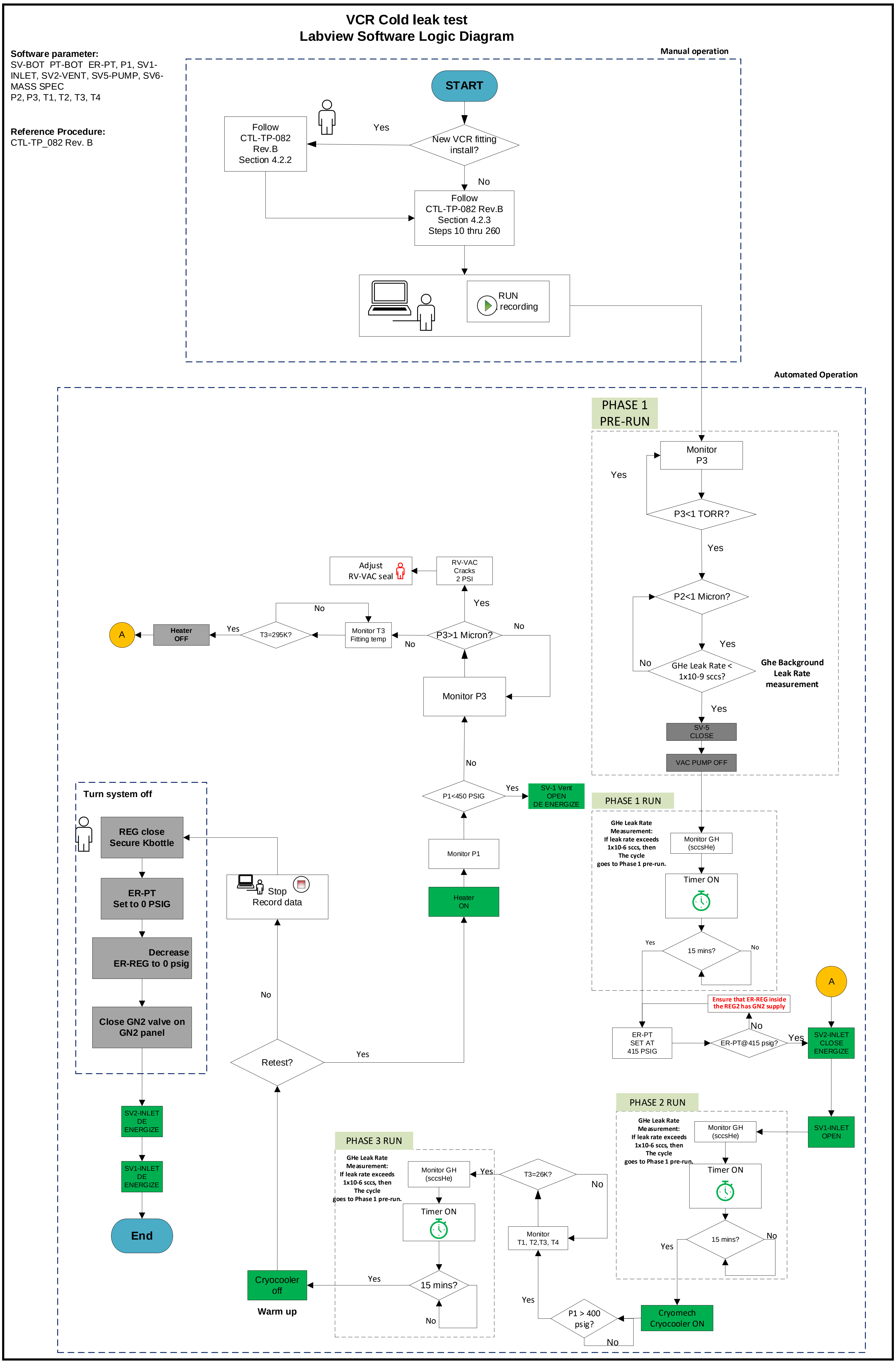
Appendix B. Swagelok Fitting Installation Instructions

VCR Fitting Installation Instructions



Swagelok

Appendix C. Software Flow Logic (Complete)

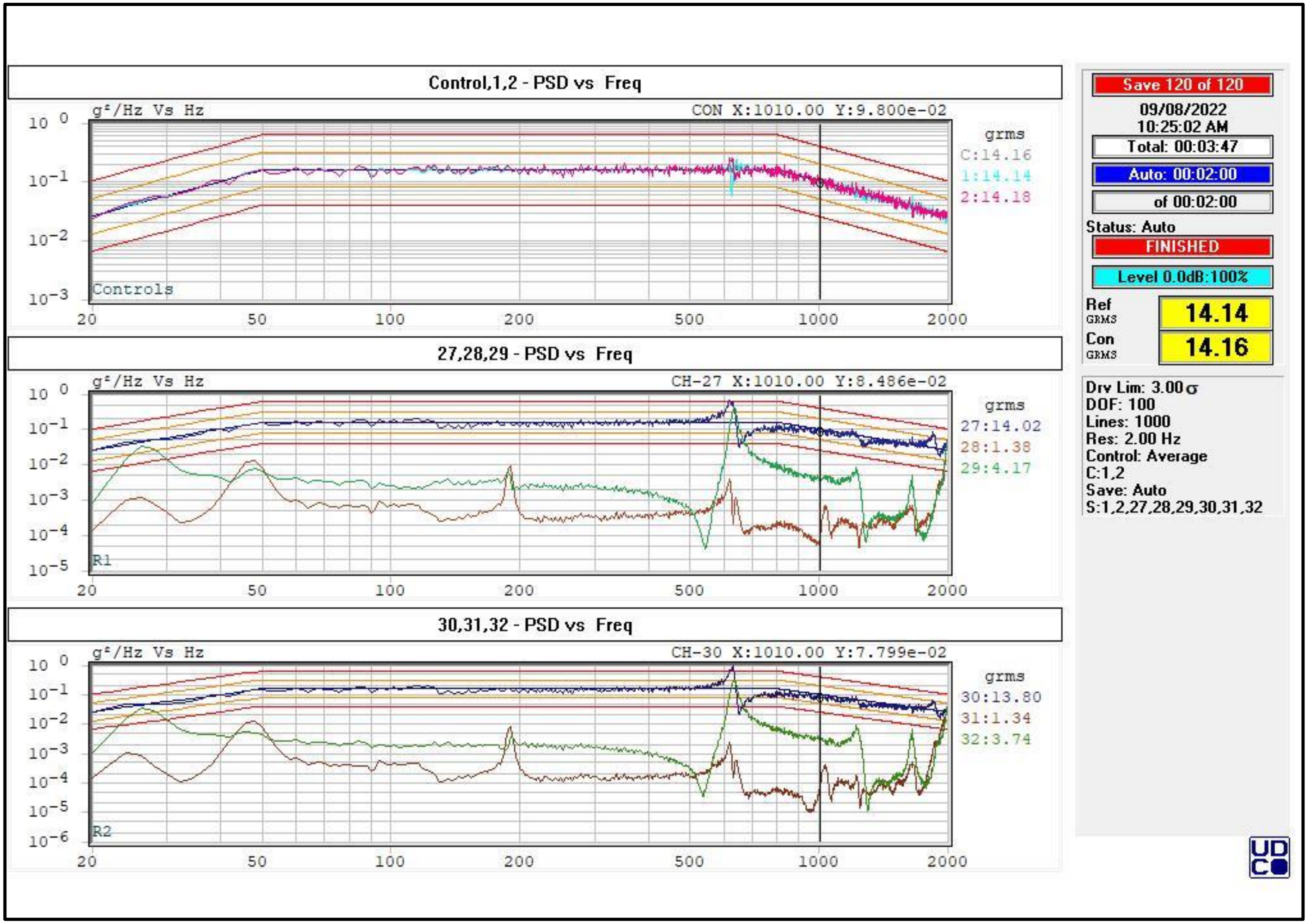


Appendix D. VCR Fitting Vibration Test Report

Random Test Report

SETUP NAME: VCR Fitting Vibration Testing
SETUP DESC: VTL-5296
SETUP COMMENTS: Rudy Werlink NEL60 (321) 861-7327
Ch 1-8 M77278 Cal Due 11/30/2022
Ch 9-16 M76959 Cal Due 10/14/2022
Ch17-24 MC1478 Cal Due 2/9/2023
Ch25-32 MC1477 Cal Due 3/28/2023
RUN NAME: X-Axis 01-025 and 01-050 Nickel
PROJECT FOLDER: T2000
SAVE NUMBER: 120

STATUS INFORMATION
TEST EVENT TIME: Thursday, September 08, 2022 at 10:25:02 AM
TEST STATUS: FINISHED
TEST MODE: AUTO
TOTAL TIME ELAPSED (HH:MM:SS): 00:03:47
AUTO TIME ELAPSED (HH:MM:SS): 00:02:00
TEST LEVEL: 0.0 dB
REFERENCE: 14.14 g rms
CONTROL: 14.16 g rms


Control,1,2 - PSD vs Freq
g²/Hz Vs Hz
CON X:1010.00 Y:9.800e-02
grms
C:14.16
1:14.14
2:14.18
Controls
27,28,29 - PSD vs Freq
CH-27 X:1010.00 Y:8.486e-02
27:14.02
28:1.38
29:4.17
R1
30,31,32 - PSD vs Freq
CH-30 X:1010.00 Y:7.799e-02
30:13.80
31:1.34
32:3.74
R2
Save 120 of 120
09/08/2022
10:25:02 AM
Total: 00:03:47
Auto: 00:02:00
of 00:02:00
Status: Auto
FINISHED
Level 0.0dB:100%
Ref GRMS 14.14
Con GRMS 14.16
Drv Lim: 3.00σ
DOF: 100
Lines: 1000
Res: 2.00 Hz
Control: Average
C:1,2
Save: Auto
S:1,2,27,28,29,30,31,32

CONTROL PARAMETERS

CONTROL CHANNEL(S): 1,2
CONTROL TYPE: AVERAGE
FREQUENCY RANGE: 2000 Hz
NUMBER OF PSD LINES: 1000
FREQUENCY RESOLUTION: 2.000 Hz
DOF: 100
SIGMA DRIVE LIMITING: 3.00

INPUT CHANNEL PARAMETERS

Chan (#)	Control	Chan Wt	Save	Str	Interface Type	Units (ACC/EU)	Units Desc	Sensitivity (mV/[g,EU])	Max.Range (g,EU rms)
1	X	1.00	X	X	SE	ACCEL	g	10.03	100.00
2	X	1.00	X	X	SE	ACCEL	g	10.09	100.00
3		1.00			SE	ACCEL	g	10.00	100.00
4		1.00			SE	ACCEL	g	10.00	100.00
5		1.00			SE	ACCEL	g	10.00	100.00
6		1.00			SE	ACCEL	g	10.00	100.00
7		1.00			SE	ACCEL	g	10.00	100.00
8		1.00			SE	ACCEL	g	10.00	100.00
9		1.00			SE	ACCEL	g	10.00	100.00
10		1.00			SE	ACCEL	g	1.00	100.00
11		1.00			SE	ACCEL	g	1.00	100.00
12		1.00			SE	ACCEL	g	1.00	100.00
13		1.00			SE	ACCEL	g	1.00	100.00
14		1.00			SE	ACCEL	g	1.00	100.00
15		1.00			SE	ACCEL	g	1.00	100.00
16		1.00			SE	ACCEL	g	1.00	100.00
17		1.00			SE	ACCEL	g	1.00	100.00
18		1.00			SE	ACCEL	g	1.00	100.00
19		1.00			SE	ACCEL	g	1.00	100.00
20		1.00			SE	ACCEL	g	1.00	100.00
21		1.00			SE	ACCEL	g	1.00	100.00
22		1.00			SE	ACCEL	g	1.00	100.00
23		1.00			SE	ACCEL	g	1.00	100.00

24		1.00			SE	ACCEL	g	1.00	100.00
25		1.00			SE	ACCEL	g	1.00	100.00
26		1.00			SE	ACCEL	g	1.00	100.00
27		1.00	X	X	SE	ACCEL	g	9.98	100.00
28		1.00	X	X	SE	ACCEL	g	9.89	100.00
29		1.00	X	X	SE	ACCEL	g	10.27	100.00
30		1.00	X	X	SE	ACCEL	g	11.02	100.00
31		1.00	X	X	SE	ACCEL	g	10.76	100.00
32		1.00	X	X	SE	ACCEL	g	9.49	100.00

INPUT CHANNEL DESCRIPTION

Chan #	Description
1	C1 M76960 Cal Due 3/27/2023
2	C1 M76965 Cal Due 3/27/2023
27	R1-X M96581 Cal Due 12/29/2022
28	R1-Y M96581 Cal Due 12/29/2022
29	R1-Z M96581 Cal Due 12/29/2022
30	R2-X MC3682 Cal Due 2/18/2024
31	R2-Y MC3682 Cal Due 2/18/2024
32	R2-Z MC3682 Cal Due 2/18/2024

REFERENCE BREAK POINT TABLE

BP #	Freq Hz	Level (g^2/Hz)	Slope (dB/oct)	Alarm- (-dB)	Alarm+ (+dB)	Abort- (-dB)	Abort+ (+dB)
1	20.00	0.02600000		-3.00	3.00	-6.00	6.00
2	50.00	0.16000000		-3.00	3.00	-6.00	6.00
3	800.00	0.16000000		-3.00	3.00	-6.00	6.00
4	2000.00	0.02600000		-3.00	3.00	-6.00	6.00

Accel: 14.14 g rms, Est. Vel: 15.21 in/s pk, Est. Disp: 0.1195 in pp, Ref. Disp: 0.1053 in pp

ALARM/ABORT PARAMETERS
NUMBER OF CONTROL LINES TO TRIGGER ALARM: 40
NUMBER OF CONTROL LINES TO TRIGGER ABORT: 120
MAXIMUM DRIVE RMS VOLTAGE: 2.50 vrms

CONTROL/CHANNEL RMS ABORT LIMITS

CHAN #	Type dB/RMS	Min -dB/RMS	Max +dB/RMS
Control	dB	-6.00	6.00

TEST STARTUP & SCHEDULE PARAMETERS
START LEVEL: -20.00 dB, (10.00% of full level)
AUTO RAMP RATE: SLOW
AUTO RANGE SETTLE PERIOD: STANDARD
AUTO MODE TIMER BEGINS AT LEVEL SCHEDULE STEP: ALL/ANY STEP(S)
TEST DURATION (HH:MM:SS): 00:02:00
************* AUTO MODE DATA SAVE *************
PERIODICALLY (HH:MM:SS): 00:00:01

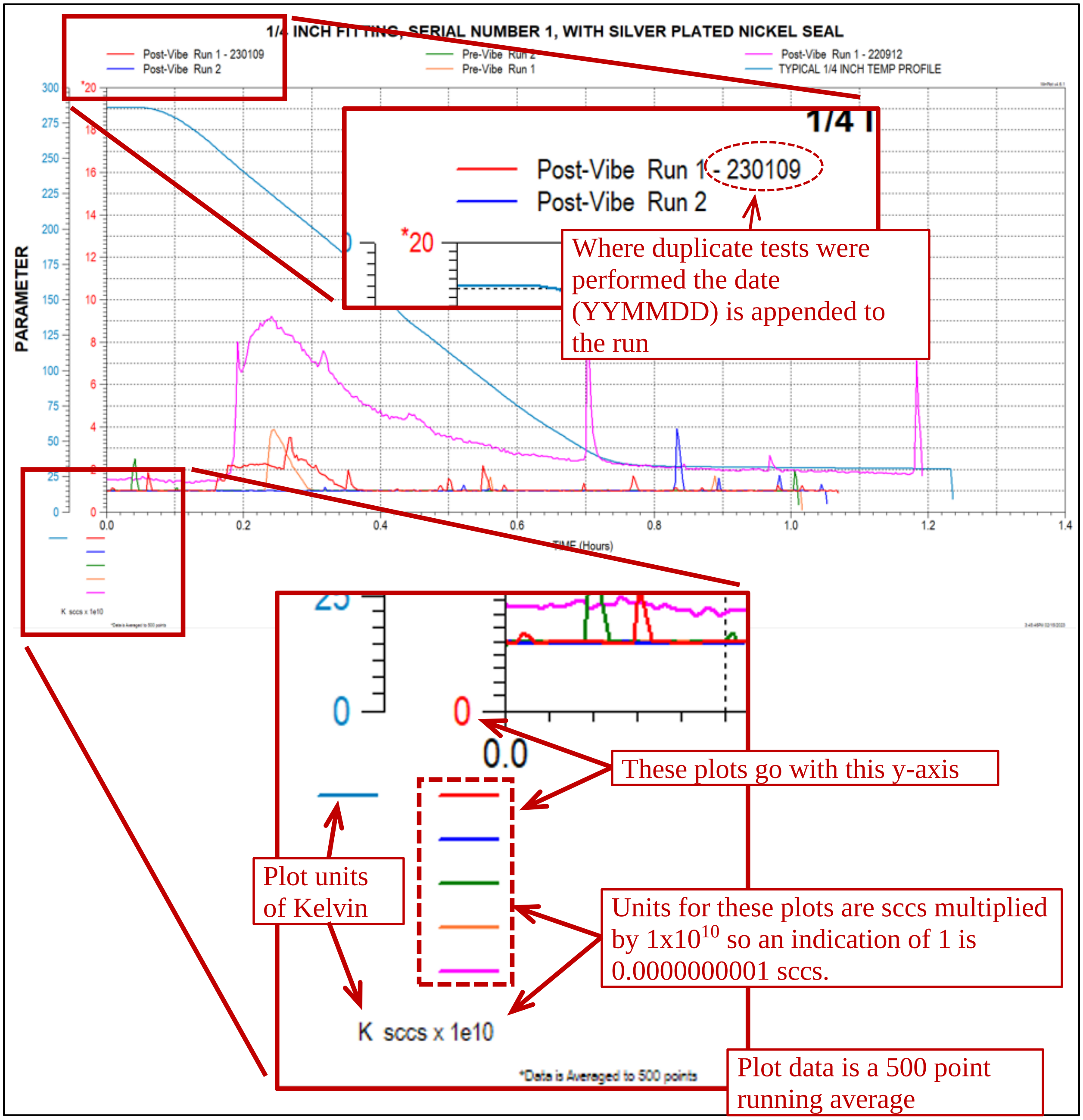
LEVEL SCHEDULE

Step #	Level (-dB)	Level (%)	Duration (HH:MM:SS)
1	0.00	100.00	00:02:00

SHAKER/AMPLIFIER SYSTEM SPECS
MAXIMUM RANDOM ACCELERATION: 100.00 g rms
MAXIMUM VELOCITY: 86.00 in/s pk
MAXIMUM DISPLACEMENT: 3200.00 mil pp
MAXIMUM RANDOM PERFORMANCE INPUT VOLTAGE: 2.50 vrms
DRIVE SCALING ADJUSTMENT: 0.20
ARMATURE WEIGHT: 110.00 lbs,   LOAD WEIGHT: 320.00 lbs

UNHOLTZ-DICKIE APEX Pro Version 1.02

Appendix E. How to read the VCR Fitting Data plots



Appendix F. Complete VCR Data File List

Size 025 = ¼”; 050 – ½”; 100 = 1”	Fitting Number	Seal Type (SS = Stainless Steel; Ni = Silver Plated Nickel)	Run Number	Test Date	Filename
025	01	SS	1	09-15-2022	20220915_15-05_01-025_SS_N_R_1_P_DP_WinPlot.csv
025	01	SS	2	09-16-2022	20220916_11-14_01-025_SS_N_R_2_P_DP_WinPlot.csv
025	01	SS	3	10-04-2022	20221004_08-52_01-025_SS_Y_R_3_P_DP_WinPlot.csv
025	01	SS	4	10-04-2022	20221004_11-33_01-025_SS_Y_R_4_P_DP_WinPlot.csv
025	02	SS	1	09-19-2022	20220919_13-07_02-025_SS_N_R_1_P_DP_WinPlot.csv
025	02	SS	2	09-20-2022	20220920_08-20_02-025_SS_N_R_2_P_DP_WinPlot.csv
025	02	SS	3	10-05-2022	20221005_08-21_02-025_SS_Y_R_3_P_DP_WinPlot.csv
025	02	SS	3	10-05-2022	20221005_08-21_02-025_SS_Y_R_3_P_DP_WinPlot-2.csv
025	02	SS	4	02-07-2023	20230207_10-35_02-025_SS_Y_R_4_P_DP_WinPlot.csv
025	03	SS	1	09-21-2022	20220921_08-06_03-025_SS_N_R_1_P_DP_WinPlot.csv
025	03	SS	2	09-22-2022	20220922_12-52_03-025_SS_N_R_2_P_DP_WinPlot.csv
025	03	SS	3	10-19-2022	20221019_08-31_03-025_SS_Y_R_3_P_DP_WinPlot.csv
025	03	SS	4	10-20-2022	20221020_06-36_03-025_SS_Y_R_4_P_DP_WinPlot.csv
025	04	SS	2	09-26-2022	20220926_11-00_04-025_SS_N_R_2_P_DP_WinPlot.csv
025	04	SS	3	01-10-2023	20230110_13-03_04-025_SS_Y_R_3_P_DP_WinPlot.csv
025	04	SS	4	01-11-2023	20230111_06-44_04-025_SS_Y_R_4_P_DP_WinPlot.csv
025	04	SS	5	12-19-2022	20221219_08-09_04-025_SS_N_R_5_P_DP_WinPlot-2.csv
025	04	SS	5	12-19-2022	20221219_08-09_04-025_SS_N_R_5_P_DP_WinPlot.csv
025	04	SS	6	10-21-2022	20221021_06-42_04-025_SS_Y_R_6_P_DP_WinPlot.csv
025	04	SS	6	10-21-2022	20221021_06-42_04-025_SS_Y_R_6_P_DP_WinPlot-2.csv
025	05	SS	1	10-03-2022	20221003_09-55_05-025_SS_N_R_1_P_DP_WinPlot.csv
025	05	SS	2	10-03-2022	20221003_13-15_05-025_SS_N_R_2_P_DP_WinPlot.csv
025	05	SS	6	10-24-2022	20221024_09-38_05-025_SS_Y_R_6_P_DP_WinPlot.csv

Size 025 = ¼”; 050 – ½”; 100 = 1”	Fitting Number	Seal Type (SS = Stainless Steel; Ni = Silver Plated Nickel)	Run Number	Test Date	Filename
025	05	SS	6	10-24-2022	20221024_09-38_05-025_SS_Y_R_6_P_DP_WinPlot-2.csv
025	01	Ni	3	01-09-2023	20230109_10-29_01-025_Ni_Y_R_3_P_DP_WinPlot.csv
025	01	Ni	3	09-12-2022	20220912_08-11_01-025_Ni_Y_R_3_P_DP_WinPlot.csv
025	01	Ni	4	01-10-2023	20230110_05-12_01-025_Ni_Y_R_4_P_DP_WinPlot.csv
025	01	Ni	5	12-15-2022	20221215_09-32_01-025_Ni_N_R_5_P_DP_WinPlot-2.csv
025	01	Ni	5	12-15-2022	20221215_09-32_01-025_Ni_N_R_5_P_DP_WinPlot.csv
025	02	Ni	1	02-08-2023	20230208_11-06_02-025_Ni_N_R_1_P_DP_WinPlot.csv
025	02	Ni	2	02-09-2023	20230209_06-40_02-025_Ni_N_R_2_P_DP_WinPlot.csv
025	02	Ni	6	09-13-2022	20220913_08-58_02-025_Ni_Y_R_6_P_DP_WinPlot-2.csv
025	02	Ni	6	09-13-2022	20220913_08-58_02-025_Ni_Y_R_6_P_DP_WinPlot.csv
025	03	Ni	1	02-09-2023	20230209_13-18_03-025_Ni_N_R_1_P_DP_WinPlot.csv
025	03	Ni	2	02-10-2023	20230210_07-09_03-025_Ni_N_R_2_P_DP_WinPlot.csv
025	03	Ni	6	09-14-2022	20220914_10-09_03-025_Ni_Y_R_6_P_DP_WinPlot.csv
025	04	Ni	1	02-10-2023	20230210_13-55_04-025_Ni_Y_R_1_P_DP_WinPlot.csv
025	04	Ni	2	20-13-2023	20232013_07-30_04-025_Ni_Y_R_2_P_DP_WinPlot.csv
025	04	Ni	3	09-23-2022	20220923_09-09_04-025_Ni_Y_R_3_P_DP_WinPlot.csv
025	04	Ni	4	09-23-2022	20220923_12-27_04-025_Ni_Y_R_4_P_DP_WinPlot.csv
025	05	Ni	1	09-08-2022	20220908_15-03_05-025_Ni_N_R_1_P_DP_WinPlot.csv
025	05	Ni	2	09-09-2022	20220909_06-39_05-025_Ni_N_R_2_P_DP_WinPlot.csv
025	05	Ni	3	09-27-2022	20220927_09-09_05-025_Ni_Y_R_3_P_DP_WinPlot.csv
025	05	Ni	4	09-27-2022	20220927_13-03_05-025_Ni_Y_R_4_P_DP_WinPlot.csv
050	01	SS	5	10-06-2022	20221006_11-08_01-050_SS_N_R_5_P_DP_WinPlot.csv
050	01	SS	6	11-21-2022	20221121_06-50_01-050_SS_Y_R_6_P_DP_WinPlot.csv
050	01	SS	6	11-21-2022	20221121_06-50_01-050_SS_Y_R_6_P_DP_WinPlot-2.csv
050	02	SS	1	10-07-2022	20221007_10-32_02-050_SS_N_R_1_P_DP_WinPlot.csv
050	02	SS	2	10-11-2022	20221011_07-29_02-050_SS_N_R_2_P_DP_WinPlot.csv

Size 025 = ¼”; 050 – ½”; 100 = 1”	Fitting Number	Seal Type (SS = Stainless Steel; Ni = Silver Plated Nickel)	Run Number	Test Date	Filename
050	02	SS	3	11-22-2022	20221122_14-01_02-050_SS_Y_R_3_P_DP_WinPlot.csv
050	02	SS	4	11-23-2022	20221123_05-43_02-050_SS_Y_R_4_P_DP_WinPlot.csv
050	02	SS	5	01-13-2023	20230113_08-11_02-050_SS_N_R_5_P_DP_WinPlot-2.csv
050	02	SS	5	01-13-2023	20230113_08-11_02-050_SS_N_R_5_P_DP_WinPlot.csv
050	03	SS	5	10-12-2022	20221012_06-20_03-050_SS_N_R_5_P_DP_WinPlot.csv
050	03	SS	5	10-12-2022	20221012_06-20_03-050_SS_N_R_5_P_DP_WinPlot-2.csv
050	03	SS	6	11-28-2022	20221128_07-26_03-050_SS_Y_R_6_P_DP_WinPlot.csv
050	03	SS	6	11-28-2022	20221128_07-26_03-050_SS_Y_R_6_P_DP_WinPlot-2.csv
050	04	SS	3	12-01-2022	20221201_07-36_04-050_SS_Y_R_3_P_DP_WinPlot.csv
050	04	SS	4	12-02-2022	20221202_11-05_04-050_SS_Y_R_4_P_DP_WinPlot.csv
050	04	SS	5	10-13-2022	20221013_09-44_04-050_SS_N_R_5_P_DP_WinPlot.csv
050	04	SS	5	10-13-2022	20221013_09-44_04-050_SS_N_R_5_P_DP_WinPlot-2.csv
050	05	SS	1	10-14-2022	20221014_10-34_05-050_SS_N_R_1_P_DP_WinPlot.csv
050	05	SS	2	10-18-2022	20221018_06-47_05-050_SS_N_R_2_P_DP_WinPlot.csv
050	05	SS	3	12-05-2022	20221205_07-35_05-050_SS_Y_R_3_P_DP_WinPlot.csv
050	05	SS	4	12-06-2022	20221206_14-29_05-050_SS_Y_R_4_P_DP_WinPlot.csv
050	05	SS	6	01-31-2023	20230131_08-49_05-050_SS_Y_R_6_P_DP_WinPlot-2.csv
050	05	SS	6	01-31-2023	20230131_08-49_05-050_SS_Y_R_6_P_DP_WinPlot.csv
050	01	Ni	5	12-07-2022	20221207_07-58_01-050_Ni_N_R_5_P_DP_WinPlot.csv
050	01	Ni	5	12-07-2022	20221207_07-58_01-050_Ni_N_R_5_P_DP_WinPlot-2.csv
050	01	Ni	6	01-11-2023	20230111_13-34_01-050_Ni_Y_R_6_P_DP_WinPlot-2.csv
050	01	Ni	6	01-11-2023	20230111_13-34_01-050_Ni_Y_R_6_P_DP_WinPlot.csv
050	02	Ni	5	12-09-2022	20221209_07-44_02-050_Ni_N_R_5_P_DP_WinPlot.csv
050	02	Ni	5	12-09-2022	20221209_07-44_02-050_Ni_N_R_5_P_DP_WinPlot-2.csv
050	02	Ni	6	01-12-2023	20230112_09-10_02-050_Ni_Y_R_6_P_DP_WinPlot-2.csv
050	02	Ni	6	01-12-2023	20230112_09-10_02-050_Ni_Y_R_6_P_DP_WinPlot.csv

Size 025 = ¼”; 050 – ½”; 100 = 1”	Fitting Number	Seal Type (SS = Stainless Steel; Ni = Silver Plated Nickel)	Run Number	Test Date	Filename
050	03	Ni	5	12-11-2022	20221211_06-58_03-050_Ni_N_R_5_P_DP_WinPlot-2.csv
050	03	Ni	5	12-11-2022	20221211_06-58_03-050_Ni_N_R_5_P_DP_WinPlot.csv
050	03	Ni	6	01-17-2023	20230117_08-49_03-050_Ni_Y_R_6_P_DP_WinPlot-2.csv
050	03	Ni	6	01-17-2023	20230117_08-49_03-050_Ni_Y_R_6_P_DP_WinPlot.csv
050	04	Ni	5	12-13-2022	20221213_07-36_04-050_Ni_N_R_5_P_DP_WinPlot-2.csv
050	04	Ni	5	12-13-2022	20221213_07-36_04-050_Ni_N_R_5_P_DP_WinPlot.csv
050	04	Ni	6	01-18-2023	20230118_07-37_04-050_Ni_Y_R_6_P_DP_WinPlot-2.csv
050	04	Ni	6	01-18-2023	20230118_07-37_04-050_Ni_Y_R_6_P_DP_WinPlot.csv
050	05	Ni	5	12-14-2022	20221214_07-37_05-050_Ni_N_R_5_P_DP_WinPlot-2.csv
050	05	Ni	5	12-14-2022	20221214_07-37_05-050_Ni_N_R_5_P_DP_WinPlot.csv
050	05	Ni	6	01-19-2023	20230119_08-09_05-050_Ni_Y_R_6_P_DP_WinPlot-2.csv
050	05	Ni	6	01-19-2023	20230119_08-09_05-050_Ni_Y_R_6_P_DP_WinPlot.csv
100	01	SS	1	11-16-2022	20221116_07-08_01-100_SS_N_R_1_P_DP_WinPlot.csv
100	01	SS	1	11-16-2022	20221116_07-08_01-100_SS_N_R_1_P_DP_WinPlot-2.csv
100	01	SS	6	01-24-2023	20230124_09-52_01-100_SS_Y_R_6_P_DP_WinPlot-2.csv
100	01	SS	6	01-24-2023	20230124_09-52_01-100_SS_Y_R_6_P_DP_WinPlot.csv
100	02	SS	5	11-17-2022	20221117_06-41_02-100_SS_N_R_5_P_DP_WinPlot.csv
100	02	SS	5	11-17-2022	20221117_06-41_02-100_SS_N_R_5_P_DP_WinPlot-2.csv
100	02	SS	6	01-25-2023	20230125_09-25_02-100_SS_Y_R_6_P_DP_WinPlot-2.csv
100	02	SS	6	01-25-2023	20230125_09-25_02-100_SS_Y_R_6_P_DP_WinPlot.csv
100	03	SS	5	11-18-2022	20221118_06-35_03-100_SS_N_R_5_P_DP_WinPlot.csv
100	03	SS	5	11-18-2022	20221118_06-35_03-100_SS_N_R_5_P_DP_WinPlot-2.csv
100	03	SS	6	01-26-2023	20230126_09-30_03-100_SS_Y_R_6_P_DP_WinPlot-2.csv
100	03	SS	6	01-26-2023	20230126_09-30_03-100_SS_Y_R_6_P_DP_WinPlot.csv
100	04	SS	5	11-19-2022	20221119_06-36_04-100_SS_N_R_5_P_DP_WinPlot.csv
100	04	SS	5	11-19-2022	20221119_06-36_04-100_SS_N_R_5_P_DP_WinPlot-2.csv

Size 025 = ¼”; 050 – ½”; 100 = 1”	Fitting Number	Seal Type (SS = Stainless Steel; Ni = Silver Plated Nickel)	Run Number	Test Date	Filename
100	04	SS	6	01-27-2023	20230127_09-20_04-100_SS_Y_R_6_P_DP_WinPlot-2.csv
100	04	SS	6	01-27-2023	20230127_09-20_04-100_SS_Y_R_6_P_DP_WinPlot.csv
100	05	SS	5	01-23-2023	20230123_07-38_05-100_SS_N_R_5_P_DP_WinPlot-2.csv
100	05	SS	5	01-23-2023	20230123_07-38_05-100_SS_N_R_5_P_DP_WinPlot.csv
100	05	SS	6	01-30-2023	20230130_08-20_05-100_SS_Y_R_6_P_DP_WinPlot-2.csv
100	05	SS	6	01-30-2023	20230130_08-20_05-100_SS_Y_R_6_P_DP_WinPlot.csv
100	01	Ni	1	10-27-2022	20221027_06-40_01-100_Ni_N_R_1_P_DP_WinPlot.csv
100	01	Ni	2	10-27-2022	20221027_10-20_01-100_Ni_N_R_2_P_DP_WinPlot.csv
100	01	Ni	3	11-04-2022	20221104_13-59_01-100_Ni_Y_R_3_P_DP_WinPlot.csv
100	01	Ni	4	11-07-2022	20221107_07-08_01-100_Ni_Y_R_4_P_DP_WinPlot.csv
100	02	Ni	1	10-28-2022	20221028_09-20_02-100_Ni_N_R_1_P_DP_WinPlot.csv
100	02	Ni	2	10-31-2022	20221031_07-40_02-100_Ni_N_R_2_P_DP_WinPlot.csv
100	02	Ni	4	11-08-2022	20221108_06-52_02-100_Ni_Y_R_4_P_DP_WinPlot.csv
100	03	Ni	1	10-31-2022	20221031_14-45_03-100_Ni_N_R_1_P_DP_WinPlot.csv
100	03	Ni	2	11-01-2022	20221101_06-40_03-100_Ni_N_R_2_P_DP_WinPlot.csv
100	03	Ni	6	11-14-2022	20221114_10-13_03-100_Ni_Y_R_6_P_DP_WinPlot.csv
100	03	Ni	6	11-14-2022	20221114_10-13_03-100_Ni_Y_R_6_P_DP_WinPlot-2.csv
100	04	Ni	5	11-01-2022	20221101_12-40_04-100_Ni_N_R_5_p_DP_WinPlot.csv
100	04	Ni	6	11-15-2022	20221115_07-38_04-100_Ni_Y_R_6_P_DP_WinPlot.csv
100	04	Ni	6	11-15-2022	20221115_07-38_04-100_Ni_Y_R_6_P_DP_WinPlot-2.csv
100	05	Ni	1	11-03-2022	20221103_13-53_05-100_Ni_N_R_1_p_DP_WinPlot.csv
100	05	Ni	2	11-04-2022	20221104_06-26_05-100_Ni_N_R_2_P_DP_WinPlot.csv
100	05	Ni	6	01-20-2023	20230120_09-54_05-100_Ni_Y_R_6_P_DP_WinPlot-2.csv
100	05	Ni	6	01-20-2023	20230120_09-54_05-100_Ni_Y_R_6_P_DP_WinPlot.csv

Appendix G. 1/4" Swagelok VCR Fitting Test Data Summary

Data Table: 1/4" Pre-Vibe, 316L Stainless Steel Seal

Data File ID Nomenclature Explanation

Date YYYYMMDD	Time HH-MM	Sample #-01, 02, 03, 04, 05 Fitting Size (025 = ¼"; 050 = ½", 100 = 1")	Seal Material (SS-Stainless Steel, Ni-Silver Plated Nickel)	Pre-Vibe (N) Post-Vibe (Y)	Run	Run #	Pass (P) Fail (F)	Test Conductor Initials	File Type
20220915	15-05	01-025	SS	N	R	1	P	DP	WinPlot.csv

Seal Type (316L SS - Stainless, Ni - Silver Plated Nickel)			SS	SS	SS	SS	SS	SS	SS	SS	SS	SS
Size (inch)			1/4 inch	1/4 inch	1/4 inch	1/4 inch	1/4 inch	1/4 inch	1/4 inch	1/4 inch	1/4 inch	1/4 inch
Pre-Vibe / Post-Vibe			Pre-Vibe	Pre-Vibe	Pre-Vibe	Pre-Vibe	Pre-Vibe	Pre-Vibe	Pre-Vibe	Pre-Vibe	Pre-Vibe	Pre-Vibe
Test ID			A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Run Number			Run 1	Run 2	Run 1	Run 2	Run 1	Run 2	Run 1	Run 2	Run 1	Run 2
Fitting Serial Number			01-025	01-025	02-025	02-025	03-025	03-025	04-025	04-025	05-025	05-025
	Units	Value										
Ambient Temperature GHe Leak Measurement (Average)	sccs x 1e-10	1.30	Pass	Pass	Pass	Pass	1.14	1.60	1.00	1.02	1.74	1.32
Ambient Temperature GHe Leak Measurement (Peak)	sccs x 1e-10	8.43	Pass	Pass	Pass	Pass	1.50	8.43	1.07	2.40	2.70	8.43
Cold GHe Leak Measurement (Average)	sccs x 1e-10	1.66	Pass	Pass	Pass	Pass	1.95	2.68	1.01	1.02	1.87	1.46
Cold GHe Leak Measurement (Peak)	sccs x 1e-10	18.42	Pass	Pass	Pass	Pass	5.25	7.67	2.13	2.18	9.95	18.42
Cold GHe Leak Test Pressure P1 (Average)	psig	416.2	413.9	415.1	414.3	417.2	414.5	416.5	415.8	424.3	415.3	414.9
Cold GHe Leak Test Temperature (Average)	K	24.7	31.4	27.4	23.8	23.8	23.9	23.7	20.1	19.8	26.9	26.4
Cold GHe Leak Test Temperature (Minimum)	K	18.8	30.3	25.8	23.2	23.1	23.3	23.1	19.2	18.8	25.2	25.1
Special Test Conditions										P1 LE 500,		T3 GE 200,

Test ID	Data File ID
A1	20220915_15-05_01-025_SS_N_R_1_P_DP_WinPlot.csv
A2	20220916_11-14_01-025_SS_N_R_2_P_DP_WinPlot.csv
A3	20220919_13-07_02-025_SS_N_R_1_P_DP_WinPlot.csv
A4	20220920_08-20_02-025_SS_N_R_2_P_DP_WinPlot.csv
A5	20220921_08-06_03-025_SS_N_R_1_P_DP_WinPlot.csv
A6	20220922_12-52_03-025_SS_N_R_2_P_DP_WinPlot.csv
A7	20221219_08-09_04-025_SS_N_R_5_P_DP_WinPlot.csv
A8	20221219_08-09_04-025_SS_N_R_5_P_DP_WinPlot-2.csv
A9	20221003_09-55_05-025_SS_N_R_1_P_DP_WinPlot.csv
A10	20221003_13-15_05-025_SS_N_R_2_P_DP_WinPlot.csv

NOTE: The **"Pass"** nomenclature in the data table indicates that a fitting/seal pair "passed" all software logic checks during testing. Data acquisition issues during the testing of some fitting/seal pairs prevented the collection of meaningful leak rate values for comparison with other fitting/seal pairs.

Data Table: 1/4" Post-Vibe, 316L Stainless Steel Seal

Data File ID Nomenclature Explanation

Date YYYYMMDD	Time HH-MM	Sample #-01, 02, 03, 04, 05 Fitting Size (025 = ¼"; 050 = ½", 100 = 1")	Seal Material (SS-Stainless Steel, Ni-Silver Plated Nickel)	Pre-Vibe (N) Post-Vibe (Y)	Run	Run #	Pass (P) Fail (F)	Test Conductor Initials	File Type
20220915	15-05	01-025	SS	N	R	1	P	DP	WinPlot.csv

Seal Type (316L SS - Stainless, Ni - Silver Plated Nickel)			SS	SS	SS	SS	SS	SS	SS	SS	SS	SS
Size (inch)			1/4 inch	1/4 inch	1/4 inch	1/4 inch	1/4 inch	1/4 inch	1/4 inch	1/4 inch	1/4 inch	1/4 inch
Pre-Vibe / Post-Vibe			Post-Vibe	Post-Vibe	Post-Vibe	Post-Vibe	Post-Vibe	Post-Vibe	Post-Vibe	Post-Vibe	Post-Vibe	Post-Vibe
Test ID			A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Run Number			Run 1	Run 2	Run 1	Run 2	Run 1	Run 2	Run 1	Run 2	Run 1	Run 2
Fitting Serial Number			01-025	01-025	02-025	02-025	03-025	03-025	04-025	04-025	05-025	05-025
	Units	Value										
Ambient Temperature GHe Leak Measurement (Average)	sccs x 1e-10	1.88	1.83	1.33	2.02	3.39	2.05	2.22	1.01	1.54	2.03	1.42
Ambient Temperature GHe Leak Measurement (Peak)	sccs x 1e-10	96.67	3.04	2.83	10.43	96.67	8.23	57.41	1.81	34.91	8.23	7.14
Cold GHe Leak Measurement (Average)	sccs x 1e-10	1.64	2.10	1.37	1.83	2.14	1.94	1.77	1.03	1.07	1.77	1.37
Cold GHe Leak Measurement (Peak)	sccs x 1e-10	24.47	6.49	1.85	5.50	18.42	10.19	24.47	2.18	6.19	10.19	9.05
Cold GHe Leak Test Pressure P1 (Average)	psig	414.6	415.8	414.8	412.9	418.8	412.5	412.3	416.6	414.2	414.2	414.4
Cold GHe Leak Test Temperature (Average)	K	25.4	24.6	25.0	23.6	27.1	27.3	27.3	23.7	21.2	27.0	26.8
Cold GHe Leak Test Temperature (Minimum)	K	19.9	24.2	25.0	22.9	25.7	25.8	25.7	23.1	19.9	25.4	25.3
Special Test Conditions				T3 GE 195,								P1 LE 500,

Test ID	Data File ID
A1	20221004_08-52_01-025_SS_Y_R_3_P_DP_WinPlot.csv
A2	20221004_11-33_01-025_SS_Y_R_4_P_DP_WinPlot.csv
A3	20221005_08-21_02-025_SS_Y_R_3_P_DP_WinPlot.csv
A4	20230207_10-35_02-025_SS_Y_R_4_P_DP_WinPlot.csv
A5	20221019_08-31_03-025_SS_Y_R_3_P_DP_WinPlot.csv
A6	20221020_06-36_03-025_SS_Y_R_4_P_DP_WinPlot.csv
A7	20230110_13-03_04-025_SS_Y_R_3_P_DP_WinPlot.csv
A8	20230111_06-44_04-025_SS_Y_R_4_P_DP_WinPlot.csv
A9	20221024_09-38_05-025_SS_Y_R_6_P_DP_WinPlot.csv
A10	20221024_09-38_05-025_SS_Y_R_6_P_DP_WinPlot-2.csv

Data Table: 1/4” Pre-Vibe, Silver Plated Nickel Seal

Data File ID Nomenclature Explanation

Date YYYYMMDD	Time HH-MM	Sample #-01, 02, 03, 04, 05 Fitting Size (025 = ¼”; 050 = ½”, 100 = 1”)	Seal Material (SS-Stainless Steel, Ni-Silver Plated Nickel)	Pre-Vibe (N) Post-Vibe (Y)	Run	Run #	Pass (P) Fail (F)	Test Conductor Initials	File Type
20220915	15-05	01-025	SS	N	R	1	P	DP	WinPlot.csv

Seal Type (316L SS - Stainless, Ni - Silver Plated Nickel)			Ni	Ni	Ni	Ni	Ni	Ni	Ni	Ni	Ni	Ni
Size (inch)			1/4 inch	1/4 inch	1/4 inch	1/4 inch	1/4 inch	1/4 inch	1/4 inch	1/4 inch	1/4 inch	1/4 inch
Pre-Vibe / Post-Vibe			Pre-Vibe	Pre-Vibe	Pre-Vibe	Pre-Vibe	Pre-Vibe	Pre-Vibe	Pre-Vibe	Pre-Vibe	Pre-Vibe	Pre-Vibe
Test ID			A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Run Number			Run 1	Run 2	Run 1	Run 2	Run 1	Run 2	Run 1	Run 2	Run 1	Run 2
Fitting Serial Number			01-025	01-025	02-025	02-025	03-025	03-025	04-025	04-025	05-025	05-025
	Units	Value										
Ambient Temperature GHe Leak Measurement (Average)	sccs x 1e-10	1.21	1.00	1.06	1.06	1.68	1.13	1.46	1.01	1.35	1.33	1.00
Ambient Temperature GHe Leak Measurement (Peak)	sccs x 1e-10	26.27	1.10	5.37	4.77	26.27	6.19	23.34	2.40	22.79	1.85	1.07
Cold GHe Leak Measurement (Average)	sccs x 1e-10	1.16	1.01	1.01	1.21	1.02	1.10	1.17	1.02	0.99	1.90	1.17
Cold GHe Leak Measurement (Peak)	sccs x 1e-10	9.95	2.24	2.58	5.37	1.85	2.29	4.34	3.68	1.07	3.27	9.95
Cold GHe Leak Test Pressure P1 (Average)	psig	415.3	415.4	414.4	414.4	412.3	414.58	415.92	417.14	417.79	417.5	414.1
Cold GHe Leak Test Temperature (Average)	K	23.8	22.2	21.8	21.9	21.9	23.77	23.78	26.82	24.79	24.9	26.1
Cold GHe Leak Test Temperature (Minimum)	K	20.8	21.3	20.9	20.9	20.8	22.97	22.95	25.15	24.59	24.8	25.0
Special Test Conditions				P1 LE 500,								

Test ID	Data File ID
A1	20221215_09-32_01-025_Ni_N_R_5_P_DP_WinPlot.csv
A2	20221215_09-32_01-025_Ni_N_R_5_P_DP_WinPlot-2.csv
A3	20230208_11-06_02-025_Ni_N_R_1_P_DP_WinPlot.csv
A4	20230209_06-40_02-025_Ni_N_R_2_P_DP_WinPlot.csv
A5	20230209_13-18_03-025_Ni_N_R_1_P_DP_WinPlot.csv
A6	20230210_07-09_03-025_Ni_N_R_2_P_DP_WinPlot.csv
A7	20230210_13-55_04-025_Ni_Y_R_1_P_DP_WinPlot.csv
A8	20232013_07-30_04-025_Ni_Y_R_2_P_DP_WinPlot.csv
A9	20220908_15-03_05-025_Ni_N_R_1_P_DP_WinPlot.csv
A10	20220909_06-39_05-025_Ni_N_R_2_P_DP_WinPlot.csv

Data Table: 1/4" Post-Vibe, Silver Plated Nickel Seal

Data File ID Nomenclature Explanation

Date YYYYMMDD	Time HH-MM	Sample #-01, 02, 03, 04, 05 Fitting Size (025 = ¼"; 050 = ½", 100 = 1")	Seal Material (SS-Stainless Steel, Ni-Silver Plated Nickel)	Pre-Vibe (N) Post-Vibe (Y)	Run	Run #	Pass (P) Fail (F)	Test Conductor Initials	File Type
20220915	15-05	01-025	SS	N	R	1	P	DP	WinPlot.csv

Seal Type (316L SS - Stainless, Ni - Silver Plated Nickel)			Ni	Ni	Ni	Ni	Ni	Ni	Ni	Ni	Ni	Ni
Size (inch)			1/4 inch	1/4 inch	1/4 inch	1/4 inch	1/4 inch	1/4 inch	1/4 inch	1/4 inch	1/4 inch	1/4 inch
Pre-Vibe / Post-Vibe			Post-Vibe	Post-Vibe	Post-Vibe	Post-Vibe	Post-Vibe	Post-Vibe	Post-Vibe	Post-Vibe	Post-Vibe	Post-Vibe
Test ID			A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Run Number			Run 1	Run 2	Run 1	Run 2	Run 1	Run 2	Run 1	Run 2	Run 1	Run 2
Fitting Serial Number			01-025	01-025	02-025	02-025	03-025	03-025	04-025	04-025	05-025	05-025
	Units	Value										
Ambient Temperature GHe Leak Measurement (Average)	sccs x 1e-10	1.87	1.04	1.29	Pass	Pass	Pass	No Data	1.90	1.13	1.01	4.83
Ambient Temperature GHe Leak Measurement (Peak)	sccs x 1e-10	19.31	2.70	19.31	Pass	Pass	Pass		3.95	2.77	1.05	5.77
Cold GHe Leak Measurement (Average)	sccs x 1e-10	2.18	1.01	1.11	Pass	Pass	Pass		2.10	1.44	3.32	4.09
Cold GHe Leak Measurement (Peak)	sccs x 1e-10	13.54	1.61	4.34	Pass	Pass	Pass		13.54	5.91	5.50	4.77
Cold GHe Leak Test Pressure P1 (Average)	psig	415.2	416.0	413.3	412.5	417.1	413.7		415.1	417.9	415.6	415.8
Cold GHe Leak Test Temperature (Average)	K	23.8	20.2	20.3	24.5	24.4	27.4		23.7	24.3	24.6	24.5
Cold GHe Leak Test Temperature (Minimum)	K	19.2	19.2	19.3	24.1	23.9	25.6		23.1	23.7	24.3	24.2
Special Test Conditions						P1 LE 500,				T3 GE 250,		

Test ID	Data File ID
A1	20230109_10-29_01-025_Ni_Y_R_3_P_DP_WinPlot.csv
A2	20230110_05-12_01-025_Ni_Y_R_4_P_DP_WinPlot.csv
A3	20220913_08-58_02-025_Ni_Y_R_6_P_DP_WinPlot.csv
A4	20220913_08-58_02-025_Ni_Y_R_6_P_DP_WinPlot-2.csv
A5	20220914_10-09_03-025_Ni_Y_R_5_P_DP_WinPlot.csv
A6	No Data
A7	20220923_09-09_04-025_Ni_Y_R_3_P_DP_WinPlot.csv
A8	20220923_12-27_04-025_Ni_Y_R_4_P_DP_WinPlot.csv
A9	20220927_09-09_05-025_Ni_Y_R_3_P_DP_WinPlot.csv
A10	20220927_13-03_05-025_Ni_Y_R_4_P_DP_WinPlot.csv

NOTE: The **"Pass"** nomenclature in the data table indicates that a fitting/seal pair "passed" all software logic checks during testing. Data acquisition issues during the testing of some fitting/seal pairs prevented the collection of meaningful leak rate values for comparison with other fitting/seal pairs.

Data Table: ½" Pre-Vibe, 316L Stainless Steel Seal

Data File ID Nomenclature Explanation

Date YYYYMMDD	Time HH-MM	Sample #-01, 02, 03, 04, 05 Fitting Size (025 = ¼"; 050 = ½", 100 = 1")	Seal Material (SS-Stainless Steel, Ni-Silver Plated Nickel)	Pre-Vibe (N) Post-Vibe (Y)	Run	Run #	Pass (P) Fail (F)	Test Conductor Initials	File Type
20220915	15-05	01-025	SS	N	R	1	P	DP	WinPlot.csv

Seal Type (316L SS - Stainless, Ni - Silver Plated Nickel)			SS	SS	SS	SS	SS	SS	SS	SS	SS	SS
Size (inch)			1/2 inch	1/2 inch	1/2 inch	1/2 inch	1/2 inch	1/2 inch	1/2 inch	1/2 inch	1/2 inch	1/2 inch
Pre-Vibe / Post-Vibe			Pre-Vibe	Pre-Vibe	Pre-Vibe	Pre-Vibe	Pre-Vibe	Pre-Vibe	Pre-Vibe	Pre-Vibe	Pre-Vibe	Pre-Vibe
Test ID			A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Run Number			Run 1	Run 2	Run 1	Run 2	Run 1	Run 2	Run 1	Run 2	Run 1	Run 2
Fitting Serial Number			01-050	01-050	02-050	02-050	03-050	03-050	04-050	04-050	05-050	05-050
	Units	Value										
Ambient Temperature GHe Leak Measurement (Average)	sccs x 1e-10	2.13	2.72	No Data	1.05	1.11	1.00	1.71	1.14	1.99	1.48	6.93
Ambient Temperature GHe Leak Measurement (Peak)	sccs x 1e-10	63.12	12.02		3.19	4.89	2.29	14.88	1.61	15.24	9.95	63.12
Cold GHe Leak Measurement (Average)	sccs x 1e-10	1.88	2.55		1.00	0.99	1.14	1.90	1.25	1.57	1.33	5.18
Cold GHe Leak Measurement (Peak)	sccs x 1e-10	17.15	10.19		1.10	1.18	2.08	10.68	15.24	8.23	7.31	17.15
Cold GHe Leak Test Pressure P1 (Average)	psig	414.2	414.4		414.2	410.5	415.0	411.7	419.8	412.4	415.2	414.3
Cold GHe Leak Test Temperature (Average)	K	42.4	24.3		20.9	20.7	24.6	24.7	186.5	26.5	26.7	26.4
Cold GHe Leak Test Temperature (Minimum)	K	19.3	23.8		19.6	19.3	24.2	24.4	25.0	25.2	25.2	25.0
Special Test Conditions						P1 LE 500,		P1 LE 500,		P1 LE 500,		

Test ID	Data File ID
A1	20221006_11-08_01-050_SS_Y_R_5_P_DP_WinPlot.csv
A2	No Data
A3	20230113_08-11_02-050_SS_N_R_5_P_DP_WinPlot.csv
A4	20230113_08-11_02-050_SS_N_R_5_P_DP_WinPlot-2.csv
A5	20221012_06-20_03-050_SS_N_R_5_P_DP_WinPlot.csv
A6	20221012_06-20_03-050_SS_N_R_5_P_DP_WinPlot-2.csv
A7	20221013_09-44_04-050_SS_N_R_5_P_DP_WinPlot.csv
A8	20221013_09-44_04-050_SS_N_R_5_P_DP_WinPlot-2.csv
A9	20221014_10-34_05-050_SS_N_R_1_P_DP_WinPlot.csv
A10	20221018_06-47_05-050_SS_N_R_2_P_DP_WinPlot.csv

Data Table: ½" Post-Vibe, 316L Stainless Steel Seal

Data File ID Nomenclature Explanation

Date YYYYMMDD	Time HH-MM	Sample #-01, 02, 03, 04, 05 Fitting Size (025 = ¼"; 050 = ½", 100 = 1")	Seal Material (SS-Stainless Steel, Ni-Silver Plated Nickel)	Pre-Vibe (N) Post-Vibe (Y)	Run	Run #	Pass (P) Fail (F)	Test Conductor Initials	File Type
20220915	15-05	01-025	SS	N	R	1	P	DP	WinPlot.csv

Seal Type (316L SS - Stainless, Ni - Silver Plated Nickel)			SS	SS	SS	SS	SS	SS	SS	SS	SS	SS
Size (inch)			1/2 inch	1/2 inch	1/2 inch	1/2 inch	1/2 inch	1/2 inch	1/2 inch	1/2 inch	1/2 inch	1/2 inch
Pre-Vibe / Post-Vibe			Post-Vibe	Post-Vibe	Post-Vibe	Post-Vibe	Post-Vibe	Post-Vibe	Post-Vibe	Post-Vibe	Post-Vibe	Post-Vibe
Test ID			A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Run Number			Run 1	Run 2	Run 1	Run 2	Run 1	Run 2	Run 1	Run 2	Run 1	Run 2
Fitting Serial Number			01-050	01-050	02-050	02-050	03-050	03-050	04-050	04-050	05-050	05-050
	Units	Value										
Ambient Temperature GHe Leak Measurement (Average)	sccs x 1e-10	1.76	1.00	1.00	1.06	2.16	1.07	1.00	1.08	1.03	4.01	4.20
Ambient Temperature GHe Leak Measurement (Peak)	sccs x 1e-10	19.31	1.10	1.68	1.33	19.31	7.14	1.10	3.86	2.24	5.00	4.89
Cold GHe Leak Measurement (Average)	sccs x 1e-10	1.84	1.01	1.03	1.00	1.80	1.02	1.01	1.01	1.01	5.03	4.44
Cold GHe Leak Measurement (Peak)	sccs x 1e-10	8.43	2.40	3.95	1.50	5.25	4.45	6.19	3.43	3.59	8.43	5.12
Cold GHe Leak Test Pressure P1 (Average)	psig	416.6	416.1	413.6	415.7	417.0	417.3	415.9	420.9	418.6	416.8	414.1
Cold GHe Leak Test Temperature (Average)	K	26.0	26.7	26.6	27.4	27.3	27.3	27.3	27.2	27.3	21.8	21.4
Cold GHe Leak Test Temperature (Minimum)	K	20.1	25.3	25.1	25.5	25.5	25.6	25.6	25.9	25.8	20.6	20.1
Special Test Conditions				P1 LE 500,								P1 LE 500,

Test ID	Data File ID
A1	20221121_06-50_01-050_SS_Y_R_6_P_DP_WinPlot.csv
A2	20221121_06-50_01-050_SS_Y_R_6_P_DP_WinPlot-2.csv
A3	20221122_14-01_02-050_SS_Y_R_3_P_DP_WinPlot.csv
A4	20221123_05-43_02-050_SS_Y_R_4_P_DP_WinPlot.csv
A5	20221128_07-26_03-050_SS_Y_R_6_P_DP_WinPlot.csv
A6	20221128_07-26_03-050_SS_Y_R_6_P_DP_WinPlot-2.csv
A7	20221201_07-36_04-050_SS_Y_R_3_P_DP_WinPlot.csv
A8	20221202_11-05_04-050_SS_Y_R_4_P_DP_WinPlot.csv
A9	20230131_08-49_05-050_SS_Y_R_6_P_DP_WinPlot.csv
A10	20230131_08-49_05-050_SS_Y_R_6_P_DP_WinPlot-2.csv

Data Table: ½" Pre-Vibe, Silver Plated Nickel

Data File ID Nomenclature Explanation

Date YYYYMMDD	Time HH-MM	Sample #-01, 02, 03, 04, 05 Fitting Size (025 = ¼"; 050 = ½", 100 = 1")	Seal Material (SS-Stainless Steel, Ni-Silver Plated Nickel)	Pre-Vibe (N) Post-Vibe (Y)	Run	Run #	Pass (P) Fail (F)	Test Conductor Initials	File Type
20220915	15-05	01-025	SS	N	R	1	P	DP	WinPlot.csv

Seal Type (316L SS - Stainless, Ni - Silver Plated Nickel)			Ni	Ni	Ni	Ni	Ni	Ni	Ni	Ni	Ni	Ni
Size (inch)			1/2 inch	1/2 inch	1/2 inch	1/2 inch	1/2 inch	1/2 inch	1/2 inch	1/2 inch	1/2 inch	1/2 inch
Pre-Vibe / Post-Vibe			Pre-Vibe	Pre-Vibe	Pre-Vibe	Pre-Vibe	Pre-Vibe	Pre-Vibe	Pre-Vibe	Pre-Vibe	Pre-Vibe	Pre-Vibe
Test ID			A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Run Number			Run 1	Run 2	Run 1	Run 2	Run 1	Run 2	Run 1	Run 2	Run 1	Run 2
Fitting Serial Number			01-050	01-050	02-050	02-050	03-050	03-050	04-050	04-050	05-050	05-050
	Units	Value										
Ambient Temperature GHe Leak Measurement (Average)	sccs x 1e-10	1.39	1.01	4.72	1.00	1.09	1.01	1.00	0.99	1.01	1.01	1.04
Ambient Temperature GHe Leak Measurement (Peak)	sccs x 1e-10	5.25	2.46	5.25	1.07	5.12	1.90	1.10	1.02	2.18	2.40	4.14
Cold GHe Leak Measurement (Average)	sccs x 1e-10	1.39	0.98	4.83	1.01	1.00	1.01	1.02	1.00	1.01	1.00	1.04
Cold GHe Leak Measurement (Peak)	sccs x 1e-10	15.60	3.68	15.60	2.77	1.05	4.89	3.95	1.10	1.77	1.10	4.66
Cold GHe Leak Test Pressure P1 (Average)	psig	415.3	416.9	413.6	415.5	413.7	417.1	417.0	413.8	414.5	416.0	414.9
Cold GHe Leak Test Temperature (Average)	K	25.8	27.6	26.9	26.8	25.0	27.3	27.1	24.6	24.5	24.3	23.9
Cold GHe Leak Test Temperature (Minimum)	K	23.1	26.3	25.5	25.1	25.0	25.9	25.7	24.3	24.0	23.7	23.1
Special Test Conditions				P1 LE 500,		P1 LE 500,		P1 LE 500,		P1 LE 500,		P1 LE 500,

Test ID	Data File ID
A1	20221207_07-58_01-050_Ni_N_R_5_P_DP_WinPlot.csv
A2	20221207_07-58_01-050_Ni_N_R_5_P_DP_WinPlot-2.csv
A3	20221209_07-44_02-050_Ni_N_R_5_P_DP_WinPlot.csv
A4	20221209_07-44_02-050_Ni_N_R_5_P_DP_WinPlot-2.csv
A5	20221211_06-58_03-050_Ni_N_R_5_P_DP_WinPlot.csv
A6	20221211_06-58_03-050_Ni_N_R_5_P_DP_WinPlot-2.csv
A7	20221213_07-36_04-050_Ni_N_R_5_P_DP_WinPlot.csv
A8	20221213_07-36_04-050_Ni_N_R_5_P_DP_WinPlot-2.csv
A9	20221214_07-37_05-050_Ni_N_R_5_P_DP_WinPlot.csv
A10	20221214_07-37_05-050_Ni_N_R_5_P_DP_WinPlot-2.csv

Data Table: ½” Post-Vibe, Silver Plated Nickel

Data File ID Nomenclature Explanation

Date YYYYMMDD	Time HH-MM	Sample #-01, 02, 03, 04, 05 Fitting Size (025 = ¼”; 050 = ½”, 100 = 1”)	Seal Material (SS-Stainless Steel, Ni-Silver Plated Nickel)	Pre-Vibe (N) Post-Vibe (Y)	Run	Run #	Pass (P) Fail (F)	Test Conductor Initials	File Type
20220915	15-05	01-025	SS	N	R	1	P	DP	WinPlot.csv

Seal Type (316L SS - Stainless, Ni - Silver Plated Nickel)			Ni	Ni	Ni	Ni	Ni	Ni	Ni	Ni	Ni	Ni
Size (inch)			1/2 inch	1/2 inch	1/2 inch	1/2 inch	1/2 inch	1/2 inch	1/2 inch	1/2 inch	1/2 inch	1/2 inch
Pre-Vibe / Post-Vibe			Post-Vibe	Post-Vibe	Post-Vibe	Post-Vibe	Post-Vibe	Post-Vibe	Post-Vibe	Post-Vibe	Post-Vibe	Post-Vibe
Test ID			A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Run Number			Run 1	Run 2	Run 1	Run 2	Run 1	Run 2	Run 1	Run 2	Run 1	Run 2
Fitting Serial Number			01-050	01-050	02-050	02-050	03-050	03-050	04-050	04-050	05-050	05-050
	Units	Value										
Ambient Temperature GHe Leak Measurement (Average)	sccs x 1e-10	1.04	1.04	0.99	1.00	1.03	1.02	1.19	1.00	1.08	1.00	1.00
Ambient Temperature GHe Leak Measurement (Peak)	sccs x 1e-10	12.02	3.86	1.10	1.85	3.19	2.29	12.02	2.03	4.89	1.90	1.57
Cold GHe Leak Measurement (Average)	sccs x 1e-10	1.00	0.99	1.00	0.99	1.00	0.99	1.01	1.00	1.01	0.99	0.99
Cold GHe Leak Measurement (Peak)	sccs x 1e-10	2.03	1.10	1.81	1.07	1.13	1.10	1.81	1.72	2.03	1.10	1.13
Cold GHe Leak Test Pressure P1 (Average)	psig	415.3	414.2	412.3	421.4	414.2	420.3	413.6	415.4	413.5	414.2	413.5
Cold GHe Leak Test Temperature (Average)	K	20.6	20.7	20.7	21.1	20.3	20.0	20.1	20.5	20.6	20.8	20.7
Cold GHe Leak Test Temperature (Minimum)	K	18.6	19.4	19.4	19.6	19.1	18.6	18.8	19.0	19.1	19.4	19.3
Special Test Conditions				P1 LE 500,		P1 LE 500,		P1 LE 500,		P1 LE 500,		P1 LE 500,

Test ID	Data File ID
A1	20230111_13-34_01-050_Ni_Y_R_6_P_DP_WinPlot.csv
A2	20230111_13-34_01-050_Ni_Y_R_6_P_DP_WinPlot-2.csv
A3	20230112_09-10_02-050_Ni_Y_R_3_P_DP_WinPlot.csv
A4	20230112_09-10_02-050_Ni_Y_R_3_P_DP_WinPlot-2.csv
A5	20230117_08-49_03-050_Ni_Y_R_6_P_DP_WinPlot.csv
A6	20230117_08-49_03-050_Ni_Y_R_6_P_DP_WinPlot-2.csv
A7	20230118_07-37_04-050_Ni_Y_R_6_P_DP_WinPlot.csv
A8	20230118_07-37_04-050_Ni_Y_R_6_P_DP_WinPlot-2.csv
A9	20230119_08-09_05-050_Ni_Y_R_6_P_DP_WinPlot.csv
A10	20230119_08-09_05-050_Ni_Y_R_6_P_DP_WinPlot-2.csv

Appendix I. 1" Swagelok VCR Fitting Test Data Summary

Data Table: 1” Pre-Vibe, 316L Stainless Steel

Data File ID Nomenclature Explanation

Date YYYYMMDD	Time HH-MM	Sample #-01, 02, 03, 04, 05 Fitting Size (025 = ¼”; 050 = ½”, 100 = 1”)	Seal Material (SS-Stainless Steel, Ni-Silver Plated Nickel)	Pre-Vibe (N) Post-Vibe (Y)	Run	Run #	Pass (P) Fail (F)	Test Conductor Initials	File Type
20220915	15-05	01-025	SS	N	R	1	P	DP	WinPlot.csv

Seal Type (316L SS - Stainless, Ni - Silver Plated Nickel)			SS	SS	SS	SS	SS	SS	SS	SS	SS	SS
Size (inch)			1 inch	1 inch	1 inch	1 inch	1 inch	1 inch	1 inch	1 inch	1 inch	1 inch
Pre-Vibe / Post-Vibe			Pre-Vibe	Pre-Vibe	Pre-Vibe	Pre-Vibe	Pre-Vibe	Pre-Vibe	Pre-Vibe	Pre-Vibe	Pre-Vibe	Pre-Vibe
Test ID			A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Run Number			Run 1	Run 2	Run 1	Run 2	Run 1	Run 2	Run 1	Run 2	Run 1	Run 2
Fitting Serial Number			01-100	01-100	02-100	02-100	03-100	03-100	04-100	04-100	05-100	05-100
	Units	Value										
Ambient Temperature GHe Leak Measurement (Average)	sccs x 1e-10	1.02	1.03	1.04	1.02	1.00	1.03	1.02	1.03	1.00	1.00	1.08
Ambient Temperature GHe Leak Measurement (Peak)	sccs x 1e-10	4.04	1.33	4.04	2.83	1.13	2.24	2.18	2.90	1.53	1.18	2.58
Cold GHe Leak Measurement (Average)	sccs x 1e-10	1.01	1.01	1.00	1.01	1.04	1.01	1.00	1.02	1.00	0.99	1.00
Cold GHe Leak Measurement (Peak)	sccs x 1e-10	3.12	1.85	1.21	1.85	3.12	1.94	1.10	2.35	1.72	1.10	1.07
Cold GHe Leak Test Pressure P1 (Average)	psig	413.4	415.6	411.0	414.8	411.7	412.02	412.61	414.4	411.2	417.1	413.7
Cold GHe Leak Test Temperature (Average)	K	23.6	24.5	24.5	22.3	22.5	23.52	23.47	23.0	23.5	24.3	24.2
Cold GHe Leak Test Temperature (Minimum)	K	20.5	24.1	24.1	20.5	21.0	22.44	22.36	21.6	22.4	23.8	23.6
Special Test Conditions				P1 LE 500,		P1 LE 500,		P1 LE 500,		P1 LE 500,		P1 LE 500,

Test ID	Data File ID
A1	20221116_07-08_01-100_SS_N_R_1_P_DP_WinPlot.csv
A2	20221116_07-08_01-100_SS_N_R_1_P_DP_WinPlot-2.csv
A3	20221117_06-41_02-100_SS_N_R_5_P_DP_WinPlot.csv
A4	20221117_06-41_02-100_SS_N_R_5_P_DP_WinPlot-2.csv
A5	20221118_06-35_03-100_SS_N_R_5_P_DP_WinPlot.csv
A6	20221118_06-35_03-100_SS_N_R_5_P_DP_WinPlot-2.csv
A7	20221119_06-36_04-100_SS_N_R_5_P_DP_WinPlot.csv
A8	20221119_06-36_04-100_SS_N_R_5_P_DP_WinPlot-2.csv
A9	20230123_07-38_05-100_SS_N_R_5_P_DP_WinPlot.csv
A10	20230123_07-38_05-100_SS_N_R_5_P_DP_WinPlot-2.csv

Data Table: 1" Post-Vibe, 316L Stainless Steel

Data File ID Nomenclature Explanation

Date YYYYMMDD	Time HH-MM	Sample #-01, 02, 03, 04, 05 Fitting Size (025 = ¼"; 050 = ½", 100 = 1")	Seal Material (SS-Stainless Steel, Ni-Silver Plated Nickel)	Pre-Vibe (N) Post-Vibe (Y)	Run	Run #	Pass (P) Fail (F)	Test Conductor Initials	File Type
20220915	15-05	01-025	SS	N	R	1	P	DP	WinPlot.csv

Seal Type (316L SS - Stainless, Ni - Silver Plated Nickel)			SS	SS	SS	SS	SS	SS	SS	SS	SS	SS
Size (inch)			1 inch	1 inch	1 inch	1 inch	1 inch	1 inch	1 inch	1 inch	1 inch	1 inch
Pre-Vibe / Post-Vibe			Post-Vibe	Post-Vibe	Post-Vibe	Post-Vibe	Post-Vibe	Post-Vibe	Post-Vibe	Post-Vibe	Post-Vibe	Post-Vibe
Test ID			A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Run Number			Run 1	Run 2	Run 1	Run 2	Run 1	Run 2	Run 1	Run 2	Run 1	Run 2
Fitting Serial Number			01-100	01-100	02-100	02-100	03-100	03-100	04-100	04-100	05-100	05-100
	Units	Value										
Ambient Temperature GHe Leak Measurement (Average)	sccs x 1e-10	1.02	0.99	0.99	1.00	0.99	1.03	1.00	1.00	1.08	1.00	1.14
Ambient Temperature GHe Leak Measurement (Peak)	sccs x 1e-10	9.49	1.21	1.10	1.94	1.10	2.83	1.13	1.68	6.05	1.50	9.49
Cold GHe Leak Measurement (Average)	sccs x 1e-10	1.02	1.00	1.08	0.99	1.04	1.02	1.01	1.06	1.00	0.99	1.02
Cold GHe Leak Measurement (Peak)	sccs x 1e-10	4.66	1.61	4.66	1.07	3.86	2.08	2.40	3.59	1.10	1.10	2.97
Cold GHe Leak Test Pressure P1 (Average)	psig	414.0	413.8	412.4	414.8	412.7	412.3	412.3	415.1	414.7	418.6	413.6
Cold GHe Leak Test Temperature (Average)	K	22.8	22.6	22.6	22.7	22.7	22.7	23.0	23.5	23.5	22.7	22.5
Cold GHe Leak Test Temperature (Minimum)	K	20.9	21.0	21.0	21.1	21.1	21.3	21.6	22.5	22.4	21.2	20.9
Special Test Conditions				P1 LE 500,		P1 LE 500,		P1 LE 500,		P1 LE 500,		P1 LE 500,

Test ID	Data File ID
A1	20230124_09-52_01-100_SS_Y_R_6_P_DP_WinPlot.csv
A2	20230124_09-52_01-100_SS_Y_R_6_P_DP_WinPlot-2.csv
A3	20230125_09-25_02-100_SS_Y_R_6_P_DP_WinPlot.csv
A4	20230125_09-25_02-100_SS_Y_R_6_P_DP_WinPlot-2.csv
A5	20230126_09-30_03-100_SS_Y_R_6_P_DP_WinPlot.csv
A6	20230126_09-30_03-100_SS_Y_R_6_P_DP_WinPlot-2.csv
A7	20230127_09-20_04-100_SS_Y_R_6_P_DP_WinPlot.csv
A8	20230127_09-20_04-100_SS_Y_R_6_P_DP_WinPlot-2.csv
A9	20230130_08-20_05-100_SS_Y_R_6_P_DP_WinPlot.csv
A10	20230130_08-20_05-100_SS_Y_R_6_P_DP_WinPlot-2.csv

Data Table: 1" Pre-Vibe, Silver Plated Nickel Seal

Data File ID Nomenclature Explanation

Date YYYYMMDD	Time HH-MM	Sample #-01, 02, 03, 04, 05 Fitting Size (025 = ¼"; 050 = ½", 100 = 1")	Seal Material (SS-Stainless Steel, Ni-Silver Plated Nickel)	Pre-Vibe (N) Post-Vibe (Y)	Run	Run #	Pass (P) Fail (F)	Test Conductor Initials	File Type
20220915	15-05	01-025	SS	N	R	1	P	DP	WinPlot.csv

Seal Type (316L SS - Stainless, Ni - Silver Plated Nickel)			Ni	Ni	Ni	Ni	Ni	Ni	Ni	Ni	Ni	Ni
Size (inch)			1 inch	1 inch	1 inch	1 inch	1 inch	1 inch	1 inch	1 inch	1 inch	1 inch
Pre-Vibe / Post-Vibe			Pre-Vibe	Pre-Vibe	Pre-Vibe	Pre-Vibe	Pre-Vibe	Pre-Vibe	Pre-Vibe	Pre-Vibe	Pre-Vibe	Pre-Vibe
Test ID			A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Run Number			Run 1	Run 2	Run 1	Run 2	Run 1	Run 2	Run 1	Run 2	Run 1	Run 2
Fitting Serial Number			01-100	01-100	02-100	02-100	03-100	03-100	04-100	04-100	05-100	05-100
	Units	Value										
Ambient Temperature GHe Leak Measurement (Average)	sccs x 1e-10	3.17	1.11	1.08	1.49	2.62	1.61	2.14	1.97	No Data	8.23	8.31
Ambient Temperature GHe Leak Measurement (Peak)	sccs x 1e-10	47.50	2.83	1.90	5.37	10.94	10.94	47.50	18.42		9.49	20.25
Cold GHe Leak Measurement (Average)	sccs x 1e-10	4.45	0.04	1.21	0.05	0.04	1.66	1.30	1.92		22.18	11.66
Cold GHe Leak Measurement (Peak)	sccs x 1e-10	26.90	1.33	4.24	0.21	0.77	6.81	2.77	9.49		26.90	15.98
Cold GHe Leak Test Pressure P1 (Average)	psig	413.6	413.0	414.8	415.6	412.5	412.1	408.7	415.1		416.1	414.9
Cold GHe Leak Test Temperature (Average)	K	23.2	22.7	22.8	23.5	24.1	22.4	22.3	22.9		24.1	23.7
Cold GHe Leak Test Temperature (Minimum)	K	20.7	21.3	21.3	22.5	23.4	20.8	20.7	21.5		23.4	22.8
Special Test Conditions												

Test ID	Data File ID
A1	20221027_06-40_01-100_Ni_N_R_1_P_DP_WinPlot.csv
A2	20221027_10-20_01-100_Ni_N_R_2_P_DP_WinPlot.csv
A3	20221028_09-20_02-100_Ni_N_R_1_P_DP_WinPlot.csv
A4	20221031_07-40_02-100_Ni_N_R_2_P_DP_WinPlot.csv
A5	20221031_14-45_03-100_Ni_N_R_1_P_DP_WinPlot.csv
A6	20221101_06-40_03-100_Ni_N_R_2_P_DP_WinPlot.csv
A7	20221101_12-40_04-100_Ni_N_R_5_p_DP_WinPlot.csv
A8	No Data
A9	20221103_13-53_05-100_Ni_N_R_1_p_DP_WinPlot.csv
A10	20221104_06-26_05-100_Ni_N_R_2_P_DP_WinPlot.csv

Data Table: 1” Post-Vibe, Silver Plated Nickel Seal

Data File ID Nomenclature Explanation

Date YYYYMMDD	Time HH-MM	Sample #-01, 02, 03, 04, 05 Fitting Size (025 = ¼”; 050 = ½”, 100 = 1”)	Seal Material (SS-Stainless Steel, Ni-Silver Plated Nickel)	Pre-Vibe (N) Post-Vibe (Y)	Run	Run #	Pass (P) Fail (F)	Test Conductor Initials	File Type
20220915	15-05	01-025	SS	N	R	1	P	DP	WinPlot.csv

Seal Type (316L SS - Stainless, Ni - Silver Plated Nickel)			Ni	Ni	Ni	Ni	Ni	Ni	Ni	Ni	Ni	Ni
Size (inch)			1 inch	1 inch	1 inch	1 inch	1 inch	1 inch	1 inch	1 inch	1 inch	1 inch
Pre-Vibe / Post-Vibe			Post-Vibe	Post-Vibe	Post-Vibe	Post-Vibe	Post-Vibe	Post-Vibe	Post-Vibe	Post-Vibe	Post-Vibe	Post-Vibe
Test ID			A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Run Number			Run 1	Run 2	Run 1	Run 2	Run 1	Run 2	Run 1	Run 2	Run 1	Run 2
Fitting Serial Number			01-100	01-100	02-100	02-100	03-100	03-100	04-100	04-100	05-100	05-100
	Units	Value										
Ambient Temperature GHe Leak Measurement (Average)	sccs x 1e-10	1.41	1.45	1.00	No data	1.18	1.03	1.00	1.01	1.01	4.02	0.99
Ambient Temperature GHe Leak Measurement (Peak)	sccs x 1e-10	28.21	19.77	1.07		13.22	2.24	1.99	1.53	2.18	28.21	1.07
Cold GHe Leak Measurement (Average)	sccs x 1e-10	2.00	8.71	1.00		1.00	1.03	1.00	1.01	1.00	2.29	1.01
Cold GHe Leak Measurement (Peak)	sccs x 1e-10	15.60	15.60	1.10		1.10	3.51	1.61	1.39	1.10	7.67	2.03
Cold GHe Leak Test Pressure P1 (Average)	psig	415.0	414.3	413.3		417.5	415.1	413.0	420.6	413.9	414.5	412.8
Cold GHe Leak Test Temperature (Average)	K	23.1	23.9	23.3		24.4	22.5	22.7	23.2	23.2	22.6	22.5
Cold GHe Leak Test Temperature (Minimum)	K	20.8	23.0	22.2		23.9	20.8	21.2	21.9	22.0	21.1	20.9
Special Test Conditions						P1 LE 500,	T3 GE 255,	P1 LE 500,		P1 LE 500,		P1 LE 500,

Test ID	Data File ID
A1	20221104_13-59_01-100_Ni_Y_R_3_P_DP_WinPlot.csv
A2	20221107_07-08_01-100_Ni_Y_R_4_P_DP_WinPlot.csv
A3	No data
A4	20221108_06-52_02-100_Ni_Y_R_4_P_DP_WinPlot.csv
A5	20221114_10-13_03-100_Ni_Y_R_6_P_DP_WinPlot.csv
A6	20221114_10-13_03-100_Ni_Y_R_6_P_DP_WinPlot-2.csv
A7	20221115_07-38_04-100_Ni_Y_R_6_P_DP_WinPlot.csv
A8	20221115_07-38_04-100_Ni_Y_R_6_P_DP_WinPlot-2.csv
A9	20230120_09-54_05-100_Ni_Y_R_6_P_DP_WinPlot.csv
A10	20230120_09-54_05-100_Ni_Y_R_6_P_DP_WinPlot-2.csv