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PDRD Project 19039 - All Metal Vacuum Scroll Pump Development for Tritium (U)

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PREFACE OR ACKNOWLEDGEMENTS

Input to this report and support of this effort was provided by various organizations and individuals. Content was enabled by U.S. governmental funding of the effort to identify a 2nd source supplier of an all metal vacuum scroll pump suitable for processing tritium gas at Savannah River Site and other government nuclear facilities located in the U.S. The enabling organizations include the Savannah River Nuclear Solutions Procurement Department, the Savannah River Tritium Enterprise, and the National Nuclear Security Administration. Air Squared Inc., located in Broomfield, CO, an Original Equipment Manufacturer (OEM) of custom vacuum scroll pumps and compressors, is also acknowledged for their technical efforts to develop a suitable, all-metal vacuum scroll pump for processing tritium gas.

EXECUTIVE SUMMARY

Currently the United States relies on a single source, foreign company, Eumeca (formerly Normetex) for the supply of an all metal vacuum scroll pump to process tritium. This "one of a kind", all metal, vacuum scroll pump utilizes no "wetted", polymeric materials that degrade prematurely when exposed to tritium. U.S. based vacuum scroll pump suppliers typically utilize a polymer, Teflon®, as a tip seal material at the edge of the scroll impellers for proper pump function. Teflon® is known to degrade within a relatively short time frame (approximately 1 year) when continually exposed to tritium gas. This degradation results in "flaking" of the Teflon® material which results in particulate contamination of the process gas stream. While filtration of the particulate is possible, doing so requires additional maintenance which is costly in a glovebox environment. In addition, filtration can degrade pumping system performance as particulate collects in the filter media over time.

To date, all of the well established U.S and European based vacuum scroll pump manufacturers have been uninterested in developing an all metal vacuum scroll pump that does not use a polymeric scroll tip seal. This position is taken as the vacuum scroll pump manufacturers do not see a large enough market to make it profitable for them to develop and market an all metal vacuum scroll pump. In the mid 2000s, one company, Air Squared, Inc., a small Original Equipment Manufacturer (OEM) specializing in design and fabrication of custom scroll vacuum pumps and compressors, was willing to pursue the effort. The first design effort incorporated Vespel® as a polymeric tip seal material. Results of this effort led to realizing the affect that the Met-Bel MB-601 metal bellows pump has on performance when used as a backing pump for an all metal vacuum scroll pump without a scroll tip seal. As a result, Air Squared subsequently designed an all metal vacuum scroll pump without a tip seal material for evaluation. Although the initial, all metal version of the Air Squared pump was found deficient in regard to scroll impeller stiffness, which resulted in scroll contact, general design and pump performance was verified to be adequate.

SRS PDRD Project 19039 was launched in 2019 as a 3rd attempt with Air Squared, Inc. in regard to development of an all metal vacuum scroll pump for consideration as an equivalent to the Eumeca/ Normetex pump. The effort specified 300 series stainless steel for the scroll impellers, all metal sealing, and design to meet tritium throughput and ultimate vacuum requirements. In addition, a 60 psig design pressure rating requirement was specified for the pump containment boundary. The 3rd generation Air Squared pump has been designed, fabricated, and has received preliminary testing. Preliminary testing has indicated proper leak tightness and pump performance. However, work continues regarding development of a pumping chamber containment bellows that can be subjected to 66 psig without damage to the bellows. Work will continue in 2020 and 2021 to pursue a pumping chamber containment bellows that meets the pressure rating requirement.

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LIST OF ABBREVIATIONS

CFM	Cubic Feet per Minute
DOE	Department of Energy
OEM	Original Equipment Manufacturer
MIT	Massachusetts Institute of Technology
NNSA	National Nuclear Security Administration
SRNL	Savannah River National Laboratory
SRS	Savannah River Site
SRTE	Savannah River Tritium Enterprise
TEF	Tritium Extraction Facility
VFD	Variable Frequency Drive

1.0 Information/Background

Savannah River Site and other DOE nuclear facilities utilize a pumping train that consists of a Eumeca (formerly Normetex) all metal vacuum scroll pump backed by a Senior Flexonics Metal Bellows MB-601 diaphragm pump. This pumping train combination produces a peak throughput gas flow of 8-9 CFM and an ultimate vacuum pressure of less than or equal to 0.01 Torr. This basic design and pump train configuration is used in both the SRS tritium processing facility gloveboxes as well as the SRS Tritium Extraction Facility (TEF). Both of these pumps are "all metal" in that they do not have any "wetted" materials that are non-metallic and that are exposed to the tritium process gas. Furthermore, the "wetted" materials are also compatible with tritium in that they have low tritium gas solubility, are chemically inert, and do not degrade prematurely when exposed to tritium. The Eumeca all metal vacuum scroll pump, formerly manufactured by Normetex, uses very close scroll impeller clearances, both radially and axially. As such, close machining tolerances and special fabrication methods are needed to achieve the required tight clearances without creating scroll impeller rubbing and interference. In addition, internal design of the Eumeca all metal vacuum scroll pump includes a pumping chamber that is hermetically sealed so that hydrocarbons associated with bearing greases and oils do not contaminate the process fluid. This is accomplished by the use of a shroud and hydroformed bellows for the Eumeca scroll pump and two separate bellows for the Metal Bellows MB-601 diaphragm pump.

During execution of the new Tritium Extraction Facility project at SRS, it was discovered that Normetex, a French company, was considering going out of business and would no longer be producing the Normetex, 9 CFM, all metal vacuum scroll pump. This concern resulted in an effort to identify an alternate supplier for a suitable, all metal, vacuum scroll pump. Rather than to try and design the pump at Savannah River Site, it was decided to research off site suppliers to see if any commercially available pumps existed that would be suitable or if one of the existing vacuum scroll pump manufacturers would be interested in pursuing design and fabrication of an all metal vacuum scroll pump. Research determined that scroll technology was the only vacuum pumping technology that would acceptably meet the tritium processing requirements. It was also determined that the existing vacuum scroll pump manufacturers were not interested in developing an all metal vacuum scroll pump due to limited market demand. One of these manufacturers, Varian/Agilent, stated in 2006 it would cost them 1-2 million dollars to design, market, and produce a new pump product line. Shown below are existing, commercial vacuum scroll pumps that are not all metal (e.g., they contain a polymeric scroll impeller tip seal).

Agilent IDP-15 Dry Scroll Pump
(Teflon Tip Seal, 9 CFM Throughput)

Edwards nXDS15i Dry Scroll Pump
(Teflon Tip Seal, 9 CFM Throughput)

Figure 1-1. Existing, Commercial Vacuum Scroll Pumps

Research done in the mid-2000's identified one company, Air Squared, Inc., located in Broomfield, CO, that did custom scroll vacuum pump and compressor design and fabrication. They were contacted and, as a result, they expressed an interest in pursuing design and fabrication of an all metal vacuum scroll pump. Air Squared's president, Robert Shafer, has a master's degree from MIT in mechanical engineering, did his master's thesis on scroll compressor technology, and was involved with design and development of the very first scroll vacuum pump ultimately manufactured by IWATA. Based on Mr. Shafer's credentials, and since Air Squared was the only company that expressed an interest in the pump development effort, Air Squared was contracted to produce a prototype pump for evaluation.

Part way through the design phase, Air Squared stated that they would have an 80% success rate if Air Squared were allowed to use Vespel® as a scroll impeller tip seal material and a 50% chance of success if they were not allowed to use a scroll impeller tip seal material. After careful consideration and discussions with SRTE engineering and management, and since Vespel® was known to be the best polymer available in regard to degradation resistance when exposed to tritium, it was decided to allow the use of a scroll tip seal made from Vespel®. Initial run-in testing of the 1st Air Squared development pump was performed in January of 2006. This initial testing found that the scroll impellers (fixed and orbiting) were not aligned properly. As a result, "metal to metal" contact was realized by the scrolls. Work was done to realign the scroll impellers and follow up testing was done, despite knowing that there now would be an axial clearance between the scroll impeller tips. Below are pictures of the work at Air Squared in 2006.

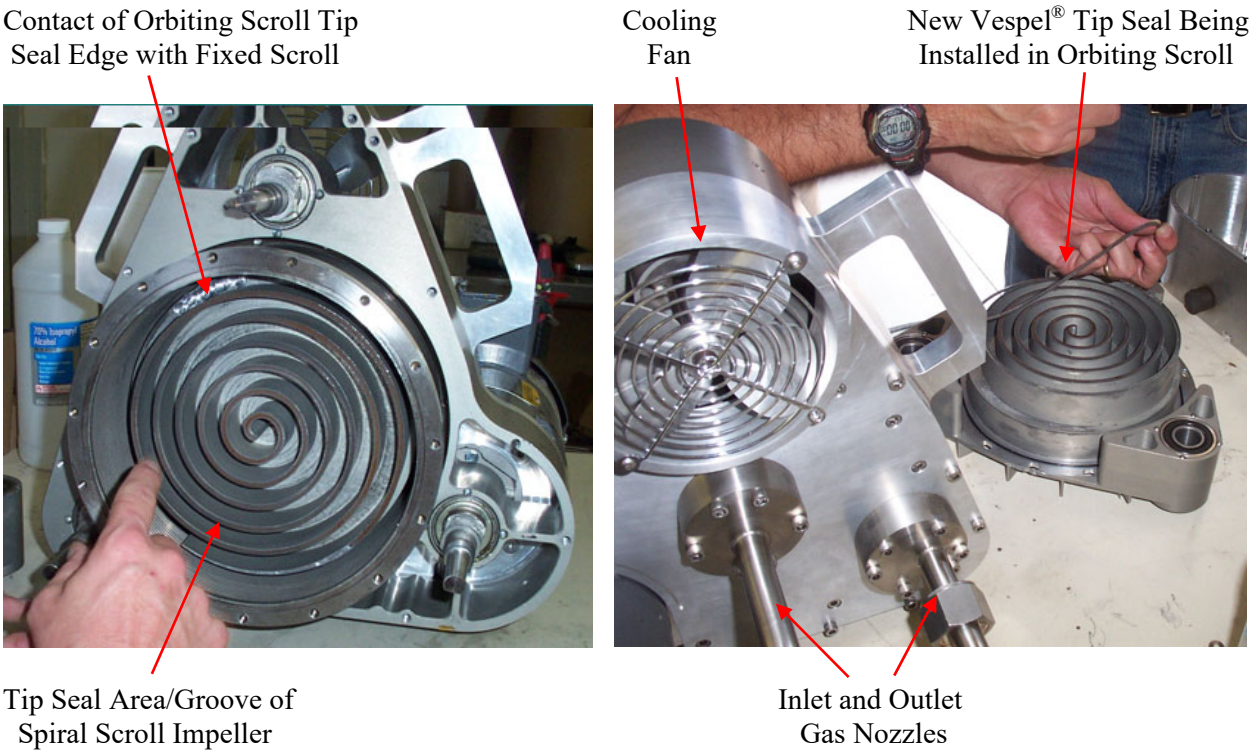

Figure 1-2. Recovery and Reassembly of 1st Air Squared Development Pump

After the installation of new Vespel® tip seals and realignment of scroll impellers, knowing that now there was an axial clearance between the scroll impeller spiral tips, the 1st Air Squared development pump was operated in conjunction with the MB-601 Metal Bellows backing pump. Despite not meeting the pump performance requirements, Robert Shafer of Air Squared was surprised about how well the pump performed when coupled with the MB-601 backing pump regarding ultimate vacuum and pumping speed. Based on this, Air Squared became more confident in designing an all metal vacuum scroll pump to meet the tritium application requirements and gained an appreciation of the effect that the Metal-Bellows MB-601 backing pump would have on overall pumping performance.

Later in 2006, Air Squared was contracted to design an all metal vacuum scroll pump without tip seals for consideration as an equivalent to the 9 CFM Normetex scroll pump. This design was completed and included 300 series stainless steel scroll impellers, all metal sealing to meet a less than 1x10E-7 std cc/sec helium leak rate, no polymeric tip seals, a pumping chamber containment bellows to prevent process fluid contamination, and external geometry to facilitate ease of installation in the SRS tritium facility gloveboxes. At that time it was learned that Normetex would not be going out of business and would continue to fabricate the 9 CFM Normetex all metal vacuum scroll pump. For this reason, fabrication and evaluation of a 2nd generation Air Squared development pump was not pursued. However, in 2015 Normetex reversed its decision and decided to go out of business. Plans were in place for a secondary company, Eumeca, to be formed that would produce the Normetex all metal vacuum scroll pump using personnel and resources obtained from Normetex. With that known, SRTE management decided to continue with the effort to have Air Squared to fabricate a 2nd generation development pump.

The effort to restart the all metal pump development effort began with a review of the work done in 2005 and 2006. Much of the 2005-2006 effort was repeated and led to essentially the same conclusion, that scroll pumping technology was the only vacuum pumping technology suitable to produce the required tritium pumping characteristics and to meet the application requirements. In addition, work was done in 2016 in an attempt to fabricate workable tip seals made from aluminum bronze, rather than Teflon®, for retrofitting in existing, commercial vacuum scroll pumps. This effort yielded some promising, yet inconsistent results. It was determined that the success rate would be 50% at best in replacing the Teflon® tip seals with tip seals made from aluminum bronze. For this reason, retrofitting existing, commercial vacuum scroll pumps with aluminum bronze tip seals was determined not to be practical.

The effort to have Air Squared fabricate a 2nd generation development pump based on the 2006 design started with a review of the 2006 pump design. As directed by SRTE engineering, and as agreed up by Air Squared, the scroll impeller material, for at least one of the scrolls, was changed from stainless steel to aluminum bronze. Fabrication and acceptance testing at Air Squared resulted in adding additional shims between the scrolls to prevent metal to metal scroll contact. Once a theoretical "sweet spot" was found in regard to shimming and scroll clearance, the pump was performance tested at Air Squared and found to meet the general performance requirements. However, after receipt and during initial run-in testing at SRS, unacceptable scroll "rubbing" and interference was encountered during operation. Efforts to repair and rework the pump were not made as feedback from Air Squared was that the pump design was insufficient in regard to scroll stiffness as well as thermal management to prevent thermal growth and scroll contact issues. Below is a picture of the 2nd generation Air Squared development pump as found during disassembly after "rubbing" had occurred.

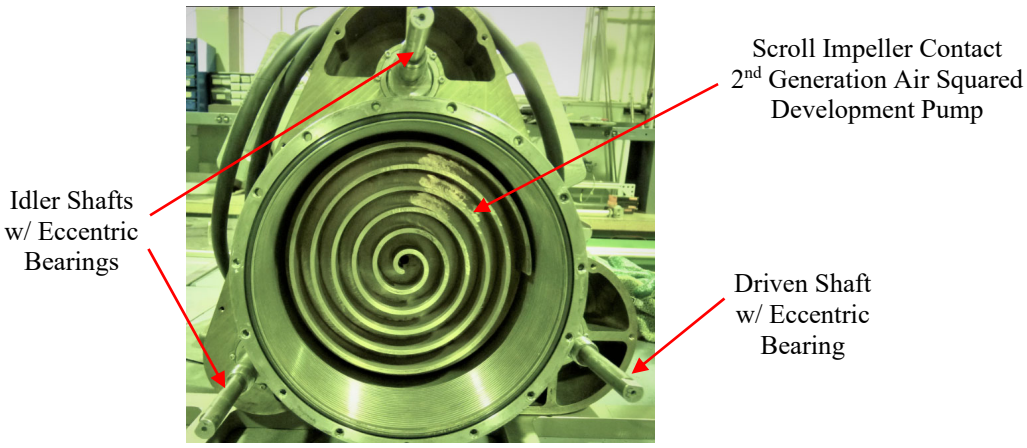

Figure 1-3. 2nd Air Squared Development Pump

The remainder of this report will discuss what has been done regarding PDRD Project 19039 which began in 2019 and concluded in 2020. It will discuss Results and Conclusions and will make Recommendations in regard to achieving success in realizing an alternative supplier of an all metal vacuum scroll pump considered equivalent to the Normetex (now Eumeca) all metal vacuum scroll pump for processing tritium gas at the DOE nuclear facilities in the United States.

2.0 Experimental Procedure

The nature of this PDRD project does not lend itself to an experimental procedure. R&D Directions were written for operation of the SRS Pump Test Rig so that the test system would be operated properly and safely so as to not jeopardize personnel safety or equipment condition during testing.

3.0 Results and Discussion

PDRD Project 19039, All Metal Vacuum Scroll Pump Development for Tritium, began with initiation of a procurement for design and fabrication of a 3rd generation Air Squared development pump. Requirements of the procurement specification included austenitic stainless steel scroll impellers, all metal sealing to meet a required 1x10E-7 std cc/sec Helium leak rate, a pumping chamber containment bellows to ensure bearing greases and hydrocarbons do not contaminate the process fluid, a less than 0.01 Torr ultimate pressure when pumping with a 30 Torr exhaust pressure, and a pumping speed curve similar to the Eumeca (formerly Normetex) pump, including a 9 CFM peak flow rate, when backed by a Metal Bellows MB-601 diaphragm pump. The procurement included a design phase whereby a design description and outline drawings were submitted to provide evidence of specification compliance. Once the design submittal was approved, work was done by Air Squared to procure the required materials and fabricate the necessary components required for assembly. This included a pumping chamber containment bellows to hermetically seal the pumping chamber from oils and greases associated with the pump bearings, etc. It should be noted that the pumping chamber containment bellows is made from nickel and is fabricated using an electroforming process. This process involves electroplating nickel onto a mandrel and dissolving the mandrel "away" using an acid. The pumping chamber bellows was fabricated by Servometer, a renowned manufacturer of electroformed nickel bellows. It should be noted that the electroformed bellows, which is roughly 8 inches in diameter, can take as long as 6 months to fabricate.

Fabrication and assembly of the 3rd generation development pump was completed in the fall of 2019 and preliminary testing was performed by Air Squared. During this testing, operational testing and pressure testing was performed on one of the two pumping chamber bellows fabricated for the project. While the bellows performed well operationally, pressure testing of the pumping chamber bellows to the required 66 psig pressure resulted in bellows deformation inside the test pump at a pressure of 50 psig. A picture of the bellows in the test pump before and after pressure testing and deformation is shown below.

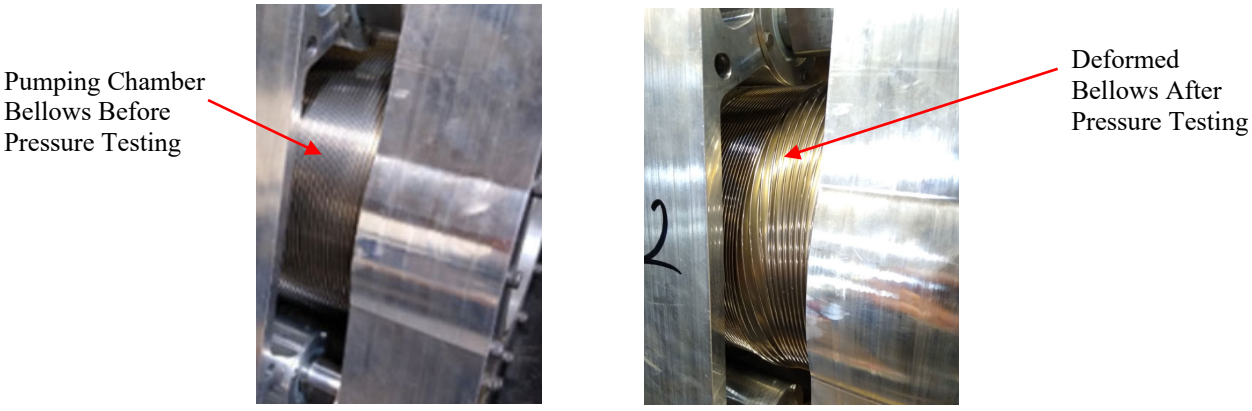

Figure 3-1. 3rd Generation Pump, Bellows Before and After Pressure Testing

Despite a pumping chamber bellows that didn't meet the pressure rating requirement, it was decided to move forward and performance test the 3rd generation Air Squared pump to verify proper pumping performance and leak tightness when backed by the Metal Bellows MB-601 pump. This testing was done with the 2nd spare bellows that was fabricated by Servometer and installed in the pump. In parallel, Air Squared would pursue development of a higher pressure rated bellows with Servometer. Preliminary testing at Air Squared using the Air Squared test system indicated that performance requirements would be met. Based on preliminary test results, representatives from SRS visited the Air Squared in Broomfield, CO to witness testing in accordance with the procurement specification. In addition, in order to validate results obtained from the Air Squared pump test system against the SRS pump test system previously fabricated to evaluate candidate pumps, the SRS pump test stand system was shipped to Air Squared. This allowed testing to be done both on the Air Squared and SRS pump test stands for comparison purposes. Below are pictures of the original, Normetex/Eumeca vacuum scroll pump and of the 3rd generation Air Squared development pump. Pictures of the Air Squared and SRS pump test stands are shown on the next page.

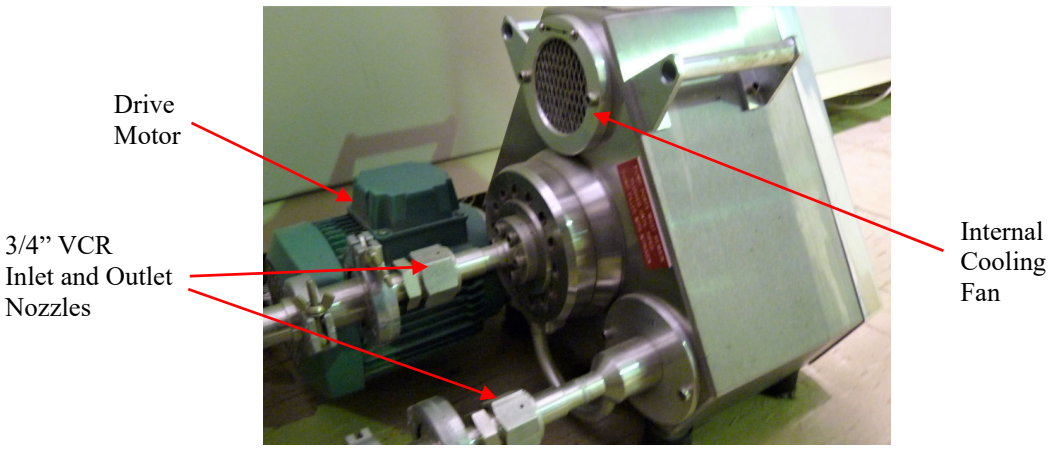

Figure 3-2. Normetex/Eumeca 9 CFM All Metal Vacuum Scroll Pump

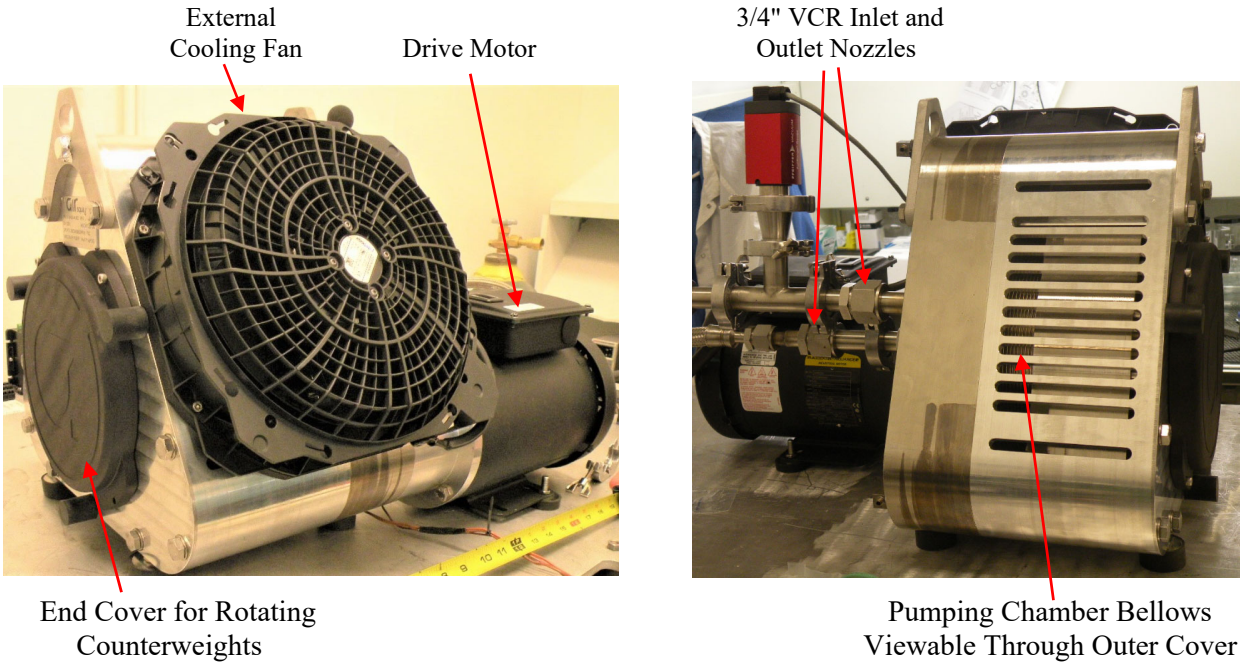

Figure 3-3. 3rd Generation Air Squared All Metal Vacuum Scroll Pump

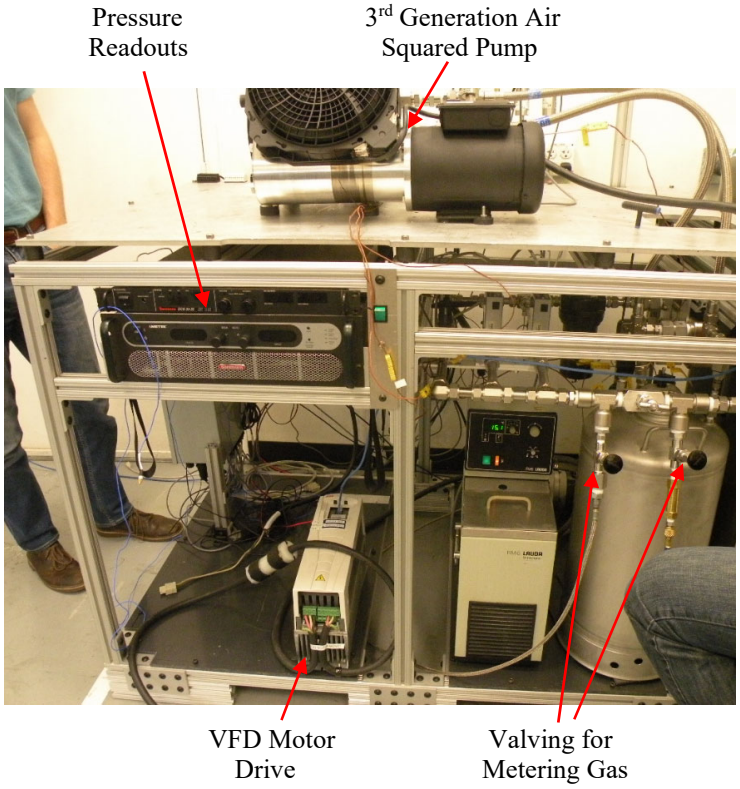

Figure 3-4. Air Squared Pump Test Stand

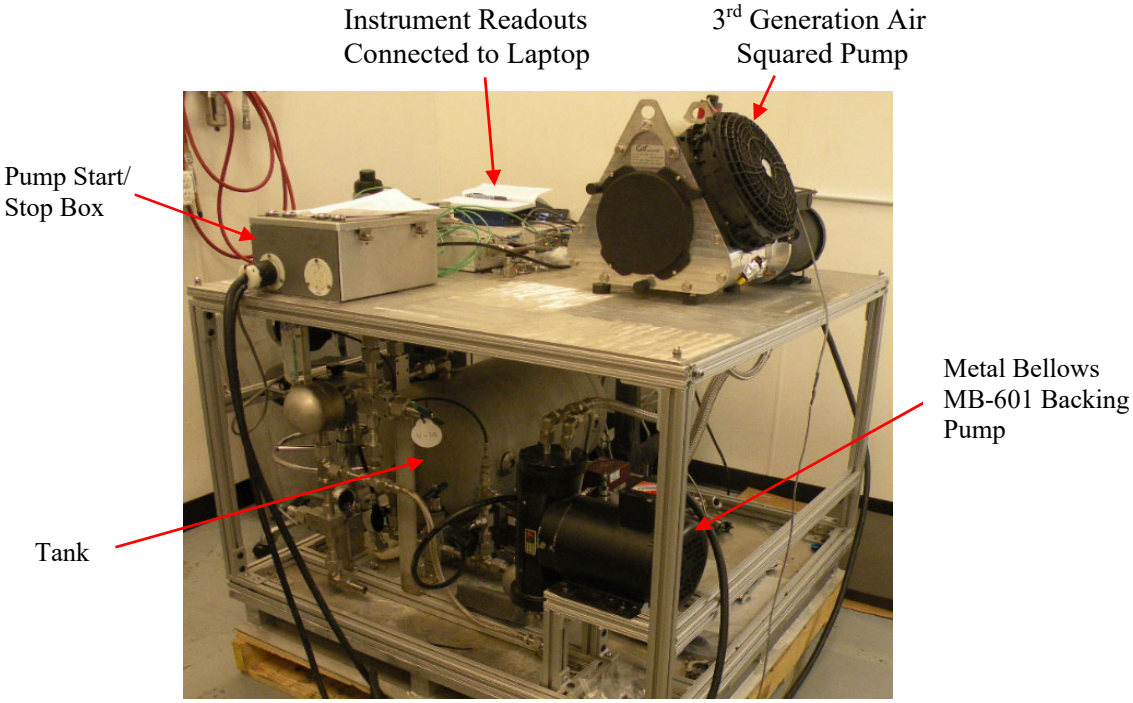

Figure 3-5. SRS Pump Test Stand

The main difference between the Air Squared pump test stand and the SRS pump test stand is that the Air Squared pump test stand uses a certain amount of gas that is metered into the system and manual valves are adjusted to create certain back pressures on the discharge of the all metal vacuum scroll test pump. Pump inlet and exhaust pressures are measured by transducers and flow rates are measured by calibrated mass flow meters. A Senior Flexonics Metal Bellows MB-601 pump is not part of the test system and system tubing is somewhat small in diameter. In contrast, the SRS pump test uses a Metal Bellows MB-601 backing pump and tank of a known volume. The SRS pump test stand utilizes prototypic tubing sizes, valves, and filters. Flow rate is calculated based on measuring pressure change from the tank over time and using the ideal gas law. Using the SRS pump test system, pump down time from the tank can be determined as well as pumping speed verses pump inlet pressure and ultimate vacuum created at the inlet to the test pump and in the tank. Below and on the following pages is the original flow rate vs inlet pressure curve generated for the Met-Bel/Normetex pumping train, the baseline flow and ultimate vacuum curves generated using a spare Normetex pump at SRS in 2019, and the pump and ultimate vacuum curves for the Air Squared 3rd generation development pump generated in December of 2019.

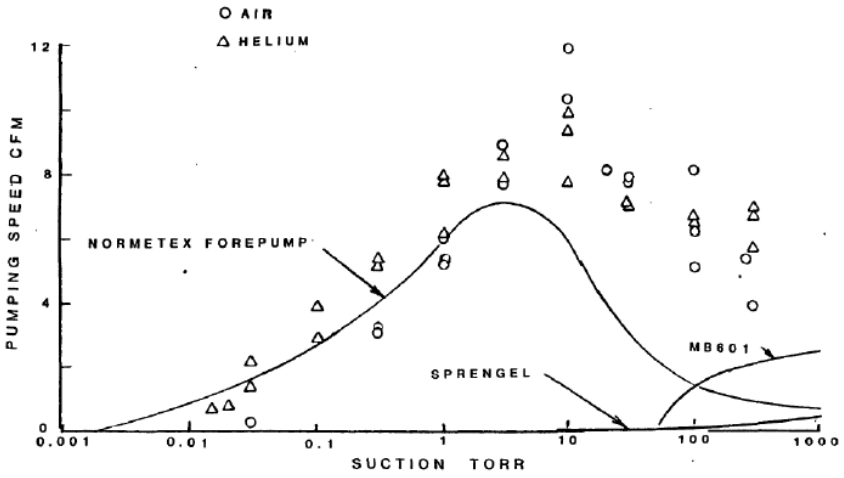

Figure 3-6. Normetex Pumping Speed vs. Inlet Pressure

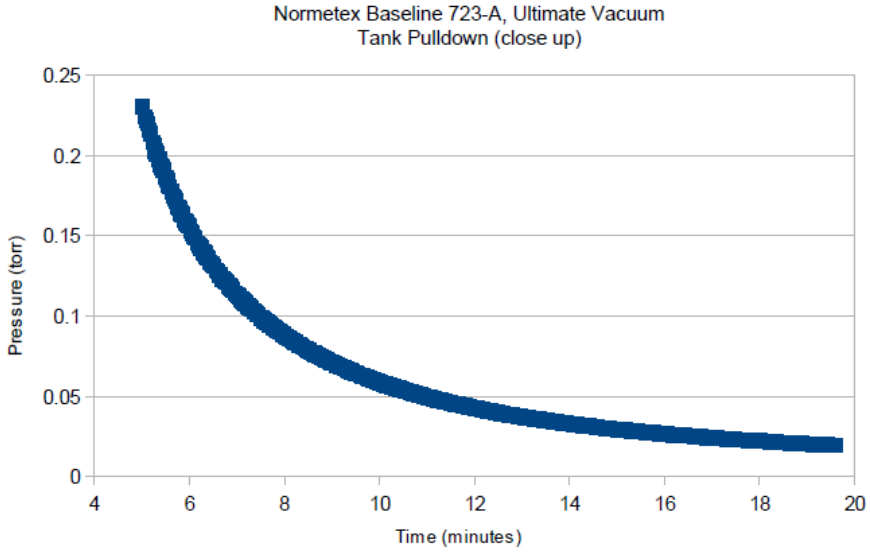

Figure 3-7. Baseline Normetex Ultimate Vacuum – Pulldown Time

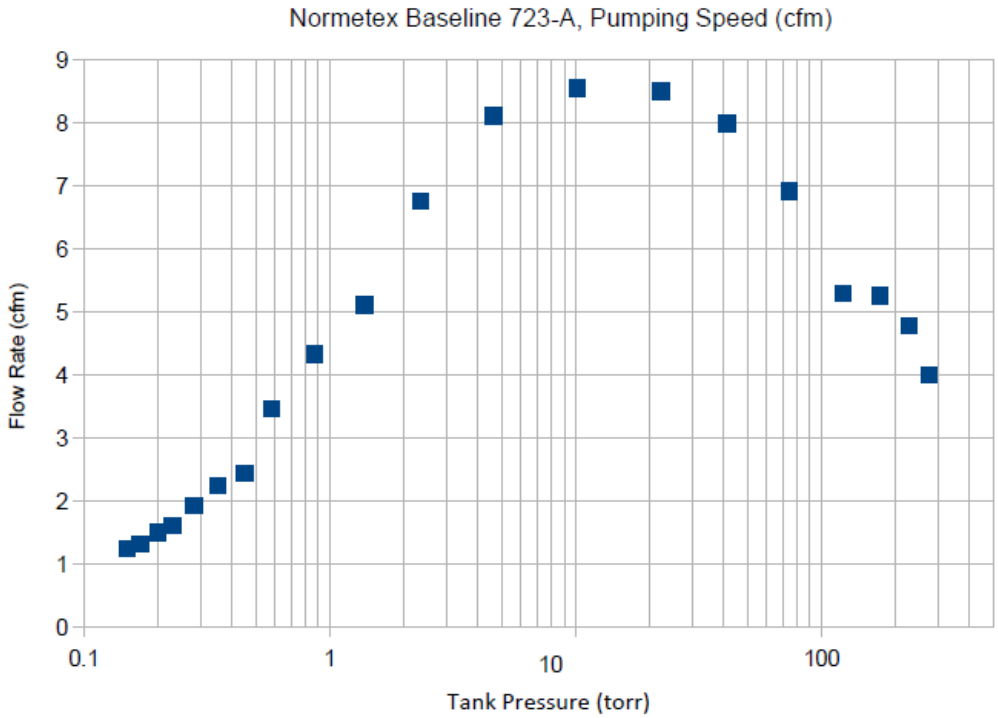

Figure 3-8. Baseline Normetex Pumping Speed (backed by MB-601 pump)

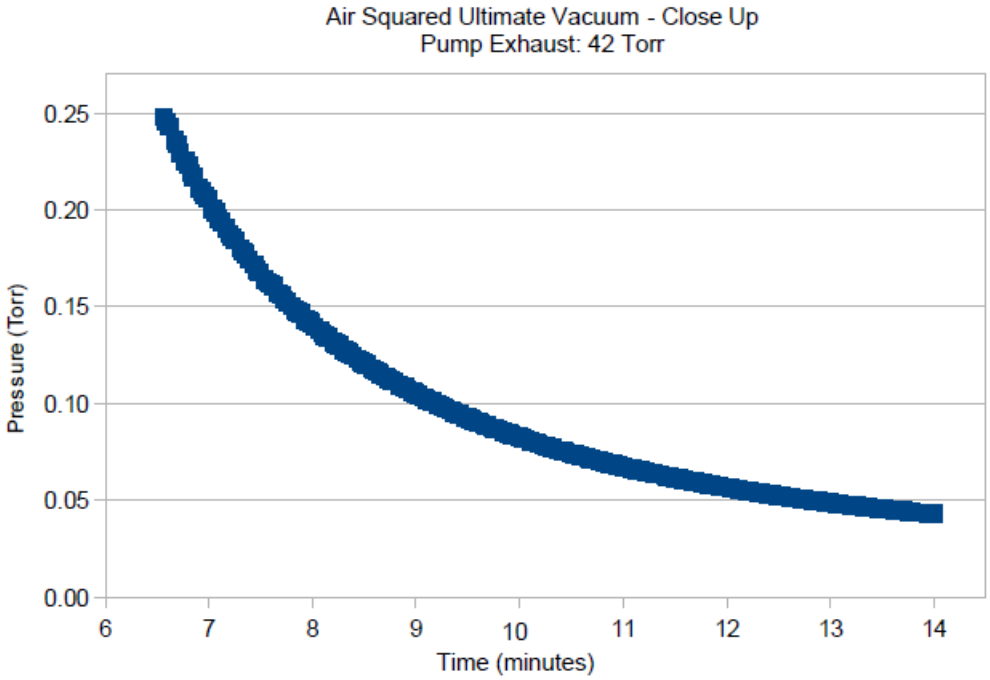

Figure 3-9. Air Squared Pump Ultimate Vacuum (42 Torr Exhaust Pressure)

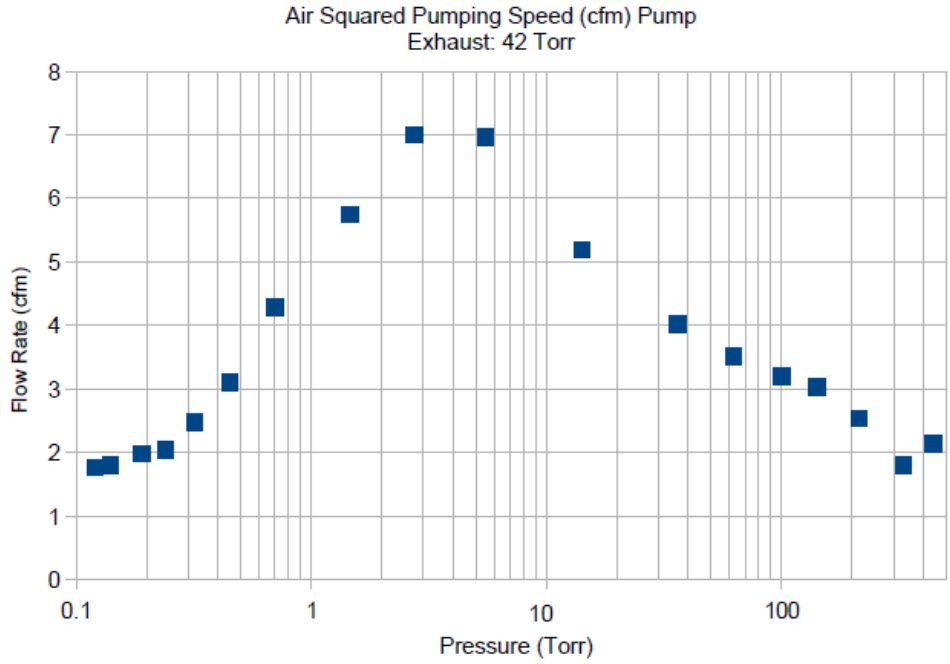

Figure 3-10. Air Squared Pumping Speed (42 Torr Exhaust Pressure)

Inspection of the pumping curves and ultimate vacuum curves indicate that the 3rd generation Air Squared all metal vacuum scroll development pump peak throughput is about 1-1.5 CFM less than the 8-9 CFM pumping curve peak of the Eumeca (formerly Normetex) all metal vacuum scroll pump when backed by the Metal Bellows MB-601 diaphragm pump. In addition, ultimate vacuum and pump down time appears to be higher for the Air Squared 3rd generation pump in that roughly 0.04 Torr ultimate vacuum was achieved (vs 0.02 Torr for the Eumeca/Normetex pump) and it took roughly 13 minutes (vs 11 minutes) to achieve a 0.05 Torr inlet pressure when pumping from the SRS pump test rig tank. It should be noted that a complete evaluation of the Air Squared 3rd generation development pump has not yet been completed as work is still being done to develop a higher pressure rated pumping chamber containment bellows. Figures 3-7 thru 3-10 were generated using the SRS pump test stand. Figures 3-7 thru 3-8 were generated during baseline testing at SRS which is roughly 550 feet above sea level. Figures 3-9 thru 3-10 were generated in Broomfield, CO, roughly 5400 ft above sea level. It is believed that the elevation difference could be the reason for peak flow and ultimate vacuum differences when testing at Air Squared in Colorado verses baseline testing at SRS. In addition, pump curves generated by Air Squared in December of 2019 using the Air Squared pump test stand, with SRS representatives in attendance, showed a peak pumping curve closer to 8 CFM and an ultimate vacuum closer to 0.03 Torr. It should be mentioned during preliminary testing at Air Squared in 2019, indications were that the SRS pump test rig, with the Air Squared 3rd generation pump installed, may not have been as leak tight as was achieved at SRS during baseline testing of the spare Normetex pump (Figures 3-7 and 3-8). This was most likely due to the short time duration (one week) allotted at Air Squared to assemble the SRS test rig as part of preliminary acceptance testing of the 3rd generation pump. In addition, in December of 2019 it would have been prudent to ship the spare SRS Normetex pump to Air Squared for a performance comparison with the 3rd generation Air Squared pump with both pumps being evaluated on the Air Squared pump test stand. This is being considered for upcoming work in 2020 and 2021. While achieving an ultimate vacuum of 0.01-0.02 Torr when backed by the Metal Bellows MB-601 diaphragm pump is a true requirement, it should be noted that something less than a 9 CFM peak pumping curve peak (e.g., 8 CFM) is considered acceptable as long as the time it takes to pump tritium gas from one tank to another in the facility does not cause lengthy, unacceptable delays in the processing operations.

4.0 Conclusions

Although significant progress was made from 2006 to 2020, development of an alternate supplier of an all metal vacuum scroll pump that can be considered equivalent to the Eumeca/Normetex vacuum scroll pump has yet to be achieved. Efforts to date have centered around collaboration with Air Squared, Inc., a custom scroll vacuum pump and compressor manufacturer located in Broomfield, CO. Development of an all metal vacuum scroll pump, without polymeric scroll impeller tip seals, is a challenge in that specialized machining methods and close machine tolerances are needed to achieve the scroll impeller geometry and required scroll clearances to produce a functioning pump. Air Squared, to date, has produced three prototype, development pumps, with the most recent pump being nearly acceptable for the SRS tritium processing application. It should be noted that the Air Squared design is different than the Normetex/Eumeca scroll pump design in that Normetex/Eumeca pump design utilizes a pumping chamber "shroud" and smaller diameter bellows to achieve the required hermetic sealing. This is in contrast to the Air Squared pump design that does not incorporate a shroud but rather a large, electroformed bellows that completely surrounds the pumping chamber to achieve the required hermetic sealing. It should also be mentioned that the 3rd generation Air Squared development pump, with stainless steel scroll impellers, weighs 200 lbs verses 150 lbs for the Eumeca/Normetex pump. Remaining work with Air Squared includes development of a pumping chamber containment bellows that can be subjected to 66 psig without damage or deformation. In addition, additional work is needed to verify performance of the 3rd generation Air Squared development pump both at Air Squared using the Air Squared pump test stand and by full evaluation and testing of the 3rd generation Air Squared pump at SRS using the SRS pump test stand system.

5.0 Recommendations, Path Forward and Future Work

Development of an alternate supplier of a reliable all metal vacuum scroll pump that can be considered equivalent to the Normetex (now Eumeca) all metal vacuum scroll pump for processing tritium is important in regard to maintaining tritium processing capability to meet United States defense needs. The transition from Normetex to Eumeca has been relatively successful with some growing pains encountered during the transition. With that said, it is still considered important to have at least one additional source for this unique, all metal vacuum scroll pump that the Department of Energy relies upon for tritium gas processing. The following are recommendations going forward regarding the pump development effort.

- Continue to work with Air Squared, Inc. regarding development of a pumping chamber containment bellows that functions properly and that can be rated for a 60 psig design pressure. In addition, perform the work necessary to properly evaluate performance of the 3rd generation Air Squared development pump against the procurement specification requirements.
- If it is determined that an acceptable pumping chamber bellows rated for a 60 psig design pressure cannot be achieved, do the testing work necessary to establish a pump design pressure rating (estimated to be 40 or 45 psig) for the existing pumping chamber containment bellows in addition to evaluation of proper pumping performance. In parallel, research those SRS tritium facility locations and processes where the Eumeca/Normetex pumps are installed to determine if and how many of the locations require a 60 psig pump design pressure rating and if a 40 or 45 psig design pressure pump would be acceptable as some of the locations.
- Should continued work with Air Squared to develop an appropriate pump not realize success, consider an effort, either using SRS on site resources and/or off site machine design/vacuum scroll pump design resources, to "re-engineer" the Normetex/Eumeca pump in an attempt to establish a United States based manufacturer capable of producing an all metal vacuum scroll pump equivalent to the Eumeca/Normetex vacuum scroll pump in regard to form and performance.

6.0 References

M-SPP-H-00544, Rev. 0, Tritium High Vacuum Pump for Defense Programs

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