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Seismic Testing of Glovebox Feedthrough Connectors and Vacuum Pumps

Lucas M. Angelette

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EXECUTIVE SUMMARY

In the design of tritium processing systems, the glovebox stripper system processes the glovebox atmosphere to recover tritium released inside the glovebox confinement. The glovebox stripper system must also be capable of processing the additional in-leakage caused by a Design Basis Accident (DBA) earthquake, in order to maintain the glovebox pressure negative relative to the room. However, it is unknown how much additional leakage occurs from electrical bulkhead feedthrough connectors after a DBA event. As there are dozens of these connectors on a tritium glovebox system, the potential increase in in-leakage can be significant.

One vital part of the glovebox stripper system are the vacuum pumps that maintain the negative atmosphere of the glovebox following a DBA earthquake. The pumps must be able to operate following an earthquake. One candidate pump is the Senior Aerospace MB-602 Metal Bellows (Met-Bel) pump. A second alternative is the hermetically sealed Edwards Vacuum nXDS15iC Scroll Pump. The Edwards scroll pump is potentially a less expensive alternative to the Met-Bel pumps, but it is unknown if this scroll pumps will survive a DBA accident and remain operational.

In order to determine the electrical feedthrough in-leakage and the candidate pumps' survivability, a seismic test was performed to simulate a DBA earthquake. This report summarizes the results of seismic test, including helium leak rates and functionality tests for the electrical feedthroughs and vacuum pumps. All components had pre- and post-test leak rates less than the threshold valve of $1x10^{-6}$ scc per sec.

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LIST OF ABBREVIATIONS

ASNT	American Society for Nondestructive Testing
AWG	American Wire Gauge
DBA	Design Basis Accident
GBSS	Glovebox Stripper System
Hz	Hertz, frequency, per second
IEEE	Institute of Electrical and Electronics Engineers
In-lbs	Inch-pounds, units for torque
LPM	Liters per minute
Met-Bel	Metal Bellows
NRC	Nuclear Regulatory Commission
PTFE	Polytetrafluoroethylene
RRS	Required Response Spectra
scc	Standard cubic centimeters, units for flow rate
SRNL	Savannah River National Laboratory
SSE	Safe Shutdown Earthquake

1.0 Introduction

In the design of tritium process systems contained in glovebox confinement, the glovebox stripper system (GBSS) is responsible for removing tritium that escapes the process piping. The gloveboxes are maintained at a negative pressure, relative to the room, to reduce the amount of escaping confinement before being processed by the GBSS. During a Design Basis Accident (DBA) earthquake, the GBSS will need to overcome any additional in-leakage from damage to the glovebox confinement boundary. A potential route for in-leakage are the electrical bulkhead feedthrough connectors. There are dozens of these connectors located on a single glovebox, so there is a potential for a significant increase of in-leakage through the multitude of connectors.

In order to design the GBSS to handle the increase in in-leakage, the leak rate of the connectors needs to be investigated. Once this is known, the type and number of pumps can be specified to meet the required flow rates for the GBSS. To accomplish this, a seismic test was performed to determine the leak rates of the electrical connectors post-DBA earthquake and test the operability of potential pumps to be used in the GBSS. This report summarizes the details of the seismic testing, leak rates, and equipment operability following a DBA seismic event

1.1 Pump Identification for a Glovebox Stripper System

A standard pump for tritium processing is the Senior Aerospace MB-601 metal bellows pump. It has a higher ultimate vacuum than other Met-Bel pumps, while still having a relateively high pumping capacity, and is comprised of a stainless-steel bellows with stainless-steel reed valves. For the GBSS, a high ultimate vacuum is not as important as the pumping capacity. Therefore, the Senior Aerospace MB-602, shown in Figure 1-2, was chosen as a candidate, since it is capable of higher volumetric flow rates with lower power requirements.

Figure 1-1: Senior Aerospace MB-602

The MB-602 can cost up to $15k per pump, so a more economical pump was selected as a second candidate to test. The Edwards Vacuum nXDS15iC, shown in Figure 1-1, is the chemically resistant variant of the nXDS15i scroll pump. The commercially available nXDS15iC is hermetically sealed, has a polytetrafluoroethylene (PTFE) tip seal, Chemraz® internal valves, a perfluoroelastomer O-ring, and stainless-steel fittings.

There are concerns with polymers components in the tritium processing streams.[1] However, due to the relatively low tritium concentrations in the glovebox atmosphere following a DBA earthquake it is not expected that the polymeric tip seals would introduce any significant impurities into the process and be a significant concern. The scroll pump is more economical than the MB-602 and can provide comparable flow rates. However, it is unknown how the scroll pump will perform following a DBA earthquake.

1.2 Electrical Bulkhead Feedthrough Connectors

Figure 1-2: Edwards Vacuum nXDS15iC

Four different electrical feedthrough connector models, manufactured by Connectronics Corp., of varying sizes, seen in Figure 1-3, and pin arrangements, listed in Table 1-1, were chosen as a representative sample to test. Two connectors of each model were used in the leak and seismic testing. The connectors have aluminum housing, glass-filled epoxy resin pin insulation, silver (#4 and #12 AWG) or gold (#16 AWG) coated pins, a polychloroprene O-ring, and an anti-rotation pin. All electrical bulkhead connectors were procured with the requirement that they have a helium leak rate less than $1x10^{-6}$ scc/sec. A jam nut is used to secure the connectors to the sealing surface, with the jam nut tightened to a torque value of 55-65 in-lbs. In tritium gloveboxes, this surface is a penetration plate that can support over a dozen different connectors.

Figure 1-3: Electrical connectors. (Left to right: MS 28-12, MS 28-22, MS 20-4, MS 20-27)

Table 1-1: Electrical connector pin arrangements

Pin Arrangement	#16 Size Pins	#12 Size Pins	#4 Size Pins
MS 20-4		4	
MS 28-22		3	3
MS 20-27	14		
MS 28-12	26		

1.3 Seismic Testing Scope

The scope of the seismic testing includes two objectives: (1) determining leak rate changes in the electrical connectors, and (2) determining vacuum pump operability. The seismic testing is focused on the survivability and leak rate increases caused by a seismic event. Because the testing is dependent on a seismic event, a simulated seismic event is utilized for this testing.

The seismic testing contains the following elements:

1. Initial construction leak testing
2. Pre-seismic testing functionality tests
3. Post-seismic functionality and leak tests

2.0 Experimental Procedure

2.1 Experimental Approach

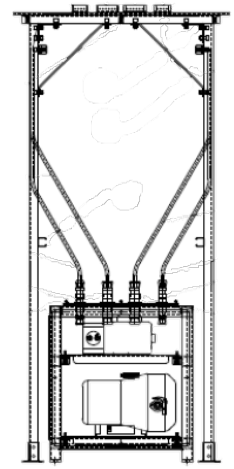

Figure 2-1: Simulated glovebox schematic

A simulated glovebox was fabricated to support the electrical connectors and vacuum pumps during the seismic test. The simulated glovebox was a box with a square carbon steel tubing frame, carbon steel sheet sides and removable front and back panels, two rails to mount the pumps, and two stainless steel plates. One stainless steel plate was fabricated for the electrical connectors, and the other plate was fabricated to support the pump electrical receptacles and gas ports for the vacuum pumps. A self-supported cable tray was fashioned to support the electrical wiring for the connectors and terminal blocks to connect power supply and measurement wiring. A schematic of the simulated glovebox and cable tray is shown in Figure 2-1. The MS 28-12 connectors did not have any plugs or wiring attached to them as a control, to remove any possible damage from the whipping wires during seismic testing.

The plugs of each electrical connector had their pins wired in series, so there were only two electrical leads for each connector. The MS 28-22 connectors had to be wired in series together, due to the odd number of pins associated with the two different wire gauges. The electrical leads were connected to terminal blocks at the top of the cable tray, so the vendor could connect the power supply and monitoring wires. The vacuum pumps were wired into electrical receptacles on the second plate, shown in Figure 2-2. Secondary twist plugs were wired between the pumps and the receptacles so that the pumps could be removed for leak testing. The inlet and outlet of the pumps were connected to bulkhead fittings on the second plate. Since the MB-602 consists of two pump heads, the heads were connected in series, resulting in only one inlet and one outlet for the pump. A Paroscientific Model 745 Digiquartz® Laboratory Standard was used to measure the vacuum levels for the two pumps prior to and after the seismic test.

A Varian 959 Helium Leak Detector backed by a Varian TriScroll 300 vacuum pump was used to perform the helium leak tests.[2] The leak tests were performed by an American Society for Nondestructive Testing (ASNT) Level II Certified Leak Tester.[3] Bell jar leak tests were used for the electrical connectors and hood tests were performed for the vacuum pumps. For the bell jar tests, an atmosphere of >50% helium was used, with a plastic bell jar used for helium introduction. An additional Varian TriScroll 300 was used to vacuum out the plastic bell jar prior to helium addition. For the hood tests, the leak detector was connected to both the inlet and outlet of the pumps, and helium was introduced to the plastic bag used for the hood until the helium concentration was >50%. Leak rates were measured following 3 minutes after helium introduction.

Figure 2-2: Gas Ports and Pump Power Connections

The electrical measurements were performed with Fluke Ampere Clamps. Power was supplied to the connectors from a 400VAC, 20A wall supply. Variac Variable Transformers and resistance banks were used to lower the amperage to approximately 7A (#16 AWG) and 16A (#4 and #12 AWG).

2.2 Seismic Testing

The seismic testing was performed by Curtiss-Wright Nuclear Division – Cincinnati Operations on a tri-axial shaker table in accordance with the testing standards IEEE-344-1975 and IEEE-323-1974. The simulated glovebox and cable tray were attached to the shaker table using commercial grade 2 or less 5/16” bolts with lock and flat washers, tightened snug. The x-, y-, and z-axis acceleration was measured via accelerometer. The system mounted to the shaker table can be seen in Figure 2-3.

Figure 2-3: Simulated glovebox mounted for seismic test

Approximately three feet of unsupported wire connected the terminal blocks to the electrical connectors. Nitrogen gas lines were connected to the pump inlet bulkhead connectors and secured to the cable tray. The nitrogen flow to each pump was controlled using a rotameter. 120VAC power cords were connected to the pump receptacles and energized prior to nitrogen flow, ensuring the pumps were operation during the seismic test.

The seismic test was performed according to the response spectra specified by SRNL, shown in Figure 2-4. The RRS was determine using US Nuclear Regulatory Commission (NRC) regulations,[4; 5] along with data obtained from the Pacific Earthquake Engineering Research Center Ground Motion Database for Central and Eastern North America.

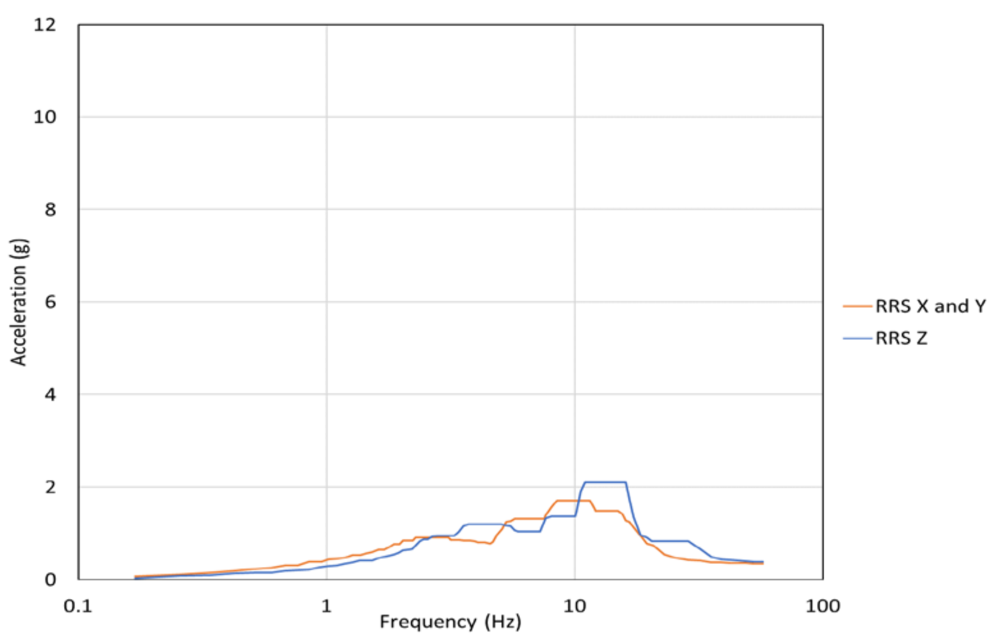

Figure 2-4: Supplied response spectra

3.0 Results and Discussion

3.1 Leak Tests

3.1.1 Installation Leak Tests

Once the electrical bulkhead feedthrough connectors were installed onto the stainless-steel plate, a leak test was to ensure that the connectors passed the maximum desired leak rate ($1x10^{-6}$ scc/s He). The leak detector was connected to a bell jar, which was placed over the connector being tested. A plastic bell jar was placed around the other end of the electrical connector, the plastic bell jar was evacuated, and then refilled with one atmosphere of helium. The leak detector measured the helium leak rate through the connector and O-ring over a three-minute interval. One of the MS 20-4 connectors was determined to have a leak through the connector (i.e., the potted pins), since the leak rate ($2.2x10^{-3}$ ssc/s He) was orders of magnitude higher than the procurement specified leak rate. A replacement connector (referred to as MS 20-4 B) was identified, installed, and successfully passed the installation leak test. Detailed results for the electrical connectors can be found in Table 3-1.

The MB-602 and nXDS15iC vacuum pumps were individually connected to the leak detector, placed into a plastic hood, and the hood was inflated with helium. Metal braided bellows tubing was used to connect the pumps to the leak detector. Both pumps successfully passed the initial leak test, detailed in Table 3-2.

Table 3-1: Initial electrical connector leak rates

Connector Type	**MS 20-27**		**MS 28-22**		**MS 28-12**		**MS 20-4**	
	A	B	A	B	A	B	A	B
Leak rate, scc/s He	6.0E-08	8.3E-08	3.0E-07	9.1E-07	1.5E-07	1.4E-07	3.9E-08	1.1E-08

Max Acceptable Leak Rate: $1.0E^{-6}$

Table 3-2: Initial pump leak rates

Pump Model	**MB-602**	**nXDS15iC**
Leak rate, scc/s He	1.9E-08	1.1E-07

Max Acceptable Leak Rate: $1.0E^{-6}$

3.1.2 Pre-Seismic Functionality Tests

Once the simulated glovebox and cable tray were received by Curtiss-Wright Nuclear Division, additional leak tests were performed by an ASNT Level II Certified Leak Tester to determine if there were any increases in leak rates caused by shipping. All connectors and pumps passed the pre-seismic leak test, as shown in Tables 3-3 and 3-4, based on the acceptance leak rate. It should be noted that the leak rates decreased on most connectors, while the MB-602 increased an order of magnitude.

The decrease for the connectors is most likely associated with the connectors settling and creating a stronger seal around the O-ring against the penetration plate. The MB-602 increase could be associated with helium trapped in the pump heads from the previous test. The pump was not energized prior to the pre-seismic leak tests to flush out any residual helium. The pumps were energized after the leak test to verify functionality and the ultimate vacuum levels achieved by each pump were recorded, shown in Table 3-4.

Table 3-3: Pre-seismic test electrical connector leak rates

Connector Type	MS 20-27		MS 28-22		MS 28-12		MS 20-4	
	A	B	A	B	A	B	A	B
Leak rate, scc/s He	1.3E-08	3.8E-08	9.2E-08	2.7E-07	8.4E-08	1.4E-07	2.3E-08	2.1E-08
Change from instillation, scc/s He	-4.70E-08	-4.50E-08	-2.08E-08	-6.40E-07	-6.60E-08	0.00E-08	-1.60E-08	1.00E-08

Max Acceptable Leak Rate: 1.0E^{-6}

Table 3-4: Pre-seismic test pump leak rates and vacuum levels

Pump Model	MB-602	nXDS15iC
Leak rate, scc/s He	3.4E-07	1.9E-08
Change from instillation, scc/s He	3.21E-07	-9.10E-08
Ultimate vacuum, psia	0.86555	0.01717

Max Acceptable Leak Rate: 1.0E^{-6}

3.1.3 Seismic Test

The simulated glovebox and supporting cable tray were loaded onto the seismic table by Curtiss-Wright Nuclear Division personnel and a tri-axial accelerometer was attached. Electrical load wires were connected to the terminal blocks on the cable tray, along with current measurement wires.

Nitrogen gas supply lines were connected to two rotameters, then to the inlet bulkhead ports for the MB-602 and nXDS15iC. Power lines were connected to the pumps but were not energized. Before power was supplied to the pumps or the bulkhead connectors, a resonance test was performed to determine if the simulated glovebox or cable tray exhibited a resonance frequency in the range used for the seismic test, starting at 1 Hz and increasing to 100 Hz. Once the resonance test was completed, power was supplied to the electrical connectors, at levels shown in Table 3-5. The vacuum pumps were energized, then nitrogen gas was supplied to the vacuum pumps at 0.19 liters per minute (LPM) and 1.5 LPM to the nXDS15iC and MB-602, respectively.

The seismic table was then energized and successfully performed two Safe Shutdown Earthquake (SSE) test, with spectra shown in Figure 3-1 to Figure 3-3 for the first SSE test, and Figure 3-4 to Figure 3-6 for the second SSE test. Measurements using the ampere clamps showed that the electrical feedthrough connectors maintained electrical continuity and the glovebox and cable tray remained structurally sound during the seismic test.

Table 3-5: Power supplied to electrical connectors

Wire Gauge	#16	#12	#4
Voltage, Volts	400	400	400
Current, Amps	6.5	6.5	15.38

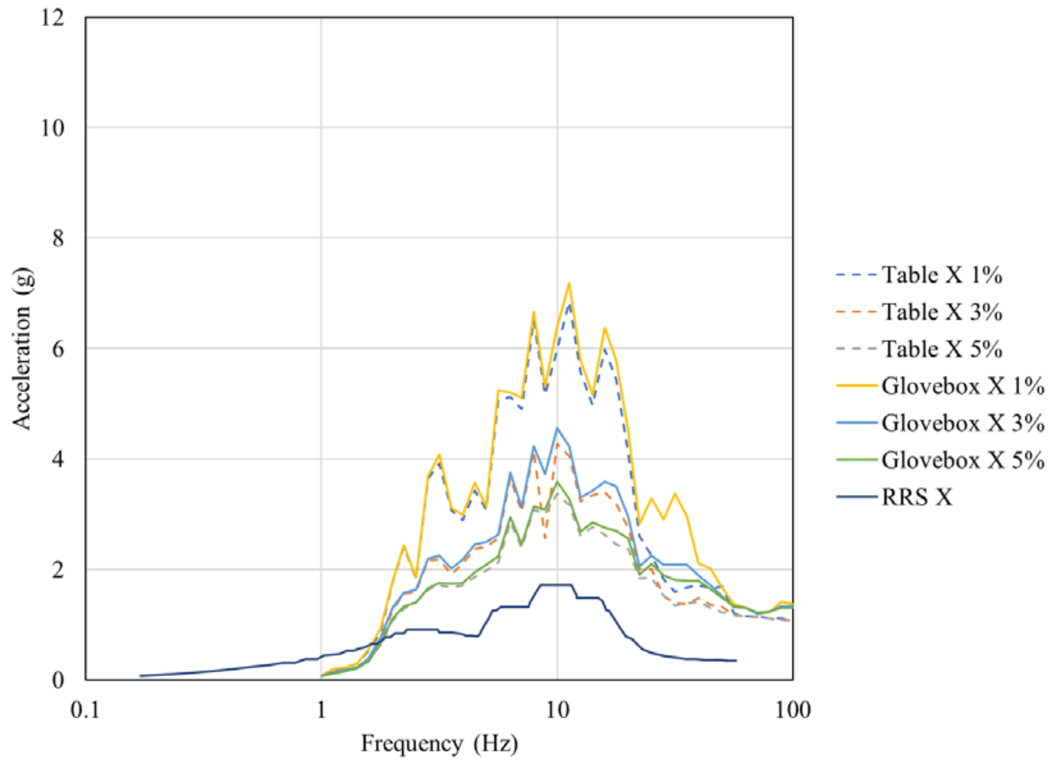

Figure 3-1: SSE Test 1 seismic table and glovebox X-axis acceleration

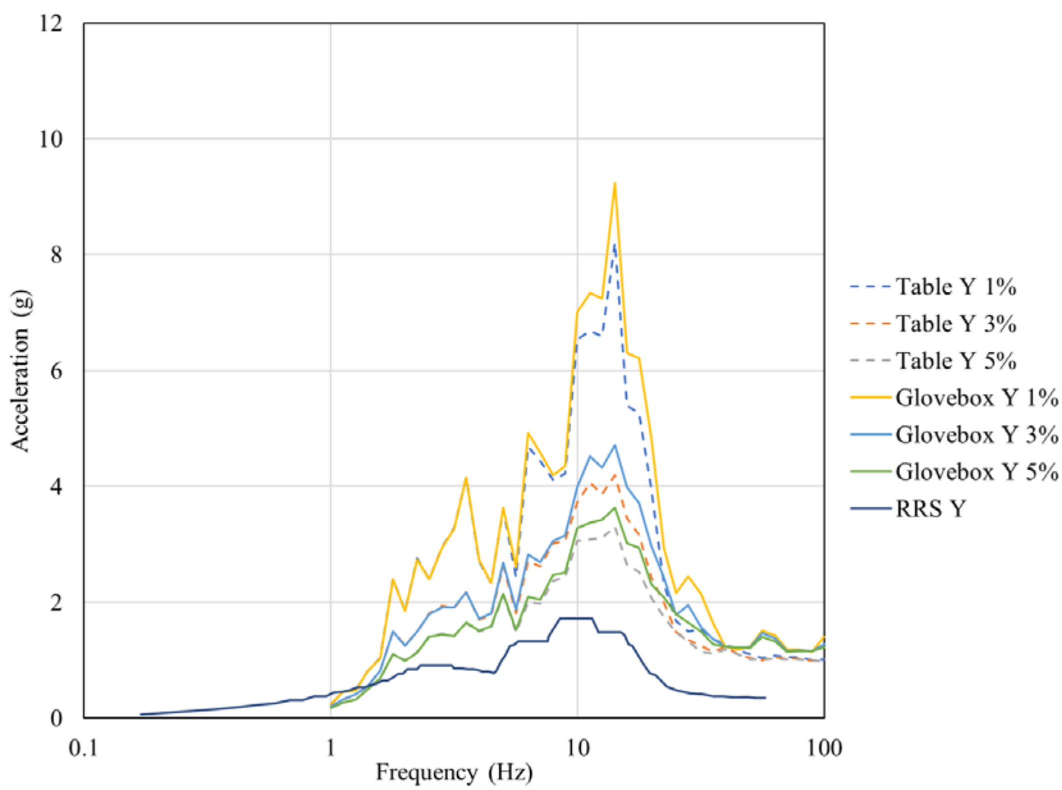

Figure 3-2: SSE Test 1 seismic table and glovebox Y-axis acceleration

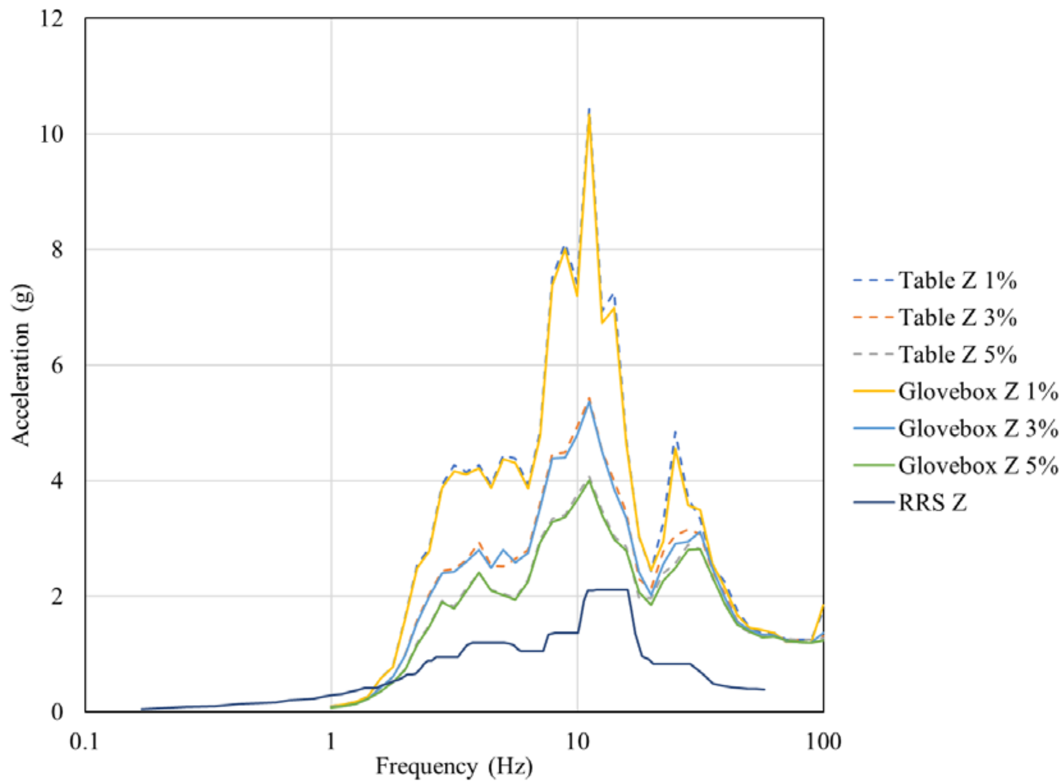

Figure 3-3: SSE Test 1 seismic table and glovebox Z-axis acceleration

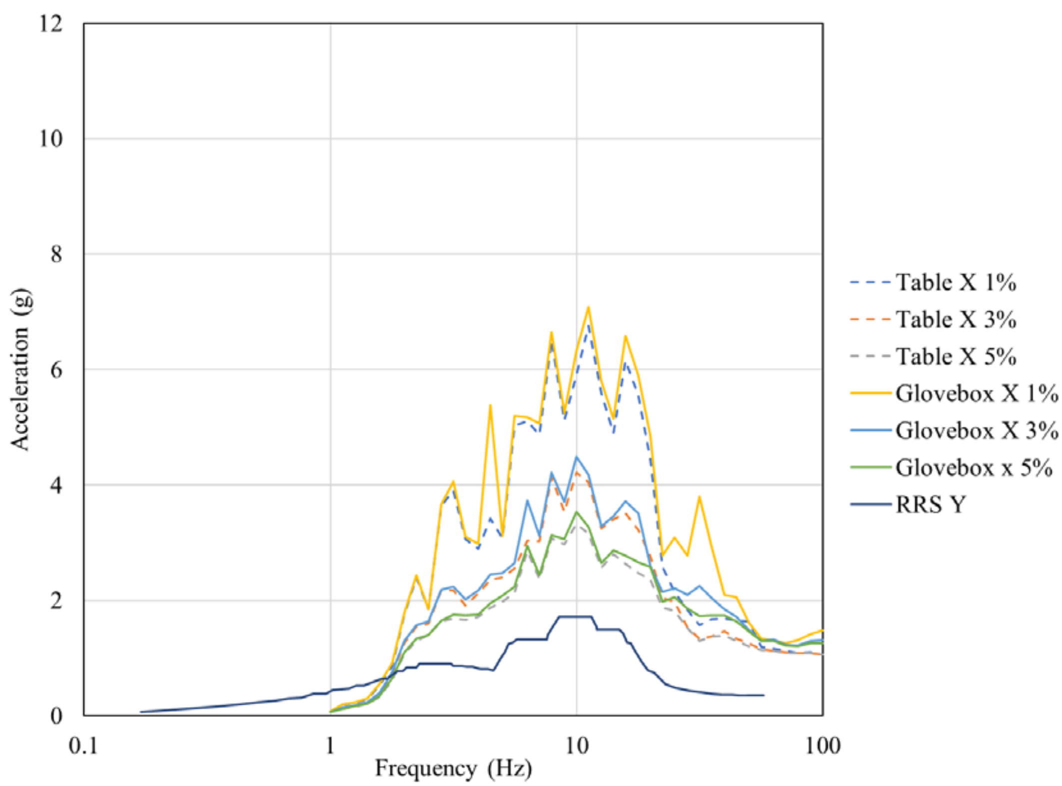

Figure 3-4: SSE Test 2 seismic table and glovebox X-axis acceleration

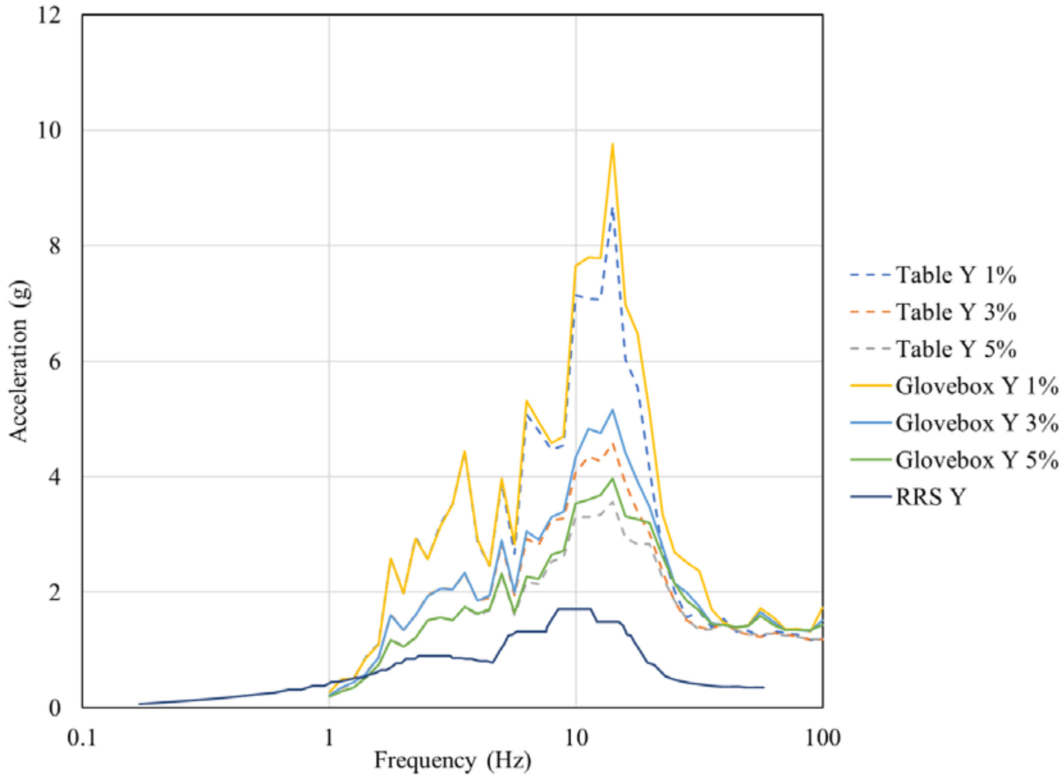

Figure 3-5: SSE Test 2 seismic table and glovebox Y-axis acceleration

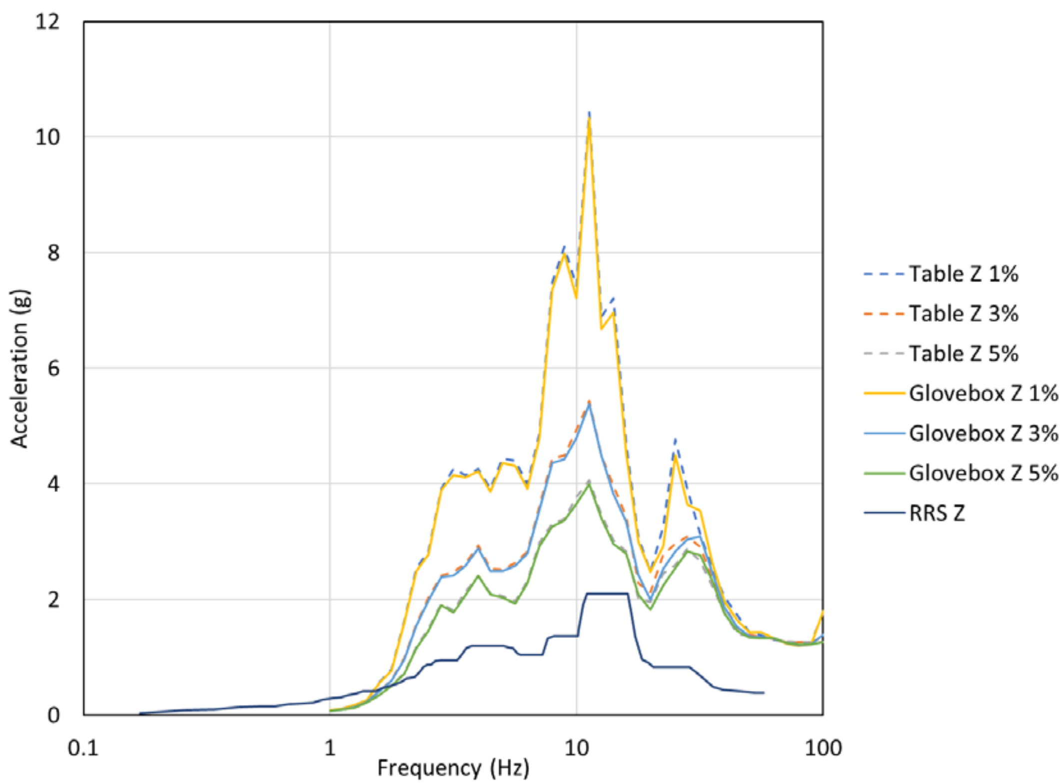

Figure 3-6: SSE Test 2 seismic table and glovebox Z-axis acceleration

3.1.4 Post-Seismic Functionality Tests

Once the seismic test was completed, the simulated glovebox and cable tray were removed from the seismic table. The plugs were disconnected from the electrical connectors and leak tests were performed. All electrical connectors and vacuum pumps successfully passed the leak tests, shown in Table 3-6 and Table 3-7.

It should be noted that the leak rate of the connectors increased in leak rates from the pre-seismic tests. However, when compared to the installation leak rate values, most connectors are still less than the installation leak rate. Two of the connectors, MS 20-27 A and MS 20-4 A, did show an order of magnitude increase in the leak rates. Given that the leak rate is still an order of magnitude less than the acceptance threshold, it is unlikely the glass-filled epoxy potting suffered significant damage.

The connectors are 1.250" diameter (MS 20) and 1.885" diameter (MS 28). Given the surface areas and the number of pins for each connector, an increase of up to 2.11×10^{-7} scc/s He (MS 20-4 A) the leak rates are still very small considering the post-seismic leak rates are still below the requirements specified for new connectors. Any damage to the potting would result in cracks and would have associated leak rates orders of magnitude higher, similar to that of the MS 20-4 connector that failed the installation leak test and was subsequently replaced. The pumps were energized prior to the pump leak tests to ensure functionality and ultimate vacuum levels were recorded for each pump.

Table 3-6: Post-seismic test electrical connector leak rates

Connector Type	MS 20-27		MS 28-22		MS 28-12		MS 20-4	
	A	B	A	B	A	B	A	B
Leak rate, scc/s He	1.6E-07	6.9E-08	1.4E-07	3.5E-07	1.1E-07	1.5E-07	2.5E-07	2.8E-08
Change from pre-seismic, scc/s He	1.47E-07	3.10E-08	4.80E-08	8.00E-08	2.60E-08	1.00E-08	2.27E-07	7.00E-09
Change from installation, scc/s He	1.00E-07	-1.40E-08	-1.60E-07	-5.60E-07	-4.00E-08	1.00E-08	2.11E-07	1.70E-08

Max Acceptable Leak Rate: $1.0E^{-6}$

Table 3-7: Post-seismic test pump leak rates and ultimate vacuum

Pump Model	MB-602	nXDS15iC
Leak rate, scc/s He	1.9E-08	1.1E-08
Change from pre-seismic, scc/s He	-3.21E-07	-8.00E-09
Change from installation, scc/s He	0.00E-08	-9.90E-08
Ultimate vacuum, psia	0.86096	0.00942

Max Acceptable Leak Rate: $1.0E^{-6}$

4.0 Conclusions

A seismic test was performed on Connectronics electrical bulkhead feedthrough connectors, a Senior Aerospace MB-602 vacuum pump, and an Edwards Vacuum nXDS15iC vacuum pump. The test spectra successfully matched the supplied seismic response spectra. The electrical connectors maintained electrical continuity throughout the seismic test, and the vacuum pumps were able to maintain operability throughout the seismic test. The leak tests performed before and after the seismic test did not increase for the vacuum pumps, compared to the installation rates. The leak rates in both tests were well below the max acceptable leak rate of $1.0x10^{-6}$ required for new connectors. The vacuum pumps were able to pump nitrogen gas during the test and maintained similar ultimate vacuum levels after the seismic test.

The results indicate the Edwards Vacuum nXDS15iC is an acceptable alternative to the Senior Aerospace MB-602 in the GBSS. Both pumps were able to maintain functionality during the seismic tests and held ultimate vacuum levels similar to those before the seismic tests were performed.

The results for the Connectronics Corp. electrical feedthrough connectors indicate the leak rate of all the connectors did increase following a DBA earthquake. However, only two out of eight connectors had a higher leak rate after seismic testing than the initial installation leak rate. The leak rates indicate that the glass-filled epoxy potting was structurally sound following the seismic test.

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