Pacific Northwest NATIONAL LABORATORY

PNNL-36268

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August 2024

Bradley G. Fritz
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U.S. DEPARTMENT OF ENERGY

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

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Pacific Northwest National Laboratory
Richland, Washington 99354

Summary

A series of multi-physics experiments, referred to as Physics Experiment 1 (PE1) is underway at the U.S. Nevada National Security Site. The PE1 series includes detonations of three underground chemical explosions. As the name implies, there are a number of experiments investigating the signals generated by the explosion. The experiment series objectives are outlined in a report from Lawrence Livermore National Laboratory.[1]

Part of the experiment series included gas migration studies. Gas tracers were embedded in the explosives and gas sampling boreholes were installed in the formation in the test bed. Connected to the boreholes is a circulation system that moves gas to a central measurement location.

This report does not describe the gas analysis or collection systems, but rather the circulation system that provides the gas for measurement. Here, we have combined parts of four project documents into a single report that describes the design, build, installation, testing, and operation of the gas sampling system.

This Low Yield Nuclear Monitoring (LYNM) research was funded by the National Nuclear Security Administration, Defense Nuclear Nonproliferation Research and Development (NNSA DNN R&D). The authors acknowledge important interdisciplinary collaboration with scientists and engineers from LANL, LLNL, NNSS, PNNL, and SNL.

[1] S. C. Myers, G. Abbott, T. Alexander, E. Alger, A. Alvarez, N. Annabelle, T. Antoun, G. Auld, A. Malach, H. Banuelos, M. Barela, T. Barnhart, P. Barrow, T. Bartlett, A. Bockman, M. Bodmer, K. Bogolub, J. Bonner, R. Borden, H. Boukhalfa, D. Bowman, C. Britt, B. Broman, S. Broome, B. Brown, J. Burghardt, D. Chester, C. Choens, K. Chojnicki, A. Churby, J. Cole, T. Coleman, J. Collard, A. Couture, G. Crosby, A. Cruz-Cabrera, D. D'Saint Angelo, M. Dea, W. Dekin, B. DeVisser, M. Dietel, C. Downs, N. Downs, E. Dzenitis, E. Eckert, S. Eras, G. Euler, S. Ezzedine, J. Fast, J. Feldman, K. Featherston, M. Foxe, C. Freimuth, B. Fritz, G. Galvin, S. Gamboa, L. Garner, T. Gascoigne, J. Gastelum, et al. 2024. A multi-Physics Experiment for Low-Yield Nuclear Explosion Monitoring. LLNL-TR-864107, Laurance Livermore National Laboratory.

Acronyms and Abbreviations

AWG	American wire gage
DAQ	data acquisition system
DOE/NNSA	Department of Energy National Nuclear Security Agency
EPDM	ethylene propylene diene monomer rubber
HE	high energy
ID	internal diameter
IDAQ	Integrated Data Acquisition System
LANL	Las Alamos National Laboratory
LLNL	Laurence Livermore National Laboratory
LYNM	Low Yield Nuclear Monitoring
MSTS	Mission Support and Test Services
NPT	national pipe thread
OD	outside diameter
PE-1	Physics Experiment 1
PFA	perfluoroalkoxy alkane
PNNL	Pacific Northwest National Laboratory
PSI	pounds per square inch
PSIA	pounds per square inch absolute
PSIG	pounds per square inch gage
PDR	preliminary design review
PVC	polyvinyl chloride
RH	relative humidity
SME	subject matter expert
SNL	Sandia National Laboratories
SS	stainless steel
VAC	voltage – alternating current
VDC	voltage – direct current
VOC	volatile organic compound

<u>Units</u>

Hz	hertz
°C	degrees Celsius
L	liters
mA	milliamps
A	amps
V	volts
ft	feet
gal	gallons
min	minutes
m	meters
µm	micrometer
W	watts

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Figures

Tables

Chapter 1 – As-Built Design Package: *Borehole Gas Delivery System*

Executive Summary

The gas delivery system circulates gas from the eight borehole sampling zones in the gas boreholes and the three tunnel environment sampling locations down the drift and through various measurement and collection instrumentation. The system then returns the gas to each sampling zone, resulting in a closed-loop system. This document provides detailed information on the design, fabrication, installation, and operation of this system. The intent of this document is to provide sufficient information to reproduce or improve upon this system for future tests. Due to the relative complexity of the borehole gas delivery system (and the large number of components), only the key portions of the system are detailed in the main body of this report. More detailed design information can be found in the appendices.

List of Appendices

While the body of this report covers the fundamental design elements, most of the detail is contained in the appendices. These appendices cover a variety of details concerning parts, procedures, testing, and checklists.

Appendix A – System Overview
Appendix B – Parts list and Component Data Sheets
Appendix C – Water Trap Design
Appendix D– Electrical Power Description
Appendix E – Data Acquisition pin –to –pin connection tables
Appendix F – Calibration of Sensors
Appendix G – Tubing Installation Procedure
Appendix H – Dual Packer Assessment
Appendix I – Permeability Test Example

1.0 Gas System Description

The gas boreholes and gas delivery system are the backbone of the gas migration phase of the PE-1 experiment. The gas delivery system moves gas from the sampling locations within each gas borehole and within the tunnel environment to the various measurement and collection systems. The system then returns the gas to the borehole, resulting in a closed-loop system that minimizes perturbations to the gas transport. This section provides a moderately detailed description of the system, with additional details captured in the Appendices.

1.1 Boreholes

1.1.1 Packer Assembly

The packer assembly isolates the borehole sample collection zone from the grout during completion and provides a rigid structure for mounting sample supply and return lines. Figure 1 shows photographs of the packer assembly used for each gas borehole. The sampling interval contains three ports: the sample inlet, the sample return, and the pressure measurement line (Figure 1). Additionally, a thermistor is installed in the sampling interval for temperature measurement, and an unused center passthrough provides a rigid stop and support in the sampling interval. All five lines that pass through the packer are welded, swaged, and capped. For up-going boreholes, a single packer was used to isolate the sampling zone from the grouted interval, while for down-going holes a dual packer system was used. The dual packer system resulted in an air gap between the sampling interval and the grouted section; this gap helped ensure that grout did not impact the sampling interval for down-going boreholes. Additional details are captured in the borehole completion report (Chapter 2).

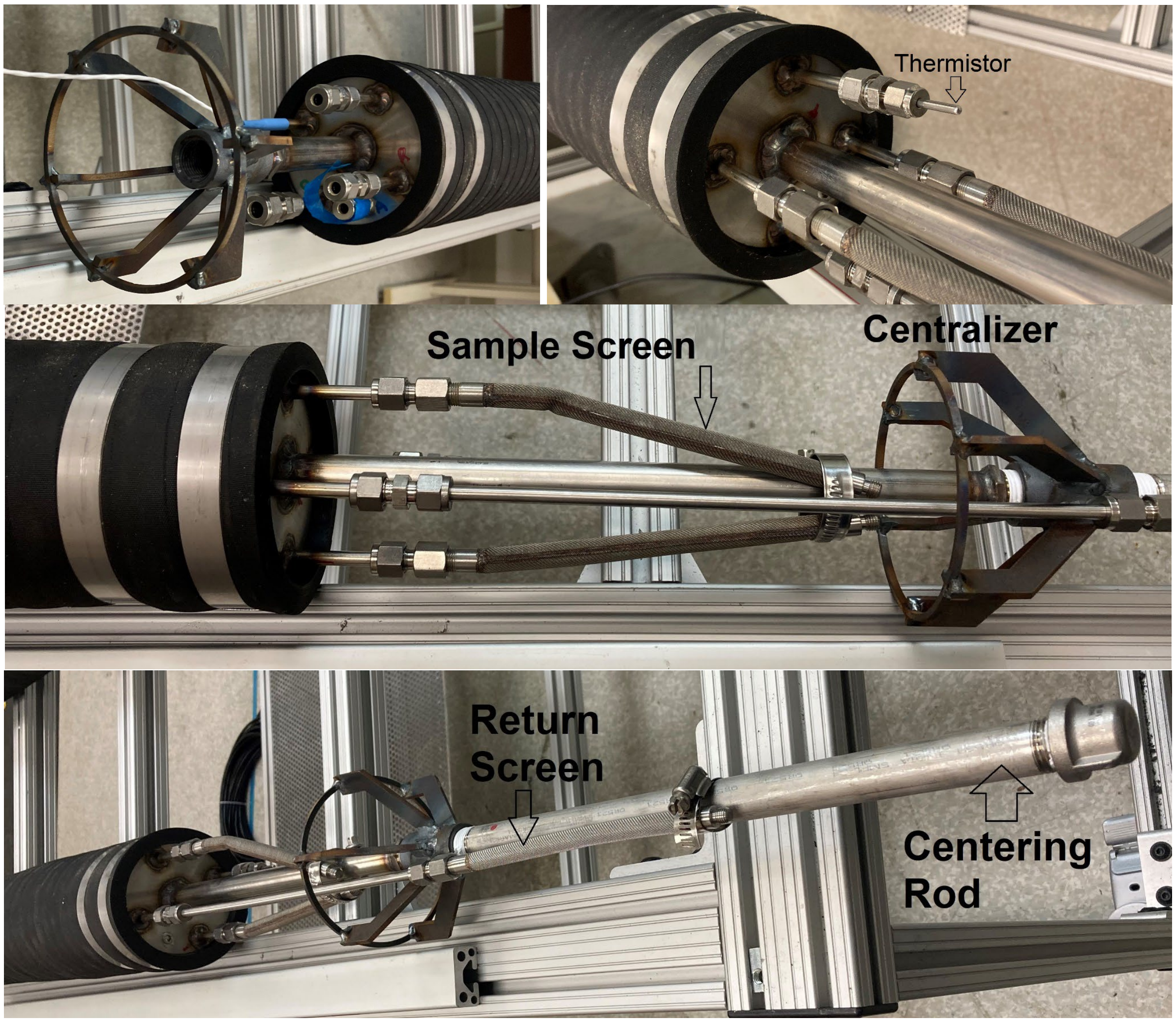


Figure 1. Borehole packer pictures.

1.1.2 Thermistor

A temperature probe extension cable was spliced onto the thermistor cable on the grouted side of the packer. The splice was made in the lab prior to shipment and used water-proof heat-shrink solder-filled butt slices. The splices were covered with a larger heat shrink and the entire splice filled with epoxy. The temperature probe extension cable extends through the flange face, is spliced to the pressure transducer cable, and routed to the system DAQ at the 650 facility. After installation, 4 of the thermistors failed. The time to failure was 6 to 10 months; the suspected failure mode was moisture intrusion into the thermistor. In the future more robust borehole temperature monitoring probes will be considered.

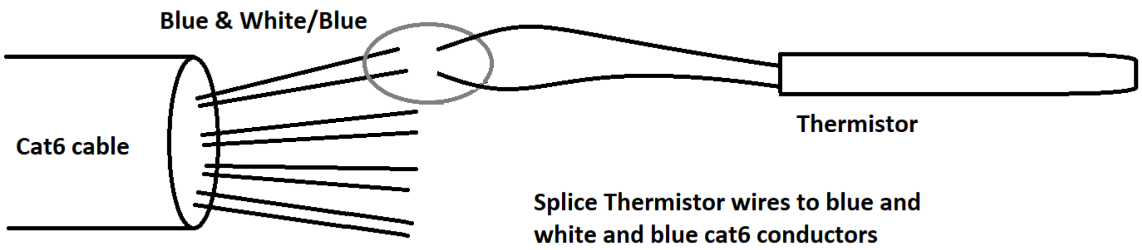


Figure 2. Thermistor splice.

1.1.3 Conveyance Line

The conveyance pipe also served as the vent line during grouting (for up-going boreholes). Perforations in the end of the conveyance pipe allowed air to pass through the conveyance line and out of the borehole as grout was filling the borehole. Centralizers and spacers ensured that grout encased all components in the borehole. For down-going holes each section of the conveyance pipe was perforated (4 holes per stick) to allow grout to fill the inside of the conveyance line. The conveyance pipe, tremie pipe, and all tubing were hand-sanded with 80 grit sandpaper to enhance grout adhesion (Figure 6).

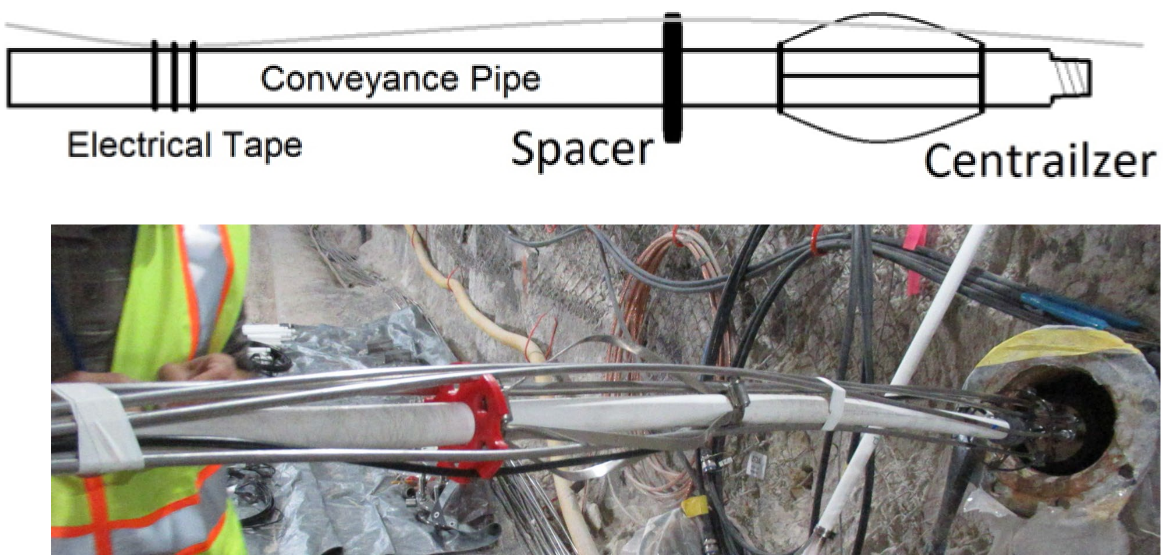


Figure 3. Conveyance pipe, centralizer, and spacer.

Figure 4. Conveyance pipe for down-going hole, perforated to allow grout to fill it.

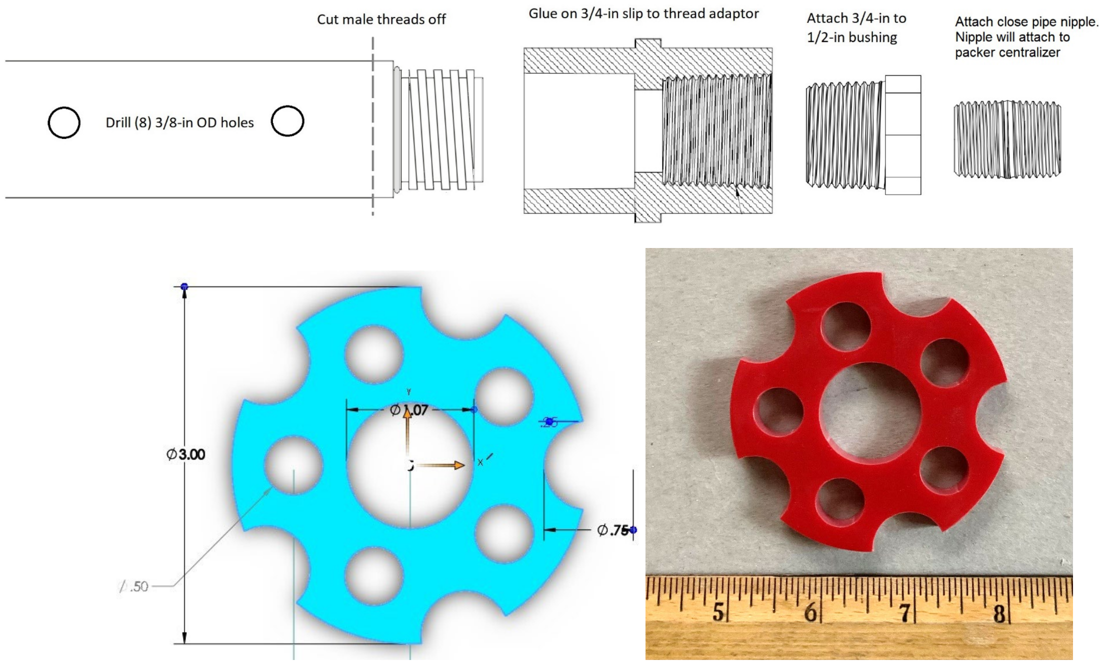


Figure 5. Packer adaptor and borehole tubing spacer.

1.1.4 Tremie Pipe

A tremie pipe was used to deliver grout to the end of the boreholes. For up-going boreholes, the tremie pipe was fixed in place two feet from the packer. Grout was pumped through the borehole collar to the end of the hole and allowed to run back down the hole to the collar, filling from the bottom. For downward going boreholes the tremie pipe was only loosely secured near the packer during installation. This allowed it to be removed during grouting. For all boreholes, the tremie pipe was a 1-inch OD polyethylene pipe. Again, additional details are captured in the borehole completion report (Chapter 2).

Figure 6. Surfaces roughened by sanding of the conveyance pipe, tremie pipe, and stainless-steel tubing.

1.1.5 Borehole Collar Flange

The borehole collar flange provided the adaptors for the grout fill tubes, the borehole sample lines, the pressure transducer line, and the packer inflation line to pass from inside the borehole and out into the tunnel (Figure 7). These were bore-through compression fittings for the tubing and cord-grips for the wiring. For up-going boreholes, the original design was modified to include a tremie pipe pass-through. The fill and vent lines also received sacrificial valves used to shut in the grout. Once the grout was cured, these valves were removed and the pipes were capped. For down-going boreholes the grout was emplaced without any hardware attached to the collar. Once grout emplacement was complete, but before grout had fully cured, the borehole collar faceplate was attached.

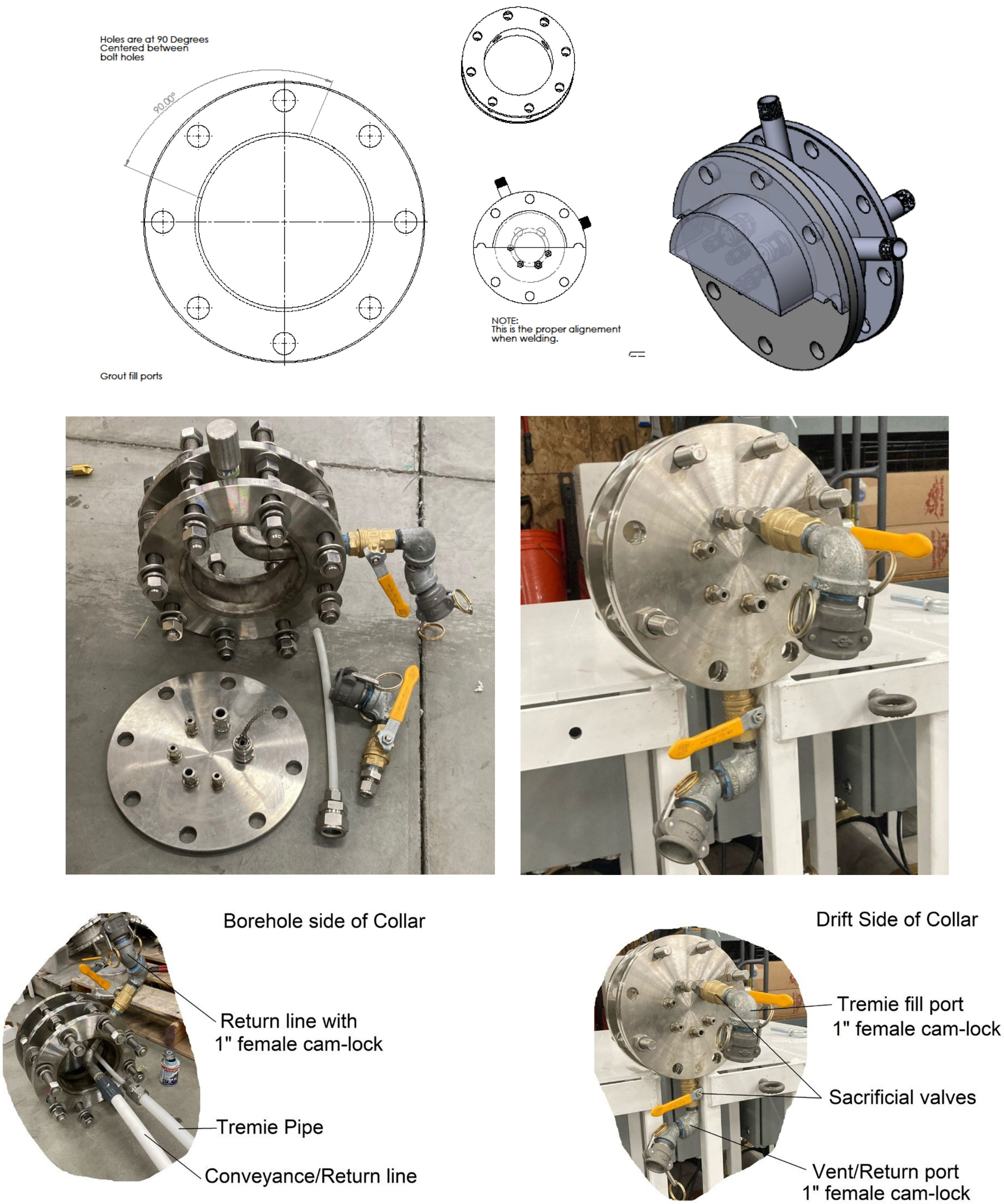


Figure 7. Borehole collar and flange assembly for upward tilted boreholes.

1.2 Tunnel Section

1.2.1 Water Trap

Water traps were included with the design of each gas borehole to capture any water that flows out of the gas sampling lines. The water trap design includes the ability to retain the captured water for subsequent analysis (Figure 8). The full water trap design and specifications are described in Appendix C. The water trap was secured to the rib adjacent to the boreholes using 16-inch long threaded rod epoxied in-place. Shock isolators provide a stand-off from the rib and the necessary shock adsorption. The water trap has an internal volume of 9.4 L. Since the amount of water potentially coming out of the borehole is unknown, a self-contained, self-powered drain system allows multiple fill-dump cycles. A pair of float switches trigger a solenoid drain valve to open when the trap is 80% full and drain until 15% full. This functionality was implemented on two borehole (GS-1 and GS-2); for the other six boreholes the drain function was disabled and the cylinders were single fill only.

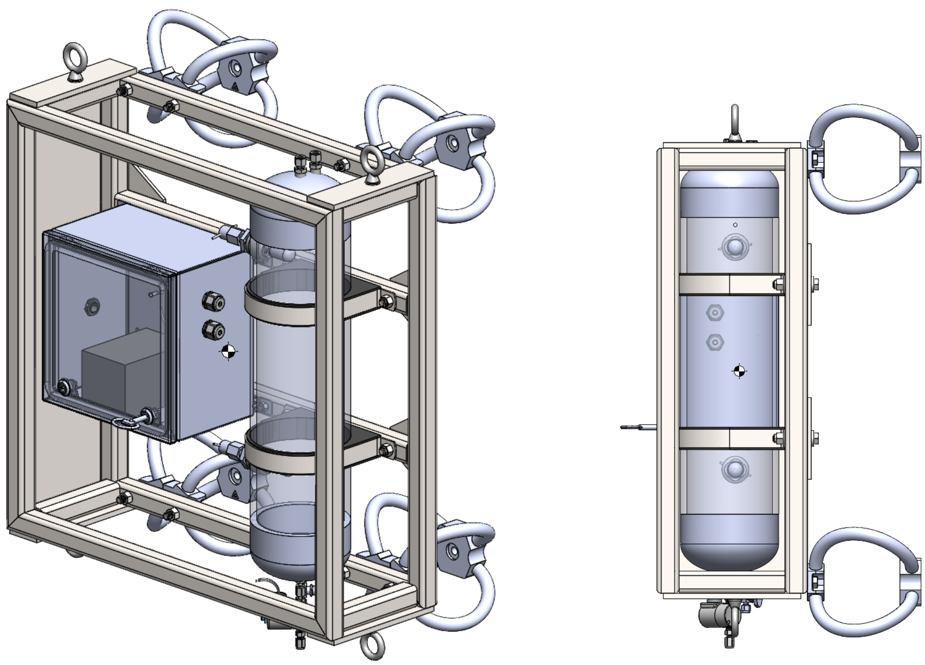


Figure 8. Water trap.

1.2.2 Pressure Transducers

The pressure inside each gas sampling zone was measured with a transducer at each borehole collar. Pressure transducers were connected to the sampling interval via a 3/8” SS line. Two brands of pressure transducer were used, but both met all requirements. Both style transducers are 0–300 psia sensors with 4–20 mA analog output and are capable of surviving the expected pressure and shock pulses. Transducers were attached to the collar with sections of bent tubing to create flex points to help shock survival. Pressure transducers, and the thermistor extension cable, were spliced to long data cables to connect back to the system DAQ.

1.2.3 Tubing Run and Rib Hangers

The gas cabinet in the 650 Facility is connected to the boreholes by long runs of 3/8″ OD stainless steel tubing. These tube runs were installed along the rib, bundled and hung with standard hangers. Similarly, the borehole data cables were run alongside the tubing.

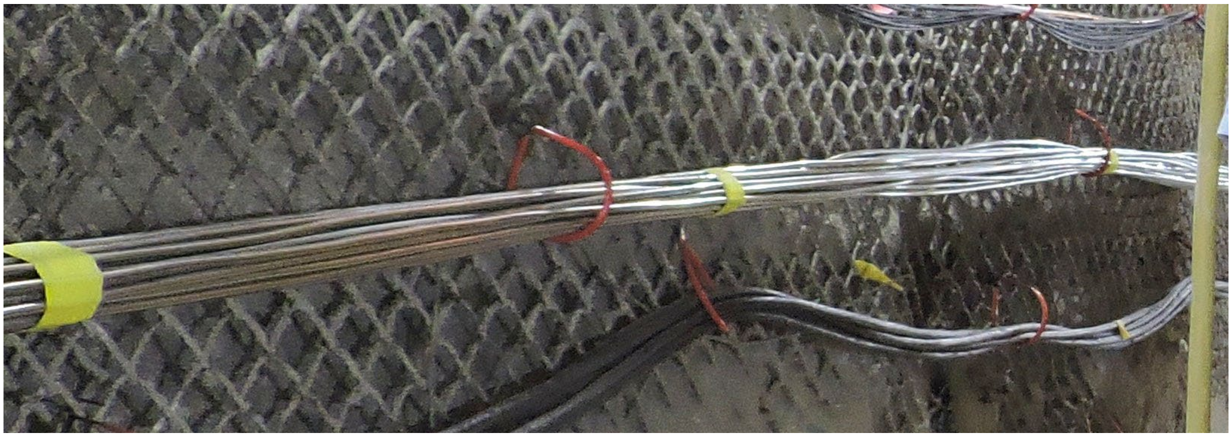


Figure 9. Tubing bundle hung along left rib.

1.2.4 Under-track Crossing

While the boreholes and tubing were installed on the left rib, the gas delivery cabinet is in an alcove in the 650 Facility along the right rib. This necessitated a crossing under the invert and tracks. The data cables were installed inside of 4-inch conduit that runs under the tracks. The tubing, however, was direct buried in a trench under the tracks. This was accomplished by cutting 16-foot lengths of tubing, bending them into a U shape, fitting them into the trench and then backfilling in the trench. This required the tubing runs along the rib to be labeled (which borehole it came from) and connected to the correct tube. After installation, pressure and flow instruments were used to verify that all boreholes were connected to the correct tubing runs and cabinet ports. As an example, it was verified that as the pump for each borehole was turned on there was a measurable pressure response in the corresponding borehole. This ensured that each of the runs of tubing and cabling were connected correctly.

1.2.5 Flex Lines

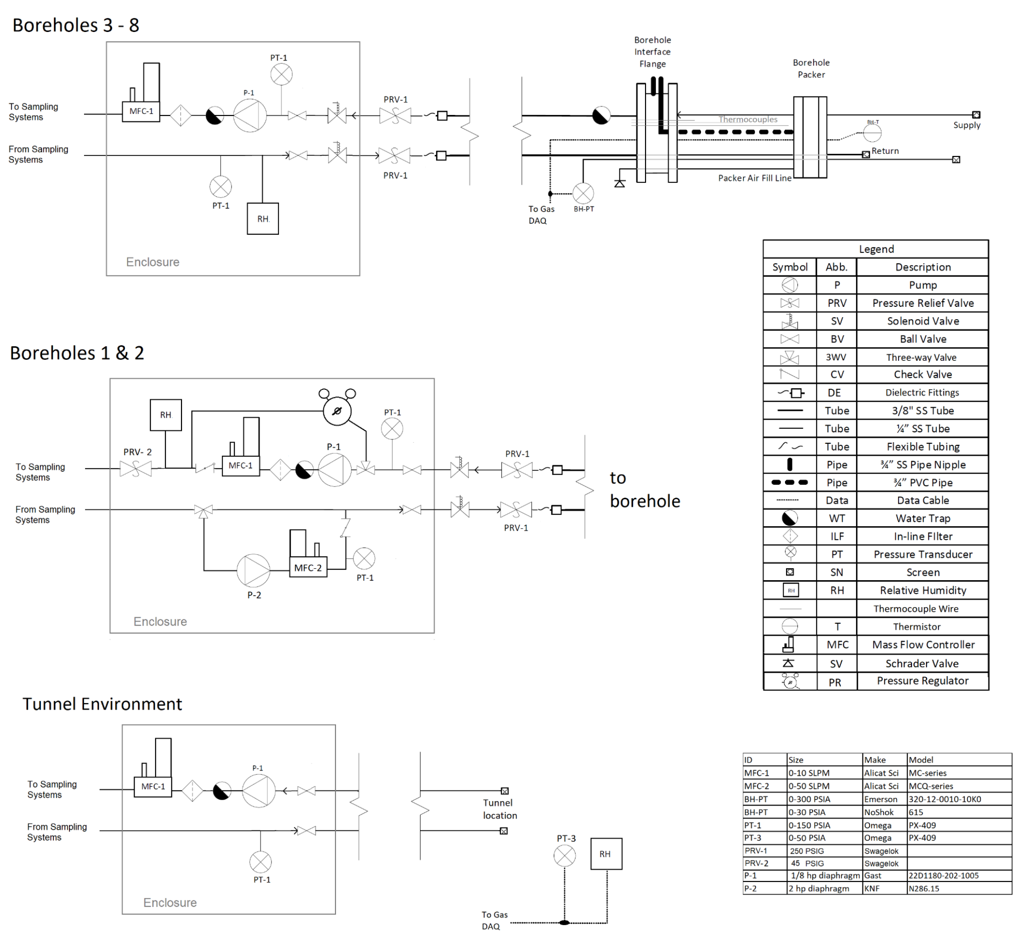
The experiment is expected to generate significant ground motion. For instruments on shock isolators, the movement will be slower, but have a longer travel path. While the hard lines were expected to provide sufficient freedom of movement, all tubing to instrument connections included a section of flexible hose. This included connections to the borehole collars, water traps and gas delivery cabinet. These flexible lines have a metal bellows interior (not plastic) to ensure chemical compatibility and provide additional freedom of movement.

1.2.6 Gas Delivery Cabinet

The gas delivery cabinet houses the pumps and other flow control components of the borehole and tunnel environment gas delivery system (Figure 10). The cabinet frame and exterior panels were custom built using T-slot rail and strut with removable aluminum panels for easy access (Figure 11). Fans with filtered inlets provide system cooling and some amount of positive pressure to the cabinet to minimize dust ingress.

The gas cabinet hardware provides a gas delivery system for other instrumentation that analyze or collect gas samples. There are a total of eleven gas sampling locations handled by the gas delivery system: eight borehole sampling zones (GS-1 through GS-8) and three tunnel environment sampling zones (TE-1 through TE-3).A circulation system was designed for each of these zones to provide suction, pulling gas from the sampling zone through several hundred meters of tubing to the pump, and then pressurizes the gas for a circulation loop and return trip to the borehole. The circulation loop provides gas flow through a gamma detection system and allows bypass flow loops through tunnel environment analysis system, HE-byproducts analysis system and grab sampling system. The gamma detection, tunnel environment, and HE-byproducts systems analyze the gas and return it to the circulation loop. The grab sampling system collections discrete samples of gas into bottles for later analysis. Figure 12 shows a diagram of how the gas delivery cabinet is connected to the analysis and sampling systems.

A low pressure diaphragm pump is installed on all eleven zones. High pressure pumps are also included in the circulation loops for two of the boreholes (GS-1 and GS-2), since these boreholes are expected to see pressures in excess of 40 psi for sustained periods of time. For these two holes, a larger pump was deemed necessary for those periods of elevated pressure, and the system was designed with a bypass loop for periods where the borehole pressure was greater than 40 psi. This bypass loop uses electrically actuated 3-way ball valves to redirect the flow stream through a pressure regulator before the gas reaches the other instrumentation, then has a larger pump to re-inject the flow back into the borehole. Figure 10 shows a schematic of how each of the eleven circulation loops were configured.



Legend		
Symbol	Abb.	Description
	P	Pump
	PRV	Pressure Relief Valve
	SV	Solenoid Valve
	BV	Ball Valve
	3WV	Three-way Valve
	CV	Check Valve
	DE	Dielectric Fittings
	Tube	3/8" SS Tube
	Tube	¼" SS Tube
	Tube	Flexible Tubing
	Pipe	¾" SS Pipe Nipple
	Pipe	¾" PVC Pipe
	Data	Data Cable
	WT	Water Trap
	ILF	In-line FIlter
	PT	Pressure Transducer
	SN	Screen
RH	RH	Relative Humidity
		Thermocouple Wire
	T	Thermistor
	MFC	Mass Flow Controller
	SV	Schrader Valve
	PR	Pressure Regulator

ID	Size	Make	Model
MFC-1	0-10 SLPM	Alicat Sci	MC-series
MFC-2	0-50 SLPM	Alicat Sci	MCQ-series
BH-PT	0-300 PSIA	Emerson	320-12-0010-10K0
BH-PT	0-30 PSIA	NoShok	615
PT-1	0-150 PSIA	Omega	PX-409
PT-3	0-50 PSIA	Omega	PX-409
PRV-1	250 PSIG	Swagelok	
PRV-2	45 PSIG	Swagelok	
P-1	1/8 hp diaphragm	Gast	22D1180-202-1005
P-2	2 hp diaphragm	KNF	N286.15

Figure 10. Schematic of gas cabinet.

Figure 11. Gas cabinet.

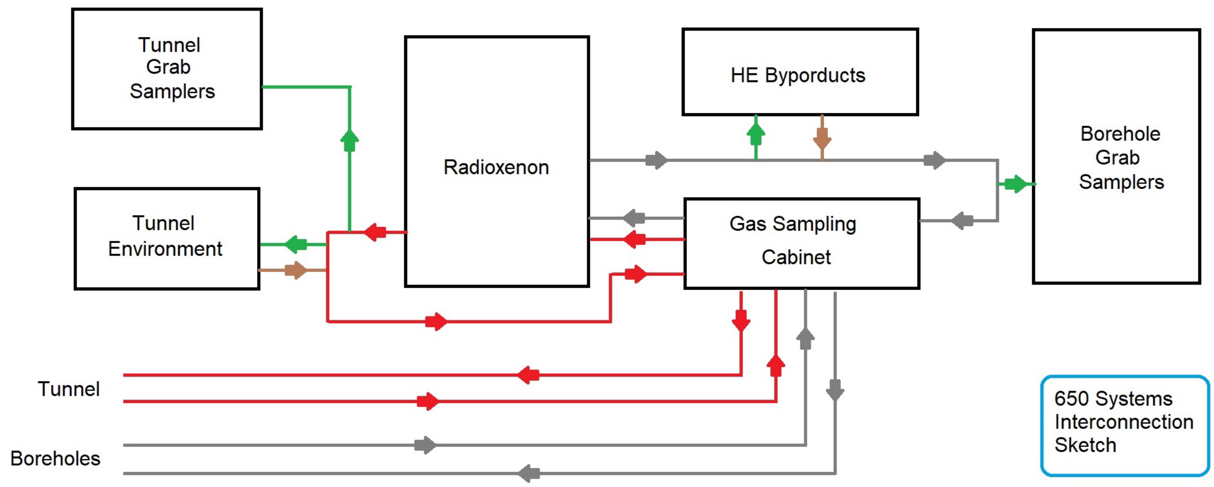


Figure 12. Gas system interconnection and flow path diagram. Note that no systems exhaust gas into the 650.

2.0 Electrical and Data Acquisition

Details of the gas cabinet power design are provided in Appendix D. This includes a description of the power components as well as the PNNL safety review of the system.

A number of instruments were installed as part of the borehole gas delivery system. The borehole pressure transducers, thermistors, and relative humidity (RH) sensors will be primary data sources; the system pressure gages are only for system diagnostics and performance indication. These instruments are connected to a DAQ module. The gas system DAQ is remotely accessible from outside of the tunnel through the project's underground network, the iDAQ. Control of the flows is automated for the experiment, but also allows manual adjustments in real-time if necessary.

3.0 Testing and Calculations

3.1 Tubing and Cable Lengths

The lengths of tubing and cabling needed for the boreholes and the tunnel were calculated based on the planned drilling locations and lengths for the boreholes (Table 1). Sufficient overage was accounted for to ensure timely completion.

Table 1. Tubing and Cable Length Calculations

Location	¼" Tubing Length[a] (ft)	3/8" Tubing in Borehole (ft)	3/8" Tubing in Tunnel (ft)	Data Cable Extension (ft)
GS-1	180	60	1834	917
GS-2	180	60	1834	917
GS-3	189	63	1782	891
GS-4	189	63	1782	891
GS-5	189	63	1710	855
GS-6	189	63	1710	855
GS-7	36	12	1450	725

Location	¼” Tubing Length a (ft)	3/8” Tubing in Borehole (ft)	3/8” Tubing in Tunnel (ft)	Data Cable Extension (ft)
GS-8	165	55	1548	774
Tunnel Env. 1	NA	NA	1700	850
Tunnel Env. 2	NA	NA	850	425
Tunnel Env. 3	NA	NA	800	400
Total	1325	450	17000	8500

a- excess tubing trimmed as necessary after installation and grouting

3.2 Pressure Drop

The pumps in the flow loop must be powerful enough to drive flow through the entire flow loop. Pressure drop through the tubing run is the single largest source of pressure loss. An online calculator was used to determine the pressure drop through the system[1]. Pressure drop was calculated for two conditions: formation pressure at ambient pressure and formation pressure at 45 psia. For the elevated pressure scenario, the flow rate is increased to maintain the 15-minute circulation time. For the ambient pressure condition, the combined round trip pressure drop through the 3/8” tubing run in the tunnel and the ¼” tubing in the borehole is calculated to be 2.23 psi. For the elevated pressure scenario, the calculated combined round trip pressure drop through the 3/8” tubing run in the tunnel and the ¼” tubing in the borehole is 4.92 psi. The pressure drop of the installed system was measured by circulating gas and measuring pressures at various points in the system under ambient formation pressure. At 4 LPM, the pressure drop between the borehole and the gas distribution cabinet was measured to be 2.25 psi, while the return from the cabinet to the borehole had a measured pressure drop of 1.75 psi for a combined round-trip pressure drop of 4 psi. The pressure drop of the final system is higher than calculated, likely due to additional fittings and bends not accounted for in the original estimate. However, pumps were selected with rated capacity several times greater than the minimum calculated capacity to account for a larger than calculated system pressure drop.

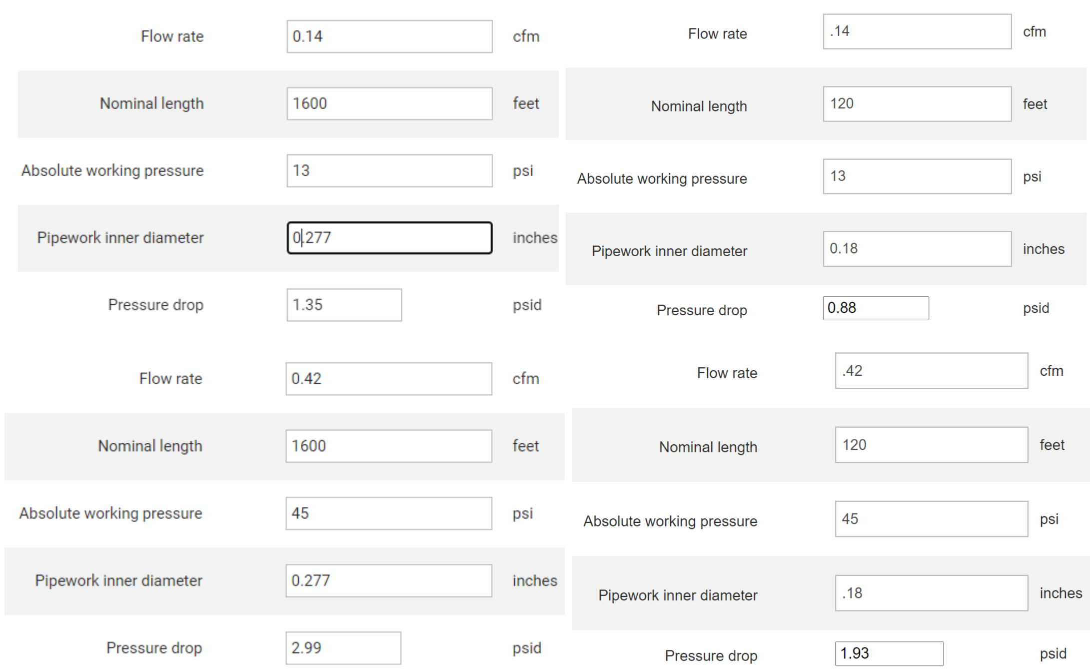


Figure 13. Pressure drop calculations using online calculator.

[1] https://www.kaeser.com/int-en/services/know-how/calculator/pressure-drop/

3.3 Residence Time

The requirement for recirculation of gas within the borehole specifies the characteristic transit time for circulation of the gas from the sampling zones to the real-time measurement systems to be 15 minutes or less. To verify that the borehole gas delivery system meets this requirement the volume of the various components were added together, which is listed in Table 2. The flow rate necessary to achieve the required recirculation time was determined. Using this calculated volume it was estimated that a flow rate of 7.7 L/min (0.27 cfm) was needed to achieve a 15 min transit time, so the 10 L/min mass flow controller was chosen to meet this requirement.. A tracer test conducted in several of the boreholes also confirmed the calculated system volume. Operational tests with the system following installation confirmed that the system has adequate power to meet the flow requirements. Chapter 4 includes detailed calcualtions of the transit time for each borehole during the experiment.

Table 2. Gas system component volumes and required flow to meet circulation timing requirements.

Component	Volume (L)	Component	Volume (L)
Borehole	8	Sampler tubing	0.5
Water trap	9.4	Secondary water trap	2
Tunnel tubing	11	Gamma detector	7.5
	Total	**38.4 L**	
Minimum Flow to meet 15 min requirement			
At 1 ATM line pressure		2.6	L/min (equiv. @STP)
At 3 ATM line pressure		7.7	L/min (equiv. @STP)

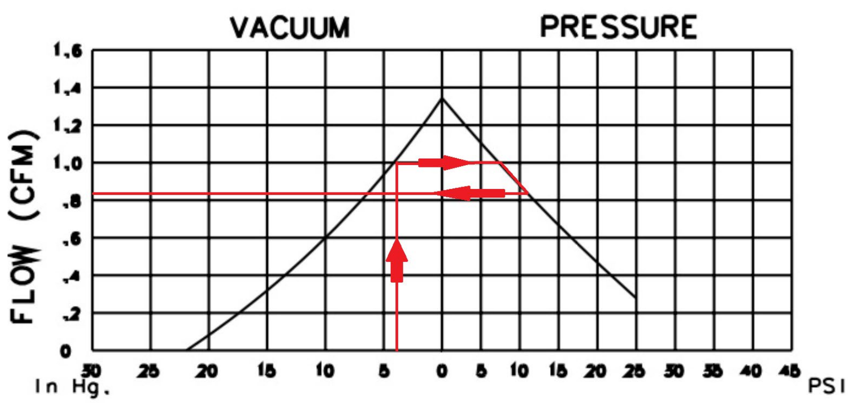


Figure 14. Pump curve and flow calculation.

3.4 Voltage Drop

The maximum voltage drop of the pressure transducer signal is calculated below (Table 3). The calculation is for the maximum distance, and the maximum current. Voltage drop will not impact the accuracy of the signal for a 4-20 mA output sensor, as long as the voltage drop is low enough that the sensor can push current through it. The pressure transducers selected require a voltage of at least 8V to operate. The gas cabinet system supplies 24V so that with the 0.77V drop at 20 mA the transducer will have adequate voltage to operate. The sensors and DAQ have sufficient voltage to drive current over these wire lengths.

Table 3. Pressure transducer voltage drop calculation.

Section	Length (ft)	Length (m)	Ohm/100 m	Wire resistance (Ohms)	Voltage drop @ 20 mA
Tunnel	667	203	9.5	19.3	0.77

3.5 Thermistor Resistance

Thermistors measure temperature as a function of resistance. Therefore, extra resistance added by longer wire lengths can influence the temperature reading. The thermistor chosen for this application is a 10,000 ohm thermistor. The wire run between the DAQ and the thermistor adds an additional 23.3 ohms of resistance, or a 0.23% bias (Table 4. Thermistor voltage drop calculation). At 20 C, a 0.23% bias is 1/5 of the rated accuracy of the thermistor, so the wire length does not impact the accuracy of the temperature measurement in a meaningful way.

Table 4. Thermistor voltage drop calculation.

Section	Length (ft)	Length (m)	Wire Size (AWG)	ohm/100 meters	Wire resistance (Ohms)
Tunnel	667	203	24	9.5	19.3
Borehole	140	43	24	9.5	4.0

3.6 Particle Loss

Any particulates larger than 15 µm in the sampling borehole will need to be filtered out to protect equipment. While the detonation, and associated shock, could result in a large amount of particulate matter within the sample collection zone, calculations estimated that most of the material will be deposited within the sample line before reaching the 650 facility (and system filters). To calculate particle loss in the tubing a common publicly available spreadsheet was used[1]. As a worst-case scenario the analysis was done for the shortest runs, with the planned geometry (i.e., multiple bends). These calculations estimated that more than 90% of the particulate material 10 µm or larger would not be transported through the entire tubing run from the borehole to the 650 facility. Similarly, a particulate line loss model was used to corroborate the calculation (DEPO Calc.); the model predicted that all of the material would deposit in the lines. This was supported by visual inspection of system filters. After running the system continuously for 6+ months a filter change was conducted. The filters appeared clean and new, and blowing compressed air through them did not dislodge any visible particulate material.

3.7 Pressure Response Lag

The decision was made to mount the pressure transducers on the borehole collar rather than in the boreholes. This was primarily due to the expected lack of survivability of transducers in some of the boreholes. The primary concern with locating the transducers at the collar is lag in signal response between the borehole sample collection zone and the transducer. An equation developed to characterize the lag and attenuation in manometer response on aircraft was used to estimate the lag time[2]. Figure 15 shows a plot of the calculated lag time for both 3/8" and ¼" diameter tubing. This calculation demonstrates that the lag time is significantly reduced by using 3/8" diameter tubing rather than ¼". A meeting with relevant SME's concluded that lag times on the order of fractions of a second was acceptable given the required data collection frequency.

[1] https://therealandrewmaynard.com/2020/05/27/the-aerosol-calculator/

[2] Sinclair, A. R. and Robins, A. W., Method for the Determination of the Time Lag in Pressure Measuring Systems Incorporating Capillaries," NACA TN 2793, Sept. 1952

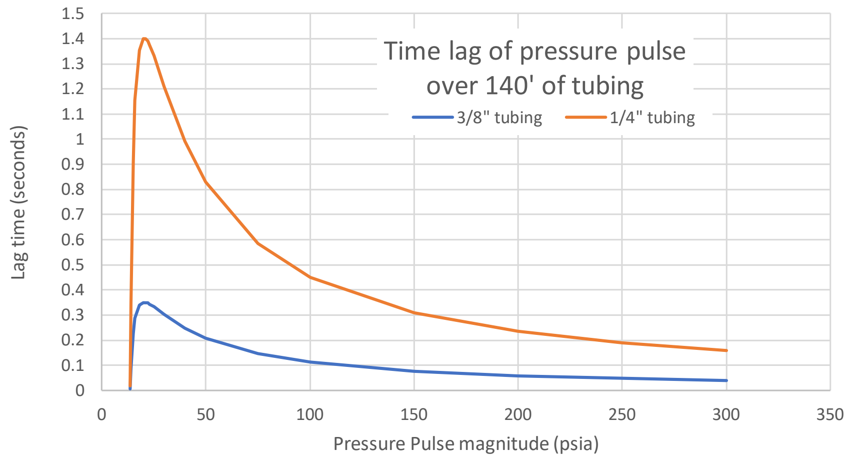


Figure 15. Time lag of pressure pulse response through 140' of ¼" and 3/8" tubing.

3.8 Power Demand

Most of the system components were selected to operate on a 24 VDC power source. The low pressure diaphragm pumps selected for the borehole and tunnel environment gas circulation loops each draw 3.2 amps at 24 VDC. Additional power draw from the power supplies include isolation solenoid valves, Mass Flow Controllers, RH probes, pressure transducers and cooling fans. The 1000-watt power supplies selected can source 40 amps continuous at (nominally) 24 VDC. The supplies are tied together in a parallel output configuration, effectively forming a single 2000W power supply. For the 8 borehole gas circulation loops, plus the 3 tunnel environment gas circulation loops, two power supplies are sufficient, and operate at about 60% of their rated capacity (Table 5). The two high pressure pumps operate on a separate dedicated 480VAC supply.

Table 5. Power demand of gas system electrical components.

Component	Power (W)	Voltage (V)	Total installed	Total Power (W)
Pump	80	24	11	880
Mass Flow Cont.	6	24	13	78
480V pump	1500	480	2	*3000**
Solenoid valve	9.5	24	8	76
Borehole Pressure Trans.	0.5	24	8	4
Tunnel Env. Pressure Trans.	0.5	24	3	1.5
System Pressure	0.5	24	19	9.5
RH Probe	0.5	24	11	5.5
Cooling fans	30	24	2	60
Circulation Fans	10	24	2	20
		Combined Total 110 VAC power demand		1135

*Power supplied separately from 480V panel. Not counted towards 110VAC power demand

3.9 Heat Generation

Each of the eleven low pressure diaphragm pumps generates heat during operation. Additionally, heat is generated during compression of the gas by the pumps. The two larger pumps for boreholes GS-1 and GS-2 also generate heat. A heat generation test was conducted by closing the cabinet and operating the sampling pumps. For the test, 9 of the 11 primary pumps and one of the large bypass pumps were run for 24 hours. The primary pumps were run at 4 L/min while the large pump was run at a 50% speed and a flow rate of 10 L/min. Circulation fans were run during the test, although they were shut off for 1 hour in the middle of the test to evaluate temperature build-up with them off, and temperature decrease once they turned back on. Temperatures of the air inside the enclosure, as well as the pump motor and pump head were made. Since the pumps include internal cooling fans for the motor, the pump head was the hottest component (due to the heat of compression). The results indicated that the system reached equilibrium after about 4 hours, with air temperatures stabilizing at around 30° C, or 6° C higher than ambient. These temperatures are all well below temperature ratings for components inside the gas sampling cabinet.

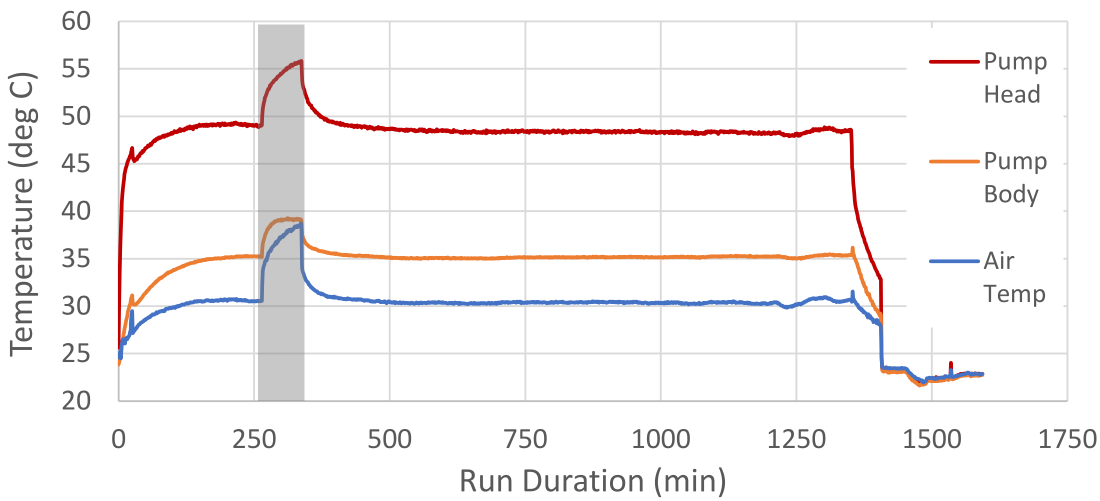


Figure 16. Temperatures measured during heat generation testing of the gas cabinet. Grey band denotes time when circulation fans were turned off.

3.10 Water Trap Sizing

Inside the gas cabinet, between the pump and the mass flow controllers, there are secondary water traps. These are to collect water condensed from the gas stream under pressure. These water traps are 2L each; this size was selected based on the maximum amount of water expected to condense out over a 4-week operational period. This calculation (Figure 17) assumed that the borehole gas was 100% saturated and at an ambient pressure of 12 psia. The excess water in the air stream in the water trap (calculated absolute humidity minus the maximum absolute humidity at that temperature) is used to determine the total water collected over the experiment period (4 weeks). The estimated water trap minimum size of 1.84 was then used to select the 2L size used in the gas cabinet.

Maximum Water Content			**Water Trap Conditions**	
At 20C (g/L)	0.0173		Pressure (psia)	30
At 30C (g/L)	0.0304		Flow Rate (L/min)	1.65
			Temp (K)	303
Borehole Conditions			Abs. Hum. (g/L)	0.0418
RH	100%		RH	138%
Pressure (psia)	12			
Flow Rate (L/min)	4		Excess Water (g/L)	0.0114
Temp (K)	293		Excess Water per 4 weeks (g)	1842
Mass flowrate water (g/min)	0.0692		Excess Water per 4 weeks (L)	1.84

Figure 17. Calculation of the excess water generated in the secondary water traps.

3.11 Gas Block Testing

The thermistor cable splice, located on the grouted side of the packer (in the borehole) required a gas block to minimize the potential for gas transport to the tunnel through the cable. The gas block design used solder filled, heat-shrink covered butt-splice connectors. These connectors were covered with a larger section of heat-shrink tubing, which was filled with epoxy. The outer heat-shrink tubing was then heated and shrank slightly, forcing epoxy into the openings around the splice and into the cable jacket. This provided a gas tight seal, as demonstrated by leak-tests.

4.0 Design Optimization

The borehole gas delivery system is primarily a mechanical system. Prior to building and installation, system testing was done as part of the design optimization process. For example, the gas recirculation pump was tested and ultimately changed. It was necessary to determine if the pump could meet the flow rate requirements with the complete plumbing arrangement under elevated formation pressures. A simulated borehole was constructed (50 feet of 5” PVC), along with a simulated instrument cabinet for the pump and mass flow controller. More than 1000 feet of 3/8” tubing was then used to connect the instrument cabinet to the packer/tubing assembly inside of the simulated borehole. A jumper between the supply and return inlet/outlet on the packer turned the prototype into a closed loop system. An air compressor was also used to test the pump capability with line pressure elevated to 45 psia.

Figure 18. Simulated 50-foot long borehole.

Additionally, prototype components were built and evaluated as part of the design optimization process. The borehole packer, the borehole tubing/piping/cable arrangement, installation of the packer string, the collar flange seal, the tubing deployment method, and the pump capability were all tested. Modifications to all components were made based on the design optimization testing on the prototype systems. The arrangement and securement of the borehole sampling zone components were improved, steel centralizers were added to the packer to prevent damage to the bladder during installation, better conveyance pipe centralizers were identified and improved spacers were designed. At the borehole collar, a number of improvements to the flange connection were made; this included the addition of threaded rod for flange securement, the use of bore-through weld-on fittings on the face, improving the grout conveyance line attachment process, and optimizing the order of operations for installation.

5.0 Future Ideas

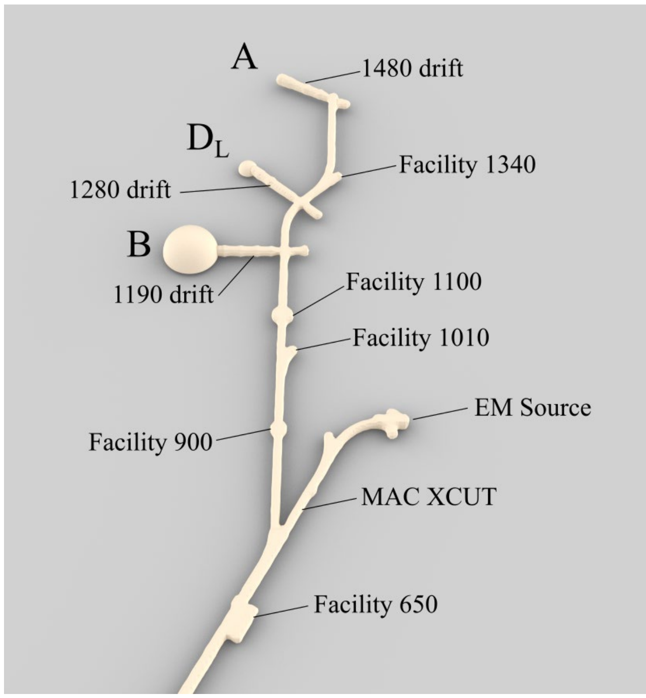
After designing, building, and installing the gas sampling system, several ideas for improvements in future systems came to light. First, heat generation in the gas cabinet from the pumps was not ideal. While circulation fans kept the internal temperature well below the temperature rating of all components, the internal water traps were warmer than the surrounding air within the 650 facility. A better design would have housed the water traps and the pumps in separate air spaces within the cabinet, allowing forced ventilation to cool the pumps while cooling the water traps below ambient temperatures with a Peltier cooler.

Several of the borehole thermistors died after installation. While they lasted longer than the original design criteria, delays resulted in a longer lag between installation and experiment execution. The borehole temperature measurement should be done differently in the future.

Appendix A – Overview

This section provides an outline summary of the borehole gas sampling system. The various primary sections of the system are each made up of parts and pieces. This outline is intended to provide an overview of what those parts are, what their important specifications are, and how they all connect to the larger system.

A.1 06 Bypass Map



The gas sampling boreholes are located on the left rib between the 1340 facility and the 1480 drift. The gas cabinet is located at the 650 facility. Tubing runs along the left rib between the two.

A.2 Borehole Sampling Zone

The borehole sampling package was pre-assembled at PNNL. The assemblies consisted of the packer, sample lines and other associated hardware.

1. Components
    a. Packer: The packer isolates the sample collection interval from the grouted section of the borehole during grouting. This keeps the sample collection interval open and allow the grout to create a good seal against the packer. Up-going holes- 1 packer. Down-going holes- 2 packers.
        i. Aardvark Environmental Packer
            (1) Physical Specifications
                (a) (4) ¼” tube pass throughs
                (b) Inflation range: 3.5” to 6”
                (c) Materials of construction

(i) stainless steel mandrel and tube ports,

(ii) EPDM rubber gland

(d) Max Pressure: 120 psi

(e) Material compatibility

(i) EPDM rubber and stainless-steel compatible with ammonia gas

(ii) EPDM may off-gas trace levels of VOCs

(iii) Helium could permeate through EPDM into packer air volume

(2) Modification

(a) Custom steel centralizers built to prevent packer gland from rubbing on bottom of borehole during insertion

(b) Center pass-through capped to prevent gas migration through the center.

b. Center rod: The center rod attaches to the packer center pass-through. It provides a hard stop for the packer assembly against the end of the borehole. It also assures consistent sampling interval volumes between boreholes and provides a mounting location for other components in the sampling interval.

i. 28" long

ii. Includes centralizer

c. Sample/return/pressure inlet screens: The sample and return lines as well as the pressure measurement line are protected from dust and debris by a standard soil gas sampling screen.

i. Specifications

(1) 6 inches long

(2) 0.0059 inch (0.15 mm) pore size (100 mesh)

d. Temperature probe: located inside of sample collection zone, this thermistor measures the temperature inside the sample collection zone

(1) Omega, TH-10-44006-1/8-2-40

(2) -80 to 150 °C

(3) 10,000 Ohm

(4) 2" stainless steel sheath

(a) Swaged to packer with bore-through fitting

(b) Strain relief on grout side provided by heat shrink and looping wire

A.3 Borehole

1. Temperature probe extension cable: this cable was spliced onto the thermistor cable on the grout side of the packer. The thermocouple cable extends through the flange face, is spliced to the pressure transducer cable, and routed to the 650 facility.

a. CableWholesale.com Part #: 10X6-722NM

i. Direct bury

ii. Shielded

        iii. Diameter: 5.4 ± 0.3 mm (~0.21")
        iv. Temperature range: -40 to 70 °C
    b. Spliced to thermistor cable behind packer
        i. Water-proof heat-shrink butt splice connectors for the individual conductor splice (McMaster Carr part number 9895K11)
        ii. Epoxy gas block
2. Tubing: tubing connects the gas sampling zone to the borehole tubing runs through the packer, grouted interval and the borehole collar/faceplate.
    a. ¼" OD stainless steel
        i. Pulled from long spool, cut to length and fittings attached at PNNL. Shipped ready for installation
        ii. 0.035" wall
        iii. 5000 psi working pressure
        iv. 21,000 psi burst pressure
    b. 3/8" OD stainless steel (for pressure transducer)
        i. 3/8" OD, 0.049" wall
        ii. 19,000 psi burst pressure
        iii. 4500 psi working pressure
        iv. Roughness coefficient: assume 0.03 mm
3. Packer air-line: packer was inflated during grout injection. Must be able to be inflated and deflated after installation.
    a. ¼" OD stainless steel
        i. Pulled from long spool, cut to length and fittings attached at PNNL. Shipped ready for installation
        ii. 0.035 inch wall
        iii. 5000 psi working pressure
        iv. 21,000 psi burst pressure
4. Conveyance pipe: used to convey packer assembly to end of borehole (air vent for upward tilted holes). Custom adaptor built to couple push rod to packer and allow grout/air to flow through the center of the push rod. Rod will terminate short of the flange assembly at the end of the borehole. Connected to collar port with PVC adaptor.
    a. PVC pipe
        i. ¾" inch, schedule 40, PVC, flush thread, 5' lengths for workability
    b. Packer Connection
        i. First stick of pipe modified to allow connection to packer center connector.
    c. Centralizers
        i. ESP Supply (W-075CEN)

(1) Placed every 5 feet (1 on every stick)

d. Tubing spreaders

i. Custom made

(1) Acrylic sheet (McMaster Carr 8505K737)

(2) Laser cut at PNNL

(3) Placed every 5 feet (1 on every stick)

ii. Secured to conveyance pipe with electrical tape

5. Packer/borehole sampling string: Borehole tubing pre-cut and sanded prior to shipment. In tunnel, full tubing lengths attached to packer. Conveyance pipe shipped with centralizer attached and spread to target width. Conveyance pipe attached to string 1 stick at a time. Tubing spreader added, tubing secured and package advanced 5-feet (1 stick length).

6. Tremie Pipe: used to convey grout to the packer end of the grouted interval

a. 1” OD polyethylene tubing

b. Compression fittings used

c. Removed for down-going boreholes

d. Grouted in-place for up-going boreholes

A.4 Borehole Collar

1. Grout adaptor: provides ports to allow grout injection and air venting from within the borehole, as well as a temperature measurement port.

a. Used for up-going holes only

b. Custom built - 6” flanges (8 bolt holes)

c. 304 Stainless steel

d. Include brass ball valves on grout ports

i. McMaster Carr Part number 4629K14

ii. Valve removed once grout is set

iii. Pipe nipple capped with SS cap (McMaster Carr Part number 4443K685)

(1) 3000 psi working pressure

e. Face plate: allows penetrations of the gas sampling, pressure monitoring and packer inflation tubing as well as the pressure transducer cable and tremie fill line (on up-going holes).

i. Design

(1) Components

(a) Blank Flange

(i) Pressure rating- 275psi at 70°F

(ii) Material compatibility- 304 SS

(b) Tube passthroughs connect borehole tubing to tunnel air space for supply, return, packer inflation and exterior pressure transducer

(i) Swagelok weld adaptor

1. (3) ¼" Weld Adapter Bore Thru

   a. SS-400-1-4WBT

2. (1) 3/8" Weld Adapter Bore Thru

   a. SS-600-1-6WBT

(ii) Pressure rating: 11,000 psig

(iii) Material compatibility: 316 SS

(2) Data cable pass through allows interior thermistor cable to pass through flange face

(a) McMaster Carr 7458K32

(b) Pressure rating N/A- grout will isolate from pressure

(c) Stainless and rubber material for ammonia compatibility

(3) Threaded rod will be used to secure the assembly together.

(a) (8) 8-inch long, ¾-10 1808 stainless steel threaded rods (McMaster Carr 95412A863)

(b) (32) ¾-10 18-8 stainless steel nuts rods (McMaster Carr 91845A330)

(c) (32) ¾-inch 18-8 stainless steel washers and lock washers (McMaster Carr 92141A056 & 92146A036)

A.5 Tunnel wall Components

1. Water Trap Rack: provides a secure mounting location for the water trap, pressure transducer and data cable during
   a. Water Trap: the primary water trap collects water that may be coming out of the borehole sampling zone. The trap will have an internal volume of 9.4 L. A self-contained, self-powered drain system will allow up to 18 L of water to be removed from the sample line. A pair of float switches will trigger the drain to open when the trap is 75% full and drain until 25% full
2. Pressure Transducer A
   a. Druck Unik
   b. Specifications
      i. 0-300 PSIA
      ii. 0.12 PSI accuracy
      iii. 4-20 mA
      iv. Burst pressure: 2900 psi
      v. Shock rating: 1000g
      vi. Data output speed: sufficient for 1 Hz data requirement
      vii. Material compatibility: all stainless wetted parts
   c. Mounting
      i. Mounted in tunnel at borehole collar

   ii. Connected to borehole with tubing
   iii. Shock isolation from coiled tubing
d. Connection: pressure transducers spliced to the data cable extension with heat-shrink butt-splice connectors.

3. Pressure Transducer B
   a. No Shock 615
   b. Specifications
      i. Measurement Range- variable as needed on a per-well basis
      ii. Units of PSIA
      iii. 4-20 mA, 2 wire output
      iv. Burst pressure- 4X full scale
      v. Shock rating- 1000g
      vi. Wetted parts and housing- 316 stainless steel
   c. Mounting
      i. Mounted in tunnel at borehole collar
      ii. Connected to borehole with tubing
      iii. Shock isolation from coiled tubing
   d. Connection: pressure transducers spliced to the data cable extension with heat-shrink butt-splice connectors.
4. Data cable extension: The data cable extension runs from each borehole back to the DAQ module at 650.
   a. Cable Wholesale (10X6-722NM), CMXT shielded direct bury
   b. Cat5e, 24 AWG
   c. Mounting- cable run on rib
   d. Grounding- cable shield drain to be grounded at 650 facility.
   e. Connectors used to minimize set-up time in the tunnel.

A.6 Tunnel Run

Tubing (supply and return) and the data cables run along the side of the tunnel wall. The tubing and cable cross under the tracks to 650 and the gas sampling system. Tubing and cables labeled with brass tags.

1. Tubing
   a. Specifications
   b. 3/8” OD, 0.049” wall
   c. 19,000 psi burst pressure
   d. 4500 psi working pressure
   e. Roughness coefficient- assume 0.03 mm

2. Installation
    a. Hung on tunnel rib
    b. Ground isolation
        i. Non-metallic tubing sections
            (1) Swagelok SS-6-DE-6
            (2) Data cable shield drain grounded at 650 facility
            (3) Per facility grounding plan
        ii. Movement isolation
            (1) Flexible sections (Swagelok FX series hose)
            (2) Located at collars and gas cabinet
        iii. Labeling
            (1) Stamped brass tags
            (2) Attached with stainless wire

A.7 Gas Delivery System

3. Enclosure
    a. Shock mounted to reduce shock to 2 G
    b. Wire rope isolators anchored to concrete pad
4. Components/Specifications
    a. Power supply: Two supplies wired in parallel for system to provide power to low-pressure pumps.
        i. Analytic Systems PWS-1000-110-24
        ii. UL listed
        iii. Switching supply with PWM
        iv. 2000 Watt continuous combined
    b. Fittings
        i. ¼ inch Swagelok
        ii. pressure rating of at least 6500 psi (limited by the NPT threads on adaptors)
    c. Tube
        i. ¼" stainless tubing with a wall thickness of 0.02"
        ii. pressure rating- 2500 psi (working pressure).
    d. Pressure Relief Valve
        i. Swagelok part number SS-4R3A-BU-SETA210
        ii. Relief pressure set to 210 psi
    e. Solenoids

(1) Peter Paul Series 20, model 21 (normally open)
(2) Fully operational above 150 psi differential
    (a) May not open at higher pressures
(3) 24 VDC coil, 9.5W (0.4A)
    (a) Closed by signal from IDAQ
    (b) Powered through relay
(4) 5000 psi burst pressure
(5) No Shock Rating
(6) Nitrile seals for ammonia compatibility

f. Filter
   i. Swagelok part number SS-4TF-15
   ii. 6000 psi working pressure
   iii. 95% removal of particles larger than 15 µm
g. Pump
   i. Gast MOA-P126-JK
   ii. Controlled by IDAQ
   iii. 24V DC
   iv. Material compatibility- Neoprene diaphragm
h. Water Trap
   i. Neo-Pure SFR2-4
   ii. 300 psi operating pressure
   iii. 2L internal volume
   iv. Material compatibility
      (1) 316 Stainless steel body
      (2) Buena-N O-ring
i. System pressure transducers
   i. Omega PX119-150AI
   ii. Range 0-150 PSIA, Accuracy 0.5%
   iii. Output 4-20 mA
   iv. Supply voltage 8-30 VDC
   v. Burst pressure 435 PSIA
   vi. Wetted materials- 304 stainless steel and Ceramic Al_2O_3
   vii. Shock- 10g
j. Mass flow controller
   i. Alicat Scientific MCS-10SLPM-D-DB9M

ii. Operating Range

(1) 0 to 10 L/min, -10 to 60 C, 0-100% non-condensing, 145 psig

iii. Burst Pressure- 175 psig

iv. 304 & 316 stainless, FFKM (Kalrez) seals

v. Outputs

(1) 4-20 mA (flow and pressure)

vi. Input

(1) 4-20 mA for set-point

k. Temperature/RH

i. Vaisala HMP110

ii. Operating Range

(1) 0-100% RH

(2) -40 to 80 Degree C

iii. Material compatibility

(1) Stainless steel body

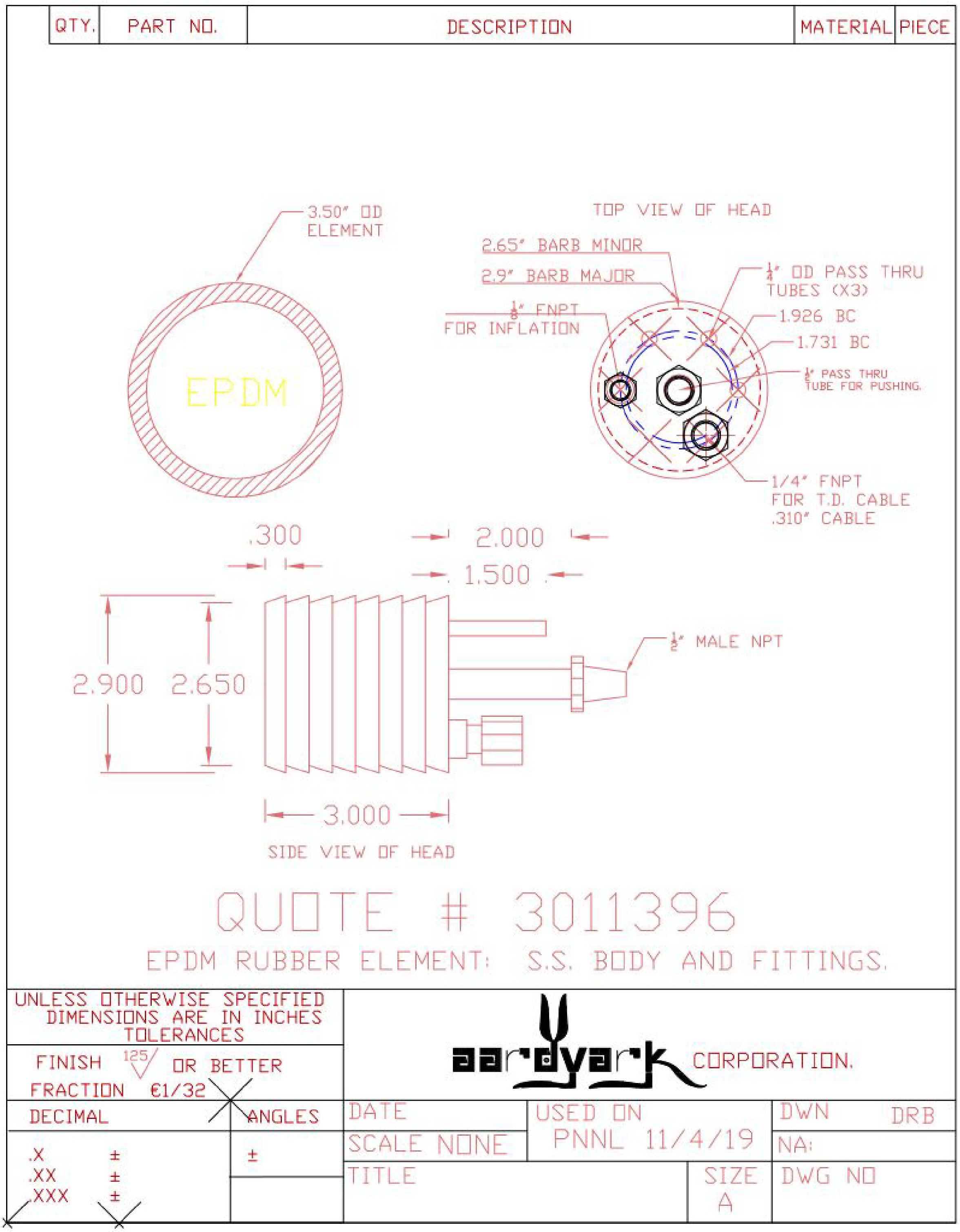
(2) Sensor is silicon chip

Appendix B – Complete Parts List and Component Data Sheets

Design location	# needed	Description	Part Number	Manufacturer/ Supplier	Size	units
Borehole	11	Packer	3011396	Aardvark	3.5	in. OD
	22	Packer centralizer	NA	Custom	3.75	in OD
	32	center rod	4813K181	McMaster Carr	14	in
	16	cap	G2526657	zoro	0.5	in
	6	Dual packer extension	4813K184	McMaster Carr	22	in
	3	Dual Packer union	4464K486	McMaster Carr	1/2	in
	24	Sample Screen	SVPT96-6SW14	ESP Supply	6	in
	32	tubing	89895K724	McMaster Carr	3	feet
	16	Thermistor	TH-10-44006-1/8-2-40	Omega	1/4	in
	16	Thermistor swage adaptor	SS-400-6-2BT	Swagelok	1/4 to 1/8	in
	2	Thermistor Extension	10X6-722NM	Cable Wholesale	1000	feet
	8	Thermistor cable splice	9895K11	McMaster Carr	10	per pkg
	8	Gas block epoxy	ClearWeld	JB Weld	5	min
	16	transducer cable splice	9895K11	McMaster Carr	10	per pkg
	5000	1/4" stainless tubing	Local supplier			
	100	Conveyance pipe	WE-075R5	ESP Supply	3/4	in
	175	centralizers	W-075CEN	ESP Supply	3/4	in
	500'	Tremie pipe	50375K55	McMaster Carr	1	in
	6	Spacers	8505K737	McMaster Carr	custom cut	
	16	coupling	4596k845	McMaster Carr		
	8	bushing	4596K414	McMaster Carr		
	16	Grout valve	4629K14	McMaster Carr		
	16	Grout cap	4443K685	McMaster Carr		
Flange Plate Adaptor	48	weld-on bore through fitting	SS-400-1-4WBT	Swagelok	1/4	inch
	16	weld-on bore through fitting	SS-600-1-6WBT	Swagelok	3/8	inch
	16	Custom Grout adaptor	NA	custom	TBD	NA
	16	Custom Flange plate	NA	custom	TBD	NA
	16	Custom protective hood	NA	custom	TBD	NA
		Tremie fill borethrough				
	8	Tremie fill adaptor		McMaster Carr		
	8	Fill valve adaptor	5182K832	McMaster Carr		
	10'	Tremie pass-through tube	50375K52	McMaster Carr	3/4	in
	128	threaded rod	95412A863	McMaster Carr	3/4-10	
	52	nuts	91845A330	McMaster Carr	9	per pkg
	52	washers	92141A056	McMaster Carr	10	per pkg
	52	lock washers	92146A036	McMaster Carr	10	per pkg
	16	Thermistor cord grip	7458K32	McMaster Carr	0.5	NPT
	32	reducing unions	SS-600-6-4	Swagelok	3/8 to 1/4	inch
Tunnel Wall	32	flexible hose connections	FX series	Swagelok		
	10	Custom Water Trap	NA	custom	TBD	NA
		Water trap isolators	MP64-86	Vibrodynamics		
		Water trap isolator anchors	3313N775	McMaster Carr	16	in
	6	Pressure transducer	Unik	Druck	300	psia
	5	Pressure transducer	615	NoShock	variable ranges	
	8	transducer adaptor fitting	SS-600-7-4	Swagelok		
Tunnel Run	3	Tunnel Data Cable	10X6-722NM	Cable Wholesale	1000	feet
	16	Thermistor cable splice	9895K11	McMaster Carr	10	per pkg
	16	flexible hose connections	FX series	Swagelok		
	30,000	3/8" tube- roll	Local supplier			
	22	Electrical isolaters	SS-6-DE-6	Swagelok	3/8	inch
Data Acquisition (DAQ)	1	CompactRIO Controller	NI 9047	National Inst.	NA	NA
	2	serial interface module	NI 9871	National Inst.	NA	NA
	1	Digital Module 5 V/TTL	NI 9401	National Inst.	NA	NA
	2	Current Output Module	NI 9266	National Inst.	NA	NA
	2	Digital Module	NI 9476	National Inst.	NA	NA
	1	High Speed Digital Module	NI 9402	National Inst.	NA	NA
	1	cRIO expansion chasis	NI 9145	National Inst.	NA	NA
	4	Analog Input Module	NI 9219	National Inst.	NA	NA
	4	Current Input Module	NI 9208	National Inst.	NA	NA
	1	Quint UPS power supply	2907066	Phoenix Contact	24	V

Design location	# needed	Description	Part Number	Manufacturer/ Supplier	Size	units
	1	Quint UPS battery Pac	2320306	Phoenix Contact	24	V
	11	Solid State Relay	DR06D12	Crydom	12	A
	1	DC-DC converter	PQDE6W-Q24-S5-T	CUI inc	24 to 5	V
Air Handling System	16	Pressure Relief Valve	SS-4R3A-BU-SETA210	Swagelok	200	psig
	16	NO solenoid valve	BP21J9DGM	Peter-Paul	350	psig
	4	Shock Isolators	HH64-4404TIM	Vibrodynamics		
	8	Isolator anchors				
	11	System filter	SS-4TF-15	Swagelok	15	um
	19	System PT	PX119-150AI	Omega	150	psia
	11	Diaphragm pump	MOA-P126-JK	Gast	24	VDC
	10	Mass Flow Controller	MCS-10SLPM-D-DB9M	Alicat	10	SLPM
	8	High humidity probe	HMP110	Vaisaila	100%	RH
	2	High Pressure Pump	N630.15ST.9E	KNF	480	V
	2	High Pressure MFC	MCHQ-50SLPM-D-M12-485-PCV30	Alicat	170	PSI
	2	Variable Frequency Drive	GS20X	Durapulse	480	V
	1	Disconnect Switch	7499K81	McMaster Carr		
	1	480V plug	HBL430C7W	Hubble	480	V
	8	NPT T filling	4464K51	McMaster Carr	0.5	inch
	8	swagelok borethrough	SS-12MO-1-8	Swagelok	12	mm
	16	swagelok adaptors	SS-400-1-8	Swagelok	0.25	in
	10	Secondary water trap	SFR2-4	Neo-pure	2.3	L
	32	Tubing inside of enclosure	89785K822	McMaster Carr	6	ft
	200	fittings inside of enclosure	various	swagelok		
	1	Enclosure	CUSTOM			
	2	Power supplies for pumps	PWS-1000-110-24	Analytic Systems	1000	Watts
	2	Shipping Crates	S-12658	Uline	wood	

Packer


QTY.
PART NO.
DESCRIPTION
MATERIAL
PIECE
3.50" OD ELEMENT
EPDM
TOP VIEW OF HEAD
2.65" BARB MINOR
2.9" BARB MAJOR
⅛" FNPT FOR INFLATION
¼" OD PASS THRU TUBES (X3)
1.926 BC
1.731 BC
½" PASS THRU TUBE FOR PUSHING.
1/4" FNPT FOR T.D. CABLE .310" CABLE
.300
2.000
1.500
½" MALE NPT
2.900
2.650
3.000
SIDE VIEW OF HEAD
QUOTE # 3011396
EPDM RUBBER ELEMENT: S.S. BODY AND FITTINGS.
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES
FINISH 125 OR BETTER
FRACTION ±1/32
DECIMAL
ANGLES
.X ±
.XX ±
.XXX ±
±
CORPORATION.
DATE
USED ON PNNL 11/4/19
DWN DRB
SCALE NONE
NA:
TITLE
SIZE A
DWG NO

Packer Center Rod

McMASTER-CARR®

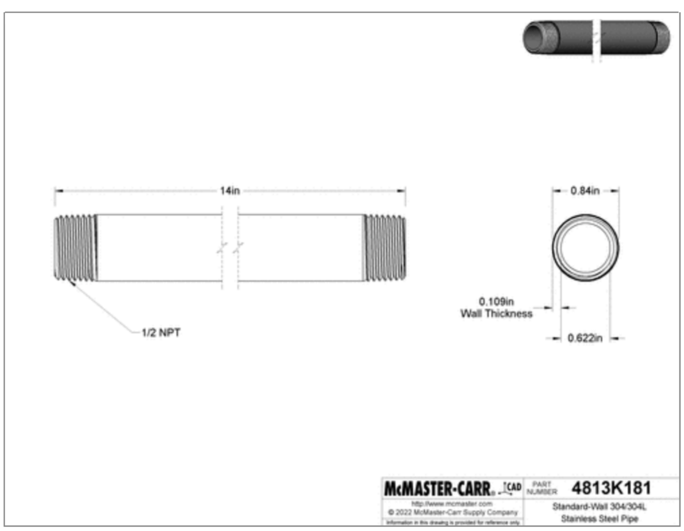
304 Stainless Steel Threaded Pipe Fittings

Low-Pressure, Straight Connector, 1/2 NPT Female 4464K354
Low-Pressure, Cap, 1/2 NPT 4464K499

For Use With	Air, Natural Gas, Oil, Steam, Water
Shape	Straight
Type	Connector
Material	304 Stainless Steel
Class	150
Fabrication	Heat Treated
Connection Type	Pipe
Connection Style	Threaded
Thread Type	NPT
Pipe Size	1/2
Maximum Pressure	150 psi @ 72° F
For Pipe	
Schedule	40
Material	304 Stainless Steel, 304/304L Stainless Steel

Standard-Wall 304/304L Stainless Steel Pipe

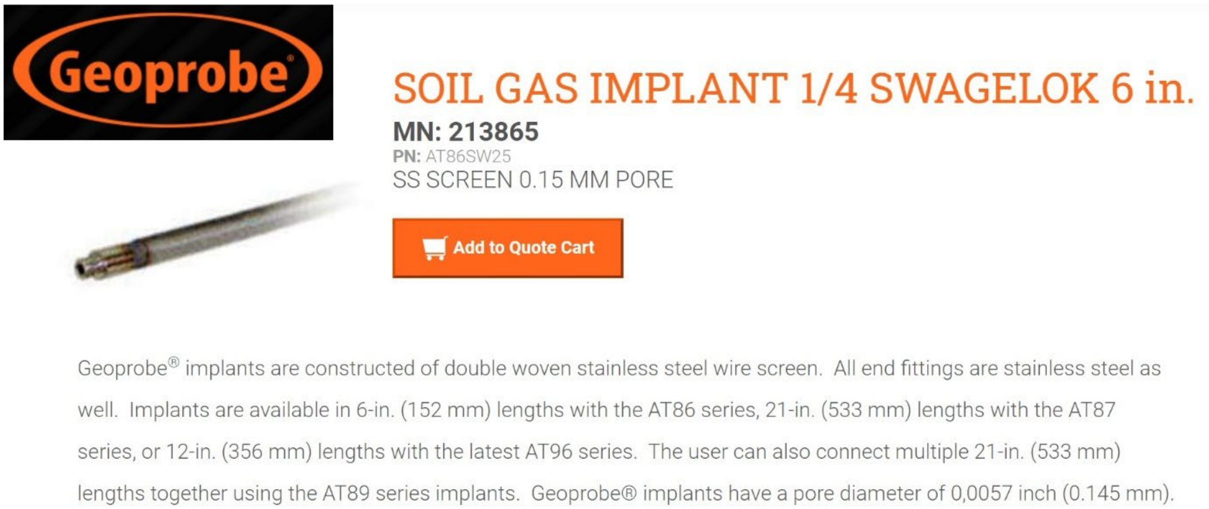
Threaded on Both Ends, 1/2 Pipe Size, 14" Long

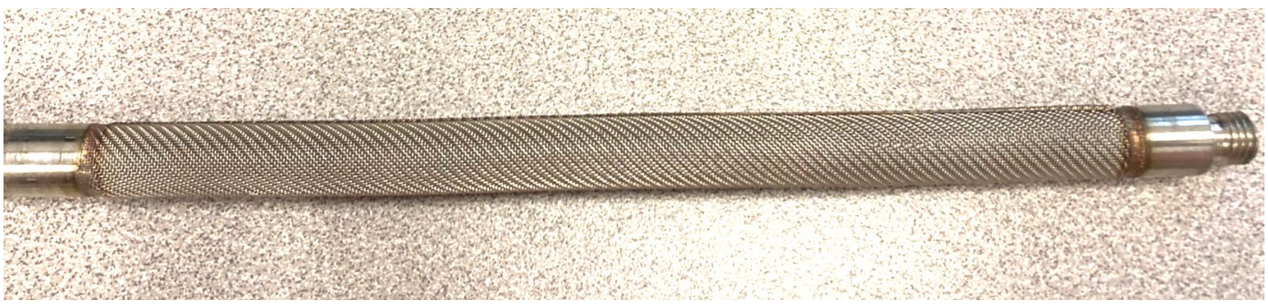


Material	304/304L Stainless Steel
Schedule	40
Threading	Threaded on Both Ends
Connection Type	Pipe
Connection Style	Threaded
Thread Type	NPT
Gender	Male
Pipe Size	1/2
Length	14"
Construction	Welded
OD	27/32"
ID	0.622"
Wall Thickness	0.109"
For Fitting	
Class	150
Material	304 Stainless Steel, 304/304L

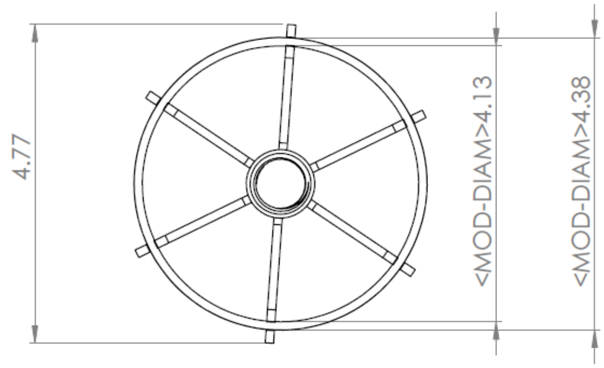
Supply and return sample line screens

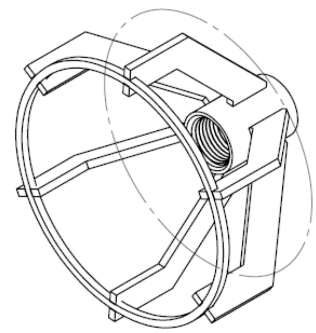
Geoprobe screens, supplied by ESP well supply

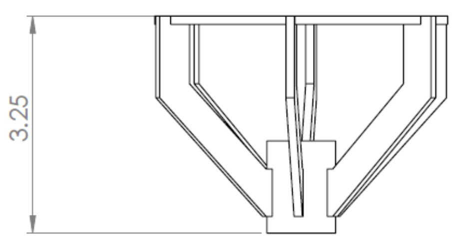




Custom Centralizers

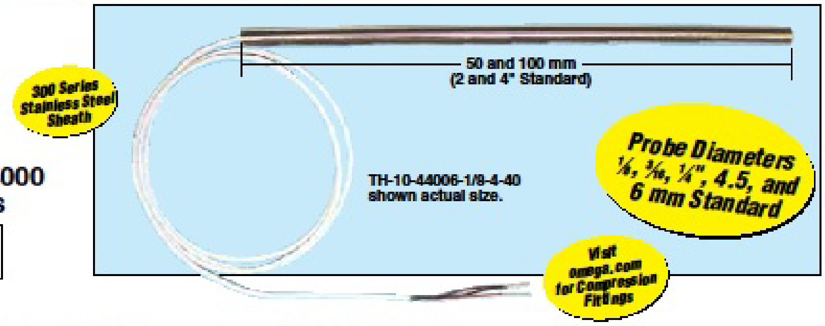






Borehole Temperature Measurement (thermistor)

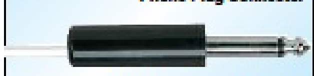
General Purpose Thermistor Probes



TH-10-44000 Series

- **Straight Stainless Steel Sheath—No Transition**
- **Temperature Range -80 to 150°C (-112 to 302°F)**
- **Variety of Thermistor Resistances Available**
- **Compatible With SSLK and BRLK Compression Fittings**
- **1 m (40") 26 AWG Stranded, PFA Insulated and Jacketed Cable with Stripped Leads Standard**

Phone Plug Connector



For phone plug termination, add "-PP" to model number for additional cost.

Standard Dimensions

To Order *Visit omega.com/th-10-44000 for Pricing and Details*

Model Number	Thermistor Resistance @ 25°C (0 to 70°C)	Tolerance Sheath	Sheath Length (inch)
TH-10-44007-(*)-2-40	5000 Ω	±0.2°C	2
TH-10-44006-(*)-2-40	10000 Ω	±0.2°C	2
TH-10-44007-(*)-4-40	5000 Ω	±0.2°C	4
TH-10-44006-(*)-4-40	10000 Ω	±0.2°C	4

** Specify probe diameter as ⅛, 3⁄16 or ¼.*

Options: *Standard probe length is 2 and 4". For longer lengths, change model number to length required (in inches) and add additional cost. Standard cable length is 1 m (40"). For longer lengths, change the model number to the length required (in inches) for additional cost. For a phone plug connector, add "-PP" to the model number for additional cost. Optional resistances of 2252, 3000 and 30,000 Ω and ±0.1°C interchangeability tolerances are available. No change in price for 2252, 3000 or 30000 Ω thermistor (±0.2°C), for ±0.1°C interchangeability tolerance add additional cost.*

Ordering Examples: TH-10-44007-1/8-2-40*, ⅛" Dia. by 2" long probe, 2252 Ω at 25°C, ±0.2°C interchageability, 40" of cable and stripped leads.* ***TH-10-44006-3/16-6-80****, 3⁄16" Dia. by 6" long probe with 10000 Ω at 25°C, ±0.2°C interchangeability, 80" of cable and stripped leads.*

Metric Dimensions

Model Number	Thermistor Resistance @ 25°C (0 to 70°C)	Tolerance Sheath	Sheath Length (mm)
TH-10-44007-(*)-50-1	5000 Ω	±0.2°C	50
TH-10-44006-(*)-50-1	10000 Ω	±0.2°C	50
TH-10-44007-(*)-100-1	5000 Ω	±0.2°C	100
TH-10-44006-(*)-100-1	10000 Ω	±0.2°C	100

** Specify probe diameter as M4.5 or M6.*

Options: *Standard probe length is 50 and 100 mm. For longer lengths, change model number to length required (in mm) for additional cost. Standard cable length is 1 m (40"). For longer lengths, change the model number to the length required (in mm) for additional cost. For a phone plug connector, add "-PP" to the model number for additional cost. Optional resistances of 2252, 3000 and 30,000 Ω and ±0.1°C interchangeability tolerances are available. No change in price for 2252, 3000 or 30000 Ω thermistor (±0.2°C), for ±0.1°C interchangeability tolerance add additional cost.*

Ordering Examples: TH-10-44007-M6-50-1*, 6 mm Dia. by 50 mm long probe with 5000 Ω at 25°C, ±0.2°C interchangeability, 1 m of cable and stripped leads.* ***TH-10-44006-M4.5-150-2****, 4.5 mm Dia. by 150 mm long probe with 10000 Ω at 25°C, ±0.2°C interchangeability, 2 m of cable and stripped leads.*

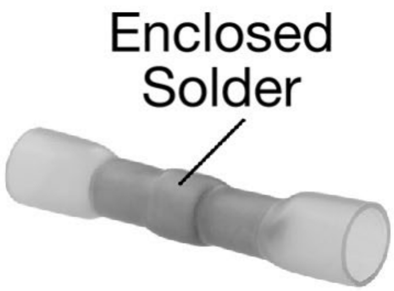
D-13

Cable Splice to Pressure Transducer

McMASTER-CARR®

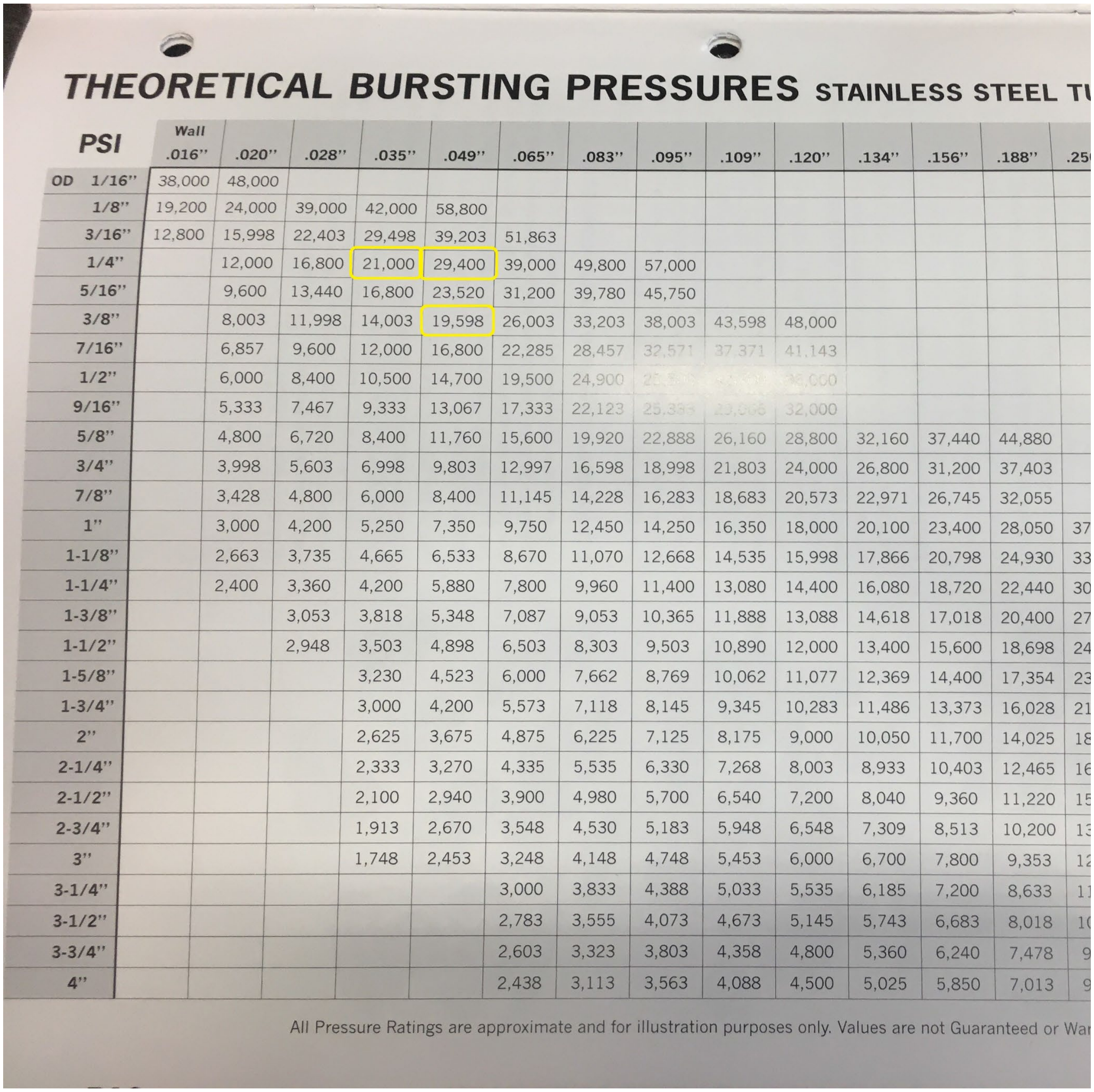
Solder-Loaded Crimp-on Butt Splices

Heat-Shrink, for 24-22 Wire Gauge 9895K11



Application	Power
Type	Splice
Splice Type	Butt
Wire Connection Type	Crimp On, Solder
For Wire Gauge	24-22
Length	0.88"
Color	Clear
Insulation	Fully Insulated
Insulation Material	Polyolefin Plastic
Terminal Material	Tin-Plated Copper
Heat Shrink Liner Material	Adhesive
Shrink Temperature	275° F
Maximum Voltage	600V
Maximum Temperature	220° F
Solder Composition	
Bismuth	58%

Tubing



THEORETICAL BURSTING PRESSURES STAINLESS STEEL TU

PSI OD	Wall .016"	.020"	.028"	.035"	.049"	.065"	.083"	.095"	.109"	.120"	.134"	.156"	.188"	.25
1/16"	38,000	48,000												
1/8"	19,200	24,000	39,000	42,000	58,800									
3/16"	12,800	15,998	22,403	29,498	39,203	51,863								
1/4"		12,000	16,800	21,000	29,400	39,000	49,800	57,000						
5/16"		9,600	13,440	16,800	23,520	31,200	39,780	45,750						
3/8"		8,003	11,998	14,003	19,598	26,003	33,203	38,003	43,598	48,000				
7/16"		6,857	9,600	12,000	16,800	22,285	28,457	32,571	37,371	41,143				
1/2"		6,000	8,400	10,500	14,700	19,500	24,900	[illegible]	[illegible]	[illegible]				
9/16"		5,333	7,467	9,333	13,067	17,333	22,123	25,333	[illegible]	32,000				
5/8"		4,800	6,720	8,400	11,760	15,600	19,920	22,888	26,160	28,800	32,160	37,440	44,880	
3/4"		3,998	5,603	6,998	9,803	12,997	16,598	18,998	21,803	24,000	26,800	31,200	37,403	
7/8"		3,428	4,800	6,000	8,400	11,145	14,228	16,283	18,683	20,573	22,971	26,745	32,055	
1"		3,000	4,200	5,250	7,350	9,750	12,450	14,250	16,350	18,000	20,100	23,400	28,050	37
1-1/8"		2,663	3,735	4,665	6,533	8,670	11,070	12,668	14,535	15,998	17,866	20,798	24,930	33
1-1/4"		2,400	3,360	4,200	5,880	7,800	9,960	11,400	13,080	14,400	16,080	18,720	22,440	30
1-3/8"			3,053	3,818	5,348	7,087	9,053	10,365	11,888	13,088	14,618	17,018	20,400	27
1-1/2"			2,948	3,503	4,898	6,503	8,303	9,503	10,890	12,000	13,400	15,600	18,698	24
1-5/8"				3,230	4,523	6,000	7,662	8,769	10,062	11,077	12,369	14,400	17,354	23
1-3/4"				3,000	4,200	5,573	7,118	8,145	9,345	10,283	11,486	13,373	16,028	21
2"				2,625	3,675	4,875	6,225	7,125	8,175	9,000	10,050	11,700	14,025	18
2-1/4"				2,333	3,270	4,335	5,535	6,330	7,268	8,003	8,933	10,403	12,465	16
2-1/2"				2,100	2,940	3,900	4,980	5,700	6,540	7,200	8,040	9,360	11,220	15
2-3/4"				1,913	2,670	3,548	4,530	5,183	5,948	6,548	7,309	8,513	10,200	13
3"				1,748	2,453	3,248	4,148	4,748	5,453	6,000	6,700	7,800	9,353	12
3-1/4"						3,000	3,833	4,388	5,033	5,535	6,185	7,200	8,633	11
3-1/2"						2,783	3,555	4,073	4,673	5,145	5,743	6,683	8,018	10
3-3/4"						2,603	3,323	3,803	4,358	4,800	5,360	6,240	7,478	9
4"						2,438	3,113	3,563	4,088	4,500	5,025	5,850	7,013	9

All Pressure Ratings are approximate and for illustration purposes only. Values are not Guaranteed or War

Conveyance Pipe

.75" X 5' PVC Well Casing, Sch40
Male X Female Threads, 8TPI

Other products by ESP

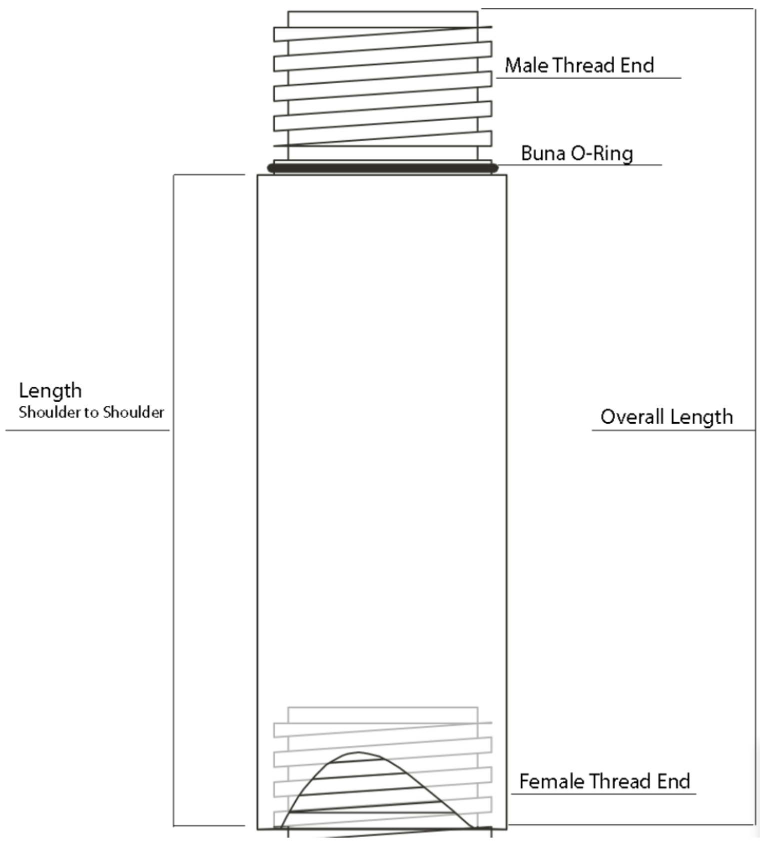
Item #: WE-075R5

Description | Reviews | Also in .75" Sch40 PVC

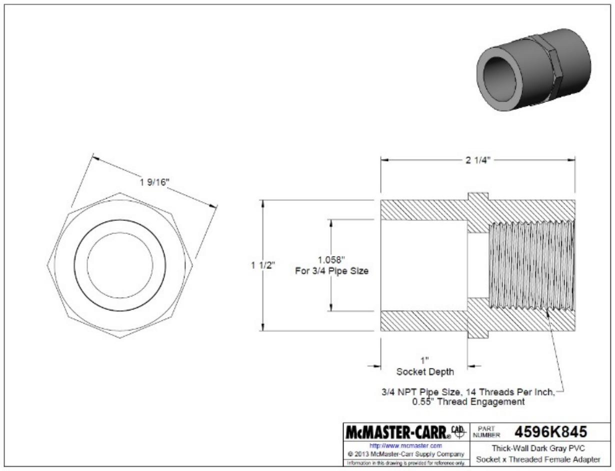
ESP's premium quality PVC Pipe is precision machined, cleaned and bagged to prevent contamination and meet environmental standards. Each piece of pipe has a Male and Female threaded end that join together to make a flush union that does not require any glue or tape. By eliminating the need for couplings, you can reduce the overall diameter of your hole and prevent snagging your pipe as it enters the hole. This thread is made to industry standards and should work with any existing flush thread pipe you have. For questions about custom pipe or bulk orders, please call us at 888-511-4377

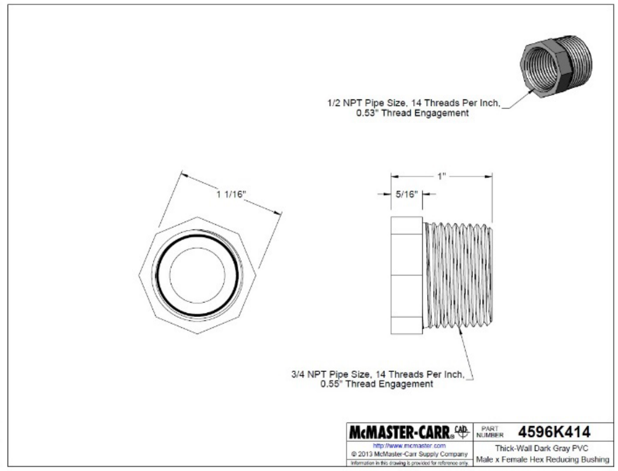
Specifications:

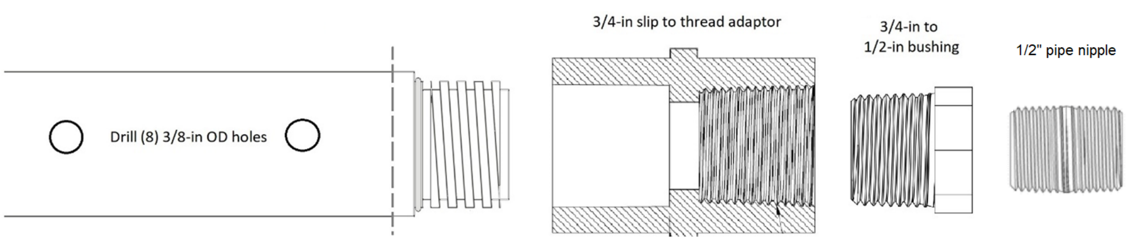
Product Size: 3/4" x 5' Casing or Riser
Schedule: 40
Length: 60" or 5ft
Overall Length: 61"
Connection: Male x Female Thread
Thread Style: Flush Thread
TPI: 8
Pipe OD: 1.050"
Pipe ID: 0.804"
O-Ring Material: Buna Rubber



Packer Connection







Conveyance to packer adaptor comes pre-assembled

Borehole Centralizers

ESP Supply

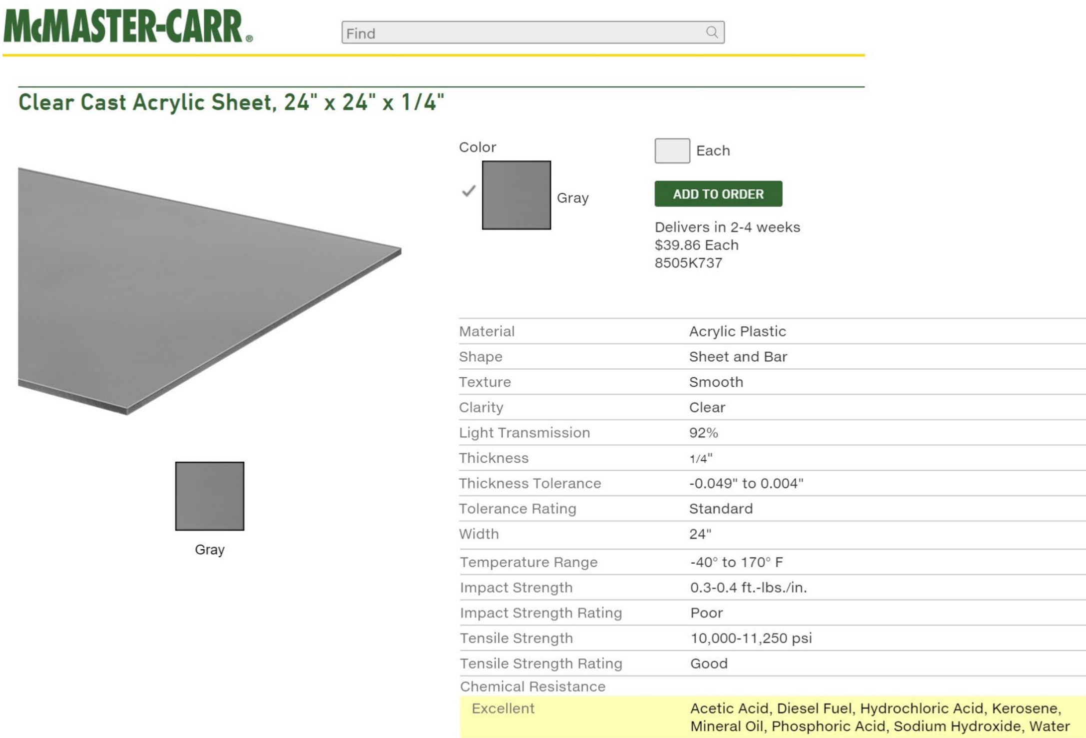
Direct Push • Environmental • Wells • Drilling

Other products by Fostco

Item #:	W-075CEN
Our Price:	**$19.50**
Quantity:	1

+ Add to Cart | Add to Wishlist

Borehole tubing spacers



McMASTER-CARR

Find

Clear Cast Acrylic Sheet, 24" x 24" x 1/4"

Color

Gray

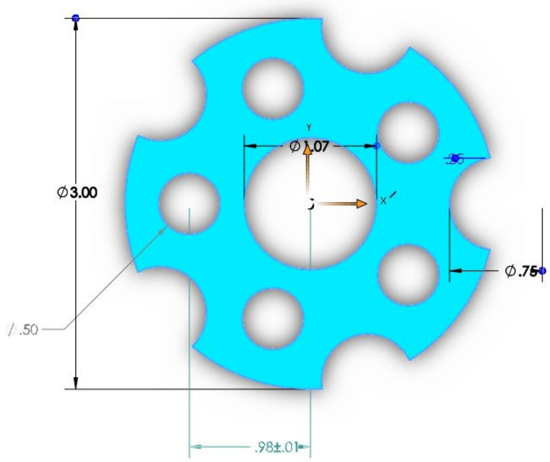
Each

ADD TO ORDER

Delivers in 2-4 weeks
$39.86 Each
8505K737

Gray

Material	Acrylic Plastic
Shape	Sheet and Bar
Texture	Smooth
Clarity	Clear
Light Transmission	92%
Thickness	1/4"
Thickness Tolerance	-0.049" to 0.004"
Tolerance Rating	Standard
Width	24"
Temperature Range	-40° to 170° F
Impact Strength	0.3-0.4 ft.-lbs./in.
Impact Strength Rating	Poor
Tensile Strength	10,000-11,250 psi
Tensile Strength Rating	Good
Chemical Resistance	
Excellent	Acetic Acid, Diesel Fuel, Hydrochloric Acid, Kerosene, Mineral Oil, Phosphoric Acid, Sodium Hydroxide, Water



Grout Adaptor

McMASTER-CARR

4629k14

Brass On/Off Valve with Lockable Lever Handle

3/4 NPT Female

Valve Function	On/Off
Valve Type	Ball
Activation	Manual
Valve Operation	Handle
Handle Style	Lever
Handle Type	Lockable
Connection Type	Pipe
Connection Style	Threaded
Pipe Size	3/4
Gender	Female × Female
Thread Type	NPT
Flow Coefficient (Cv)	66
Maximum Pressure	600 psi @ 100° F
Temperature Range	-50° to 400° F
Vacuum Rating	29.9 in. of Hg
Body Material	Brass
Ball Material	Brass
Seal Material	Fluoroelastomer Rubber
Seat Material	PTFE Plastic

McMASTER-CARR

High-Pressure 316 Stainless Steel Pipe Fitting 4443K685

Cap, 3/4 NPT

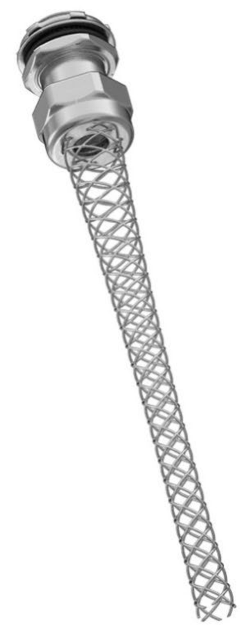
For Use With	Air, Hydraulic Fluid, Natural Gas, Oil, Steam, Water
Shape	Cap/Plug
Type	Cap
Material	316 Stainless Steel
Class	3000
Fabrication	Forged
Connection Type	Pipe
Connection Style	Threaded
Connection	NPT Female
Pipe Size	3/4
Length	1 21/64"
For Pipe	
Schedule	80
Material	316 Stainless Steel, 316/316L Stainless Steel
Specifications Met	ANSI/ASME B16.11, ASTM A182
Maximum Pressure	3,000 psi @ 72° F
Maximum Steam Pressure	2,800 psi @ 350° F
RoHS	RoHS 3 (2015/863/EU) Compliant
Country of Origin	United States

Thermistor Cable pass-through

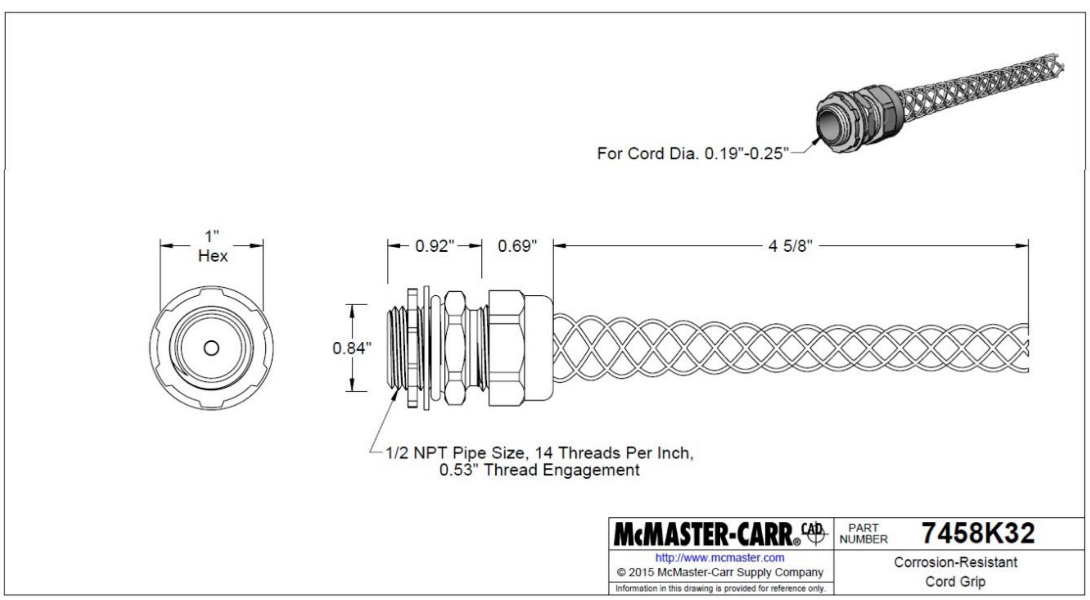
McMASTER-CARR®

Stainless Steel Liquid-Tight Cord Grip

Sure Grip, for 0.19"-0.25" Cord OD, 1/2 Knockout Size 7458K32



Shape	Straight
For Cord OD	0.19"-0.25"
Mounting Location	Knockout
For Knockout Trade Size	1/2
Mesh Length	4 5/8"
Mesh Material	Stainless Steel
Knockout Connection Type	Threaded
Thread Size	1/2
Thread Type	NPT
For Cord Shape	Round
Material	Stainless Steel
Cord Holding Type	Bushing
Bushing Material	Rubber
Temperature Range	-40° to 250° F
Flexibility	Continuous-Flex
Features	Rubber O-Ring, Zinc-Plated Steel Locknut
Environment	Corrosive, Washdown
Environmental Rating	IP67



Swagelok Check Valve - 1/3 psi SS-CHS4-BU-FG-1/3

Swagelok Check Valves

End Connections		Pressure Rating at 100°F (37°C) psig (bar)	Basic Ordering Number		Dimensions in. (mm)	
Type	Size			Series	A	B
Fractional Swagelok tube fitting	1/8 in.	6000 (413)	SS-CHS2-	CH4	2.27 (57.7)	11/16
	1/4 in.		SS-CHS4-		2.43 (61.7)	
	3/8 in.		SS-CHS6-	CH8	2.75 (69.9)	1
	1/2 in.		SS-CHS8-		2.96 (75.2)	
	3/4 in.	5000 (344)	SS-CHS12-	CH16	3.52 (89.4)	1 5/8
	1 in.	4700 (323)	SS-CHS16-		3.88 (98.6)	

CH Series

Nominal Cracking Pressure psi (bar)	Cracking Pressure Range psi (bar)	Reseal Pressure psi (bar)
1/3 (0.03)	Up to 3 (0.21)	Up to 6 (0.42) back pressure
1 (0.07)	Up to 4 (0.28)	Up to 5 (0.35) back pressure
5 (0.35)	3 to 9 (0.21 to 0.63)	Up to 2 (0.14) back pressure
10 (0.69)	7 to 15 (0.49 to 1.1)	3 (0.21) or more inlet pressure
25 (1.8)	20 to 30 (1.4 to 2.1)	17 (1.2) or more inlet pressure

Technical Data

Cracking pressure—the inlet pressure at which the first indication of flow occurs (steady stream of bubbles).

Reseal pressure—the pressure at which there is no indication of flow.

Back pressure—the differential pressure between the inlet and outlet pressures.

⚠ **For valves not actuated for a period of time, initial cracking pressure may be higher than the set cracking pressure.**

Series	Maximum Flow Coefficient (C_v)	Nominal Cracking Pressure① psi (bar)	Maximum Back Pressure at 70°F (20°C) psig (bar)
Fixed Cracking Pressure			
2C	0.10	1/3, 1, 10 and 25 (0.03, 0.07, 0.69, and 1.8)	1000 (68.9)②
4C	0.47		
6C	1.47		200 (13.7)
8C	1.68		
12C, 16C	4.48		
CH4	0.67	1/3, 1, 5, 10 and 25 (0.03, 0.07, 0.35 0.69, and 1.8)	6000 (413)③
CH8	1.8		
CH16	4.7		5000 (344)③
4CP	0.35	1/3, 1, 10 and 25 (0.03, 0.07, 0.69, and 1.8)	3000 (206)
8CP	1.20		
Adjustable Cracking Pressure			
CA	0.37	3 to 50 (0.21 to 3.5) 50 to 150 (3.5 to 10.4) 150 to 350 (10.4 to 24.2) 350 to 600 (24.2 to 41.4)	3000 (206)
4CPA	0.35		
8CPA	1.20		

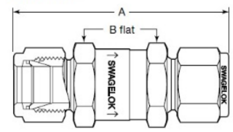
For more information about pressure ratings of valves with tube fitting end connections, see Swagelok® *Tubing Data* (MS-01-107), page 224.

① Other cracking pressures are available; contact your authorized Swagelok sales and service representative.

② For cracking pressure of 25 psi (1.8 bar), maximum back pressure is 3000 psig (206 bar).

③ Maximum back pressure may be limited by the end connection. See **Dimensions**, page 12.

CH Series



Ordering Information

To order, add a cracking pressure designator to the basic ordering number.

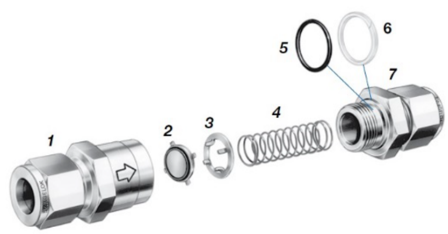
Cracking Pressure psi (bar)	Designator
1/3 (0.03)	1/3
1 (0.07)	1
5 (0.35)	5
10 (0.69)	10
25 (1.8)	25

Example: SS-CHS2-**1/3**

Component	Material Grade/ ASTM Specification
1 Inlet body	*316 SS/A479*
2 Poppet	*Fluorocarbon FKM-bonded① 316 SS/A479*
3 Poppet stop	*316 SS/A240*
4 Spring	*302 SS/A313*
5 O-ring	*Fluorocarbon FKM*
6 Backup ring	PTFE/D1710
7 Outlet body	*316 SS/A479*
Lubricant	*PTFE-based*

Wetted components listed in *italics*.

① Material Safety Data Sheet for bonding agent available on request.



Options and Accessories

Seal Materials (All Series)

Fluorocarbon FKM O-rings are standard in 316 stainless steel valves; Buna N O-rings are standard in brass valves. Other elastomer seals (poppet bonding material and O-ring) are available. To order, insert the seal material designator into the valve ordering number.

Seal Material	Designator	Temperature Rating °F (°C)
Buna N	-BU	−10 to 250 (−23 to 121)
Ethylene propylene	-EP	−50 to 300 (−45 to 148)
Fluorocarbon FKM	-VI	−10 to 375 (−23 to 190)①
Neoprene	-NE	−40 to 250 (−40 to 121)

① −10 to 400°F (−23 to 204°C) for CH series.

Pressure Transducer (NoShok)

Industrial Pressure Transmitters & Transducers

High Accuracy Heavy-Duty

CE

High pressure model

615/616 SERIES

- Vacuum ranges through 0 psig to 145,000 psig; absolute ranges from 0 psia to 15 psia through 0 psia to 300 psia
- Current and voltage outputs available
- 316 and 17-4PH Stainless Steel wetted parts
- CE compliant to suppress RFI, EMI and ESD

APPLICATIONS

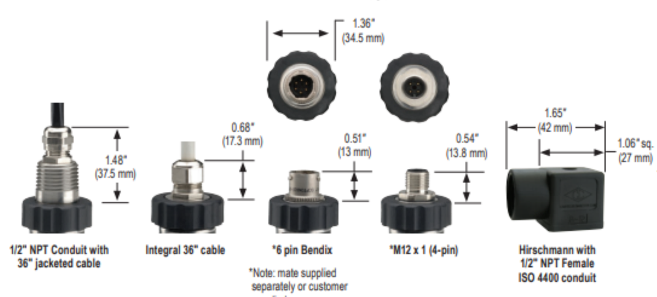
- Construction
- Hydraulics & pneumatics
- Laboratory & test equipment
- Power generation
- Stamping & forming presses
- Transportation

SPECIFICATIONS

Output signals	4 mA to 20 mA, 2-wire; 0 Vdc to 5 Vdc, 0 Vdc to 10 Vdc, 1 Vdc to 5 Vdc,3-wire
Pressure ranges	Vacuum through 0 psig to 145,000 psig Absolute from 0 psia to 15 psia through 0 psia to 300 psia
Accuracy	± 0.25% full scale (BFSL); optional ± 0.125% full scale (BFSL); (includes the effects of non-linearity, hysteresis, non-repeatability, zero point and full scale errors)
Stability	≤ ±0.2% full scale for 1 year, non-accumulating
Adjustment	± 10% full scale for zero and span
Response time	Less than 1 ms (between 10% and 90% full scale)
Service life	>100,000,000 load cycles
Temperature ranges	Compensated 32 °F to 175 °F (0 °C to 80 °C) Effect ± 0.01%/ °F for zero and span Media -20 °F to 212 °F (-30 °C to 100 °C) Ambient -15 °F to 175 °F (-10 °C to 80 °C) Storage -40 °F to 212 °F (-40 °C to 100 °C)
Power requirement*	10 Vdc to 30 Vdc (4 mA to 20 mA, 2-wire, 1 Vdc to 5 Vdc, 3-wire, 1 Vdc to 6 Vdc, 3-wire, 0 Vdc to 5 Vdc, 3-wire) 14 Vdc to 30 Vdc (0 Vdc to 10 Vdc, 3-wire, 1 Vdc to 11 Vdc, 3-wire)
Load limitations	≤ (VPower-10)/0.020 Amp for 4 mA to 20 mA ≥ 10,000 Ω for 0 Vdc to 10 Vdc, 3-wire ≥ 5,000 Ω for 0 Vdc to 5 Vdc, 3-wire
Proof pressure	3 times full scale for ranges 0 psi to 2 psi through 0 psi to 200 psi 1.75 times full scale for ranges 0 psi to 300 psi through 0 psi to 10,000 psi 1.5 times full scale for 0 psi to 15,000 psi 1.2 times full scale for ranges 0 psi to 20,000 psi through 0 psi to 145,000 psi
Burst pressure	3.8 times full scale for ranges 0 psi to 2 psi through 0 psi to 200 psi 4 times full scale for ranges 0 psi to 300 psi through 0 psi to 10,000 psi 3 times full scale for 0 psi to 15,000 psi 1.5 times full scale for ranges 0 psi to 20,000 psi through 0 psi to 145,000 psi
Measuring element	316 Stainless Steel for vacuum through 300 psi; 17-4PH Stainless Steel for ≥500 psi
Connection	316 Stainless Steel
Housing material	316 Stainless Steel
Environmental rating	IP65
Electromagnetic rating	CE compliant to EMC norm EN 61326:2014/A1:1998 RFI, EMI and ESD protection
Electrical protection	Reverse polarity, overvoltage and short circuit protection
Shock	1,000 g's according to IEC 60068-2-27
Vibration	15 g's according to IEC 60068-2-6
Weight	Approximately 7.2 oz.

* Unregulated

Also available with our 1800 Series Attachable Loop Indicator. Visit www.noshok.com for more information.



2-WIRE WIRING

	Hirschmann	Cable	M12	Bendix
+ Supply	1	Red	1	A
+ Output	2	Black	3	B

3-WIRE WIRING

	Hirschmann	Cable	M12	Bendix
+ Supply	1	Red	1	A
Common	2	Black	3	B
+ Output	3	White	4	C

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Pressure Transducer (Druck)

UNIK 5000 Specifications

Measurement

Operating Pressure Ranges:

Gauge Ranges

Any zero based range 70 mbar to 70 bar (1 to 1000 psi)

***Note**: All psi values are approximate.*

Sealed Gauge Ranges

Any zero based range 10 to 700 bar (145 to 10000 psi)

Absolute Ranges

Any zero based range 100 mbar to 700 bar (1.5 to 10000 psi)

Differential Ranges

Wet/Dry

Uni-directional or bi-directional 70 mbar to 35 bar (1 to 500 psi)

Wet/Wet

Uni-directional or bi-directional 350 mbar to 35 bar (5 to 500 psi)

Line pressure: 70 bar (1000 psi) maximum

Barometric Ranges

Barometric ranges are available with a minimum span of 350 mbar (5.1 psi)

Non-Zero Based Ranges

Non-zero based ranges are available. For non-zero based gauge ranges, please contact Druck to discuss your requirements.

Over Pressure

- 10 × FS for ranges up to 150 mbar (2 psi)
- 6 × FS for ranges up to 700 mbar (10 psi)
- 2 × FS for barometric ranges
- 4 × FS for all other ranges (up to 200 bar for ranges ≤70 bar and up to 1200 bar for ranges >70 bar)*

For differential versions the negative side must not exceed the positive side by more than:

- 6 × FS for ranges up to 150 mbar (2 psi)
- 4 × FS for ranges up to 700 mbar (10 psi)
- 2 × FS for all other ranges up to a maximum of 15 bar (200 psi)

Containment Pressure

- Ranges up to 150 mbar (2 psi) gauge 10 x FS Ranges up to 70 bar (1000 psi) gauge 6 x FS (200 bar (2900 psi) max)
- Ranges up to 70 bar (1000 psi) absolute 200 bar (2900 psi)
- Ranges above 70 bar (1000 psi)
- 1200 bar (17400 psi)*

Differential (-ve port) must not exceed positive port by more than 6 × FS (15 bar (200 psi) maximum.

Supply and Outputs

Electronics Option	Description	Supply voltage (V)	Output	Current Consumption (mA)
0	mV Passive	2.5 to 12	10 mV/V^	<2 at 10 V
1	mV Linearised	7 to 12	10 mV/V^	<3
2	mA	7 to 28**	4-20 mA	<30
3	0 to 5 V 4-wire	7 to 16**	0 to 5 V	<3
4	0 to 5 V 3-wire	7 to 16**	0 to 5 V*	<3
5	Basic Configurable (3-wire)	See below	See below	<3
6	0 to 10 V 4-wire	12 to 16**	0 to 10 V	<3
7	0.5 V to 4.5 V Ratiometric	5.0 ± 0.5	0.5 to 4.5 V	<3
8	Configurable (4-wire)	7 to 36	See below	See below
9	Configurable (3-wire)	7 to 36	See below	See below

^ with a 10 V supply mV output sensors give 100 mV over the full scale pressure.

- *Output is ratiometric to the supply voltage*
- *Output reduces pro-rata for pressure ranges below 350 mbar (5 psi)*

**0 to 5 V 3-wire output is non true zero. At pressures below 1% of span the output will be fixed at approximately 50 mV*

***32 V in non-hazardous area operation*

~ Supply voltage is between [Maximum Output + 1 V] (7 V minimum) to 16 V (32 V in non-hazardous area operation)

Basic Configurable (Option 5), Configurable 4-Wire (Option 8), Configurable 3-Wire (Option 9)

Any pressure signal output configurations will be available, subject to the following limitations:

Output Specification	Basic Configurable (Option 5)	Configurable (Options 8, 9)
Minimum span:	4 V	2 V
Maximum span:	10 V	20 V
Maximum output limit:	11 V	±10 V
Maximum zero offset:	Span / 2	±Span
Current consumption:	< 3 mA	< 20 mA @ 7 Vdc decreasing to < 5 mA @ 32 Vdc
Reverse output response:	No	Yes
Maximum operating temperature:	+125°C	+80°C

Output voltage range can be specified to a resolution of 0.1 V.

The output will continue to respond to 110% FS. i.e. if a 0 to 10 V output is specified, the output will continue to increase proportionally to applied pressure until at least 11 V.

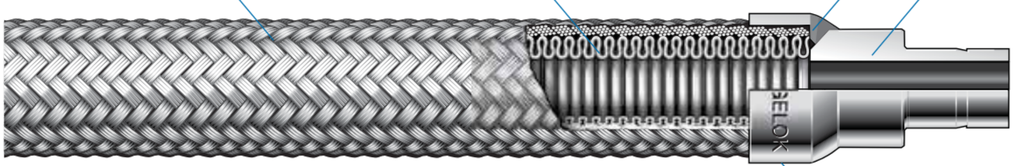
Option 5: Not true zero, the output will saturate at < 50 mV.

Options 8, 9: On startup <100 mA drawn for 10 ms typically.

Options 8, 9: Shunt calibration: not available with reverse output.

Flex Hose Connections

FX Series Metal Hose



Technical Data

Nominal Hose Size in. (mm)	Inside Diameter in. (mm)	Outside Diameter in. (mm)	Minimum Center Line Bend Radius in. (cm)		Temperature Range °F (°C)	Working Pressure at –325 to 300°F (–200 to 148°C) Vacuum to ... psig (bar)	Minimum Burst Pressure at 70°F (20°C) psig (bar)	Bulk Hose Weight lb/ft (kg/m)
			Static	Dynamic				
1/4 (6.4)	0.25 (6.4)	0.68 (17.3)	1.5 (3.81)	5.5 (14.0)	–325 to 1000 (–200 to 537)	6000 (413)	24 000 (1653)	0.49 (0.73)
3/8 (9.7)	0.38 (9.5)	0.92 (23.4)	2.5 (6.40)	7.0 (17.8)		5000 (344)	20 000 (1378)	0.77 (1.15)
1/2 (12.7)	0.51 (13.0)	0.98 (24.9)	3.0 (7.62)	8.0 (20.3)		4500 (310)	18 000 (1240)	0.85 (1.26)
3/4 (19.0)	0.75 (19.0)	1.40 (35.6)	4.0 (10.2)	10.0 (25.4)		3600 (248)	14 400 (992)	1.58 (2.35)
1 (25.4)	1.00 (25.4)	1.70 (43.2)	5.0 (12.7)	11.0 (27.9)		3000 (206)	12 000 (826)	2.32 (3.45)
1 1/4 (31.8)	1.25 (31.8)	2.00 (50.8)	6.5 (16.5)	12.5 (31.8)		2600 (179)	10 400 (716)	2.88 (4.29)
1 1/2 (38.1)	1.50 (38.1)	2.36 (59.9)	7.5 (19.1)	13.0 (33.0)		2200 (151)	8 800 (606)	3.57 (5.31)
2 (50.8)	2.00 (50.8)	2.82 (71.6)	9.0 (22.9)	14.0 (35.6)		1675 (115)	6 700 (461)	4.45 (6.62)

Pressure-temperature ratings may be limited by the end connections.

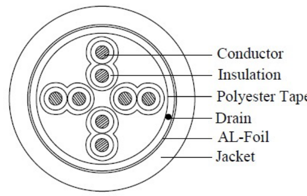
Data cable extension

REV.	DESCRIPTION	DATE
A		11-2014
B		05-2016

Construction & Material :

Item		Unit	Specification
Product			CAT.5e STP 4P CMX Rated
Conductor	Size	AWG	24
	Number	pairs	4
	Material		Solid Bare Copper
	Construction	pcs/mm	1/0.52
	Diameter	mm	0.52
Insulation	Material		HDPE
	Identification		With Strip Colour Marking On White Cores
	Min.thickness	mm	0.230
	Avg.thickness	mm	0.255
	Diameter	mm	1.035
	Color		Blue-White/Blue Orange-White/Orange Green-White/Green Brown-White/Brown
Taping	Material		Polyester Tape
	Lay Length	%	Overlap 25
Drain Wire	Material		Stranded Tinned Copper
	Construction	pcs/mm	1/0.40
Shielding	Material		AL-Foil
	Lay Length	%	Overlap 25
Jacket	Material		PE(CMX Rated)
	Min.thickness	mm	0.47
	Avg.thickness	mm	0.52
	Overall Diameter	mm	6.30±0.30
	Color		Black
	Cable Marking	CAT5E 4PR 24AWG FTP TYPE CMX UV DIRECT BURIAL OUTDOOR PE EIA/TIA-568-C ROHS xxxxFT	

RoHS



Cross Section

DRAWER	JL
CHECKED	
APPROVED	

PART NUMBER	TITLE	ID(NO.)
10X6-722NH	Direct Burial/Outdoor rated Cat 5e Black Ethernet Cable, Solid, CMX, STP ,Foil+Waterproof Tape, 24 AWG, Spool, 1000 foot	245

888-212-8295 CableWholesale.com

REV.	DESCRIPTION	DATE
A		11-2014
B		05-2016

Electrical Property :

Item	Unit	Standard
Conductor D-C Resistance @20°C	Ohm/100 Meters	≤ 9.5
D-C Resistance Unbalance @20°C	%	≤ 2.5
Max. Delay Skew	nF/100 Meters	≤ 5.6
Mutual Capacitance	nS/100 Meters	≤ 45.0
Capacitance Unbalance	pF/100 Meters	≤ 330
Characteristic Impedance (1-100MHz)	0/100 Meters	100 ± 15 ohm
Temperature Rating	Installation & Operating	-40°C to +70°C

Frequency	Attenuation	Return Loss	NEXT	PS-NEXT	ELFEXT	PS-ELFEXT	Delay	ACR
MHz	dB(100m)	dB	dB	dB	dB(100m)	dB(100m)	ns(100m)	dB
	Maximum	Minimum	Minimum	Minimum	Minimum	Minimum	Maximum	
1	2.04	20.00	65.30	62.3	64.00	61.00	570.00	63.26
4	4.05	23.01	56.27	53.3	51.96	48.96	552.00	52.22
10	6.47	25.00	50.30	47.3	44.00	41.00	545.38	43.83
16	8.25	25.00	47.24	44.3	39.92	36.92	543.00	38.99
20	9.27	25.00	45.78	42.8	37.98	34.98	542.05	36.52
25	10.42	24.32	44.33	41.3	36.04	33.04	541.20	33.91
31.25	11.72	23.64	42.88	39.9	34.10	31.10	540.44	31.16
62.5	16.69	21.54	38.36	35.4	28.08	25.08	538.55	21.37
100	21.98	20.11	35.30	32.3	24.00	21.00	537.60	13.33

RoHS

DRAWER	JL
CHECKED	
APPROVED	

PART NUMBER	TITLE	ID(NO.)
10X6-722NH	Direct Burial/Outdoor rated Cat 5e Black Ethernet Cable, Solid, CMX, STP ,Foil+Waterproof Tape, 24 AWG, Spool, 1000 foot	245

888-212-8295 CableWholesale.com

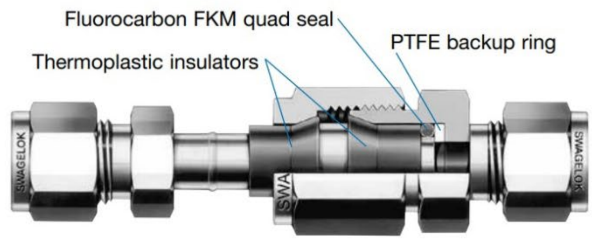
Dielectric Fittings

Dielectric fittings isolate monitoring instruments from the effects of electrical current. Installed on impulse lines ahead of monitoring stations in natural gas pipelines, the fittings interrupt cathodic current flow while permitting full fluid flow.

The fitting design is unique in that it separates the two primary functions of electrical insulation and fluid containment. Thermoplastic insulators provide high dielectric strength over a wide range of operating and climatic conditions. A fluorocarbon FKM quad seal contained in the fitting provides the primary fluid seal.

Features

- Metal components are machined from 316 stainless steel for use in rugged environments.
- Molded thermoplastic insulation with excellent electrical, chemical, and ultraviolet resistance and low water absorption maintains dielectric strength and integrity over a wide range of operating and climatic conditions.
- Gaugeable Swagelok® tube fitting or tapered pipe thread end connections (NPT/BSP) provide direct connection to tubing or piping system.



Materials

Body: 316 stainless steel
Insulators: Polyamide-imide
Quad Seal: 70 durometer fluorocarbon FKM
Backup Ring: Virgin PTFE

Technical Data

Electrical Resistance of Insulators at 70°F (20°C):
10×10^6 Ω at 10 V (dc)
Pressure Rating: 5000 psig (344 bar)
Temperature Rating: –40 to 200°F (–40 to 93°C)

End Connections			Ordering Number	Dimensions, in. (mm)						
Inlet/Outlet	Tube Size	Pipe Size		A	B	C	E	F	Fx	G
Swagelok tube fittings	1/4 in.	—	SS-4-DE-6	3.77 (95.8)	2.57 (65.3)	0.60 (15.2)	0.19 (4.8)	1/2	13/16	9/16
	3/8 in.	—	SS-6-DE-6	3.92 (99.6)	2.59 (65.8)	0.66 (16.8)	0.28 (7.1)	5/8		11/16
	1/2 in.	—	SS-8-DE-6	4.17 (106)	2.37 (60.2)	0.90 (22.9)		13/16		7/8
	12 mm	—	SS-12-MDE-6	4.23 (107)	2.43 (61.7)			22 mm		
Swagelok tube fitting/ male NPT	3/8 in.	1/4 in.	SS-6-DE-1-4	3.73 (94.7)	—	0.66 (16.8)		5/8	7/8	11/16

Dimensions shown with Swagelok nuts finger-tight. Dimensions are for reference only and are subject to change.

Power Supply

ANALYTIC SYSTEMS
Power Conversion Solutions

AC SOURCE POWER SUPPLIES | **PWS1000**

PWS1000 AC SOURCE POWER SUPPLY

The PWS1000 series of Power Supplies provides 1000 watts of continuous power at 12, 24, or 48 volts DC from a 110 or 220 volt AC source.

The newly updated single-board design is ultra-quiet and features the latest generation of current-mode PWM control. Modern switch-mode technology coupled with powerful IGBT switching transistors allow for maximum efficiency and reliability while maintaining compactness. New circuit innovations reduce output ripple to levels previously only available from bulky and inefficient linear power supplies.

Designed for ease of use the PWS1000 has a four contact output terminal (two positive and two negative contacts) for easy connection of devices, covered output voltage adjust and a bright LED display panel for at-a-glance indication of the operational status.

Reliability features include an input fuse, thermal shutdown, and output short circuit shutdown with automatic recovery. While the devices powered by the unit are protected from excessive voltage and current by an output over voltage crowbar circuit and current limiting.

3 YEAR WARRANTY

Available models

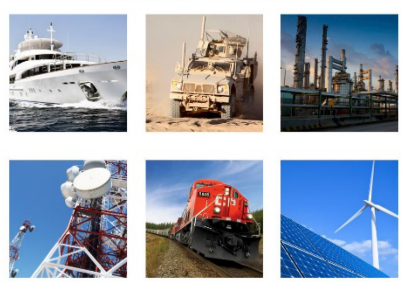
Input

110V	220V

Output

12V	24V	48V	72V

Applications



PWS1000 | AC SOURCE POWER SUPPLY

INPUT

Nominal Voltage	110VAC	220VAC
Actual Voltage	90-130VAC	180-260VAC
Input Amps (Max)	13.2A(12V) 17A (24/32/48V)	6.6A (12V) 8.5A (24/32/48V)
Input Fuse (MDA)	20A (12V) 25A (24/32/48V)	10A(12V) 15A (24/32/48V)
Input Frequency	45 -65Hz	
Noise on Input	<50mV	

OUTPUT

Nominal Voltage	12VDC	24VDC	48VDC	72VDC
Actual Voltage	13.6 ± 0.05VDC	27.2 ± 0.05VDC	54.4 ± 0.1VDC	81.6 ± 1.5VDC
Output Current	60A Cont./ 70A Peak	40A Cont./ 45A Peak	20A Cont./ 22.5A Peak	13.3A Cont./ 15A Peak
Output Crowbar	16.0 ± 0.5V	32.0 ± 1.0V	63.9 ± 2.0V	96 ± 3.0V
Output Adjustment	± 1.0 V			
Output Ripple & Noise	<50 mV			
Transient Response	<1V for 50% Surge			
Regulation (Line & Load)	< +/- 0.5%			
Duty Cycle	Peak 20% for 10 minutes maximum Continuous 100% for 24 hours per day			
Efficiency	> 80% @ Maximum Output			

MECHANICAL

Dimensions	14.5 in (36.8 cm) Long x 9.9 in (25.1 cm) Wide x 5.5 in (14.0 cm) High
Clearance	1.0 in / 2.5 cm all around
Weight	12 lb / 5.5 kg
Material and Finish	Marine Grade Black Anodized Aluminum with 18-8 Stainless Fasteners
Mounting	Wall or shelf mount
Connections	Four contact output terminals

OPTIONS

GMDSS - Digital Voltmeter/Ammeter & Remote control kit.

Parallel Output Diodes for multiple unit connection

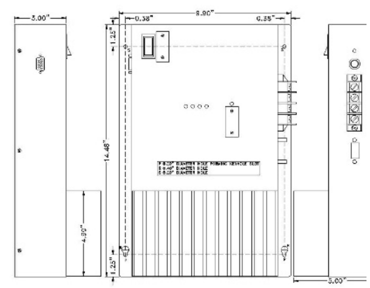
Safety Special Inspection (CSA/UL)

Integrated Digital Voltmeter/Ammeter

Heavy Duty Ruggedization with Wide OperationalTemperature range

Custom Input/Output Voltages available

DIMENSIONS



ENVIRONMENTAL AND SAFETY

Operating Temperature Range	-25°C to +40°C @ maximum output. Derate Linearly 2.5% per °C from 40°C (Optional -40°C to +55°C wide operational temperature range available)
Humidity	0 - 95% Relative Humidity (non-condensing) with standard conformal coating
Audible Noise	NONE 0db @ 3ft
Typical Service Life	> 10 years (87,600 hrs)
Isolation	Input-Case, Input-Output: 1500 VDC. Output-Case:500 VDC (1500V for 48 V Output)
Warranty	Three Years Parts and Labor
Safety	Certified to CSA C22.2 No.107.1 and UL 458

Note: Specifications are subject to change without notice.

ANALYTIC SYSTEMS
Power Conversion Solutions

AnalyticSystems.com
sales@analyticsystems.com
604.946.9981 800.668.3884

8128 River Way
Delta BC V4G 1K5

System Fittings

Pressure Rating Basis and Thread Specifications

Thread Type (End Connection)	Pressure Rating Basis	Thread Type	Reference Specification
Swagelok Tube Fittings	Swagelok tube fitting ends are rated to the working pressure of tubing as listed in Swagelok Tubing Data, MS-01-107. Careful selection of high-quality tubing is important when installing safe, leak-tight systems.	Unified Inch Screw Threads	ASME B1.1
NPT	ASME B31.3, Process Piping or pressure testing with a 4:1 design factor based on hydraulic fluid. leakage.	NPT	ASME B1.20.1, SAE AS71051

Pressure Ratings

Table 3—Fractional Stainless Steel Seamless Tubing

Allowable working pressures are calculated from an S value of 20 000 psi (137.8 MPa) for ASTM A269 tubing at –20 to 100°F (–28 to 37°C), as listed in ASME B31.3, except as noted.

For Welded Tubing

For welded and drawn tubing, a derating factor must be applied for weld integrity:

- for double-welded tubing, multiply working pressure by 0.85
- for single-welded tubing, multiply working pressure by 0.80.

Tube OD in.	Tube Wall Thickness, in.											Swagelok Fitting Series
	0.010	0.012	0.014	0.016	0.020	0.028	0.035	0.049	0.065	0.083	0.095	
	Working Pressure, psig **Note:** For gas service, select a tube wall thickness outside of the (See **Gas Service,** page 2.)											
1/16	5600	6800	8100	9400	12 000							100
1/8						8500	10 900					200
3/16						5400	7 000	10 200				300
1/4						4000	5 100	7 500	10 200①			400
5/16							4 000	5 800	8 000			500
3/8							3 300	4 800	6 500	7500①②		600
1/2							2 600	3 700	5 100	6700		810

NPT/ISO Pipe Pressure Ratings

Ratings are based on ASME Code for Pressure Piping B31.3, Process Piping, at ambient temperature.

NPT/ISO Pipe Size in.	316 SS, Carbon Steel, Alloy (20, 600, and C-276)		Brass and Aluminum		Alloy 400		Titanium		Alloy 2507 and Alloy 625		6-Moly		Alloy 825	
	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
	psig (bar)	psig (bar)	psig (bar)	psig (bar)	psig (bar)	psig (bar)	psig (bar)	psig (bar)	psig (bar)	psig (bar)	psig (bar)	psig (bar)	psig (bar)	psig (bar)
1/16	11 000 (757)	6 700 (461)	5 500 (378)	3 300 (227)	9 900 (682)	6 000 (413)	8 800 (606)	5 300 (365)	15 000 (1 033)	12 900 (888)	14 900 (1 026)	9 000 (620)	12 800 (881)	7800 (537)
1/8	10 000 (689)	6 500 (447)	5 000 (344)	3 200 (220)	9 000 (620)	5 800 (399)	8 000 (551)	5 200 (358)	15 000 (1 033)	12 500 (861)	13 500 (930)	8 800 (606)	11 600 (799)	7500 (516)
1/4	8 000 (551)	6 600 (454)	4 000 (275)	3 300 (227)	7 200 (496)	5 900 (406)	6 400 (440)	5 200 (358)	15 000 (1 033)	12 700 (875)	10 800 (744)	8 900 (613)	9 300 (640)	7600 (523)
3/8	7 800 (537)	5 300 (365)	3 900 (268)	2 600 (179)	7 000 (482)	4 700 (323)	6 200 (427)	4 200 (289)	15 000 (1 033)	10 200 (702)	10 500 (723)	7 100 (489)	9 000 (620)	6100 (420)
1/2	7 700 (530)	4 900 (337)	3 800 (261)	2 400 (165)	6 900 (475)	4 400 (303)	6 100 (420)	3 900 (268)	14 800 (1 019)	9 400 (647)	10 400 (716)	6 600 (454)	8 900 (613)	5700 (392)
3/4	7 300 (502)	4 600 (316)	3 600 (248)	2 300 (158)	6 500 (447)	4 100 (282)	5 800 (399)	3 600 (248)	10 000 (689)	8 900 (613)	9 800 (675)	6 200 (427)	8 500 (585)	5300 (365)

Gaugeable Tube Fittings and Adapter Fittings

▸ Swagelok Northwest (US)

Swagelok

Cleaning and Packaging

Fitting components are cleaned to remove machine oil, grease, and loose particles. For more information, see Swagelok *Standard Cleaning and Packaging (SC-10)* catalog, MS-06-62.

Fittings are available individually bagged; add **CP** to the ordering number. Example: SS-200-6**CP**

Pipe Thread Sealants

A thread sealant should always be used when assembling tapered threads. SWAK™ anaerobic pipe thread sealant and Swagelok PTFE tape are available. Refer to *Leak Detectors, Lubricants, and Sealants* catalog, MS-01-91, for additional information.

Port Connectors, Reducers, and Tube Adapters

Swagelok tube adapters with the machined groove are rated to the highest suggested allowable working pressure, see Swagelok *Tubing Data,* MS-01-107 for a tube outside diameter and material in question.

How to Order

Select a basic ordering number. Example **-100-6**

Add a material designator. Example: **SS**-100-6

Material	Designator	Material	Designator
316 SS	SS	Alloy 2507	2507
Aluminum	A	Alloy C-276	HC
Alloy 20	C20	Brass	B
6-Moly	6MO	Carbon steel	S
Alloy 400	M	Nylon	NY
Alloy 600	INC	PTFE	T
Alloy 625	625	Titanium (grade 4)	TI
Alloy 825	825		

Proportional Relief Valve
SS-4R3A-BU-SETA210

Proportional Relief Valves

Technical Data

Pressure-Temperature Ratings

Series	R3A				
Inlet Working Pressure①	6000 psig (413 bar); up to 8000 psig (551 bar) during relief				
Outlet Working Pressure①	1500 psig (103 bar)				
Set Pressure	50 to 6000 psig (3.4 to 413 bar)				
Seal Material	Fluoro-carbon FKM	Buna N	Neo-prene	Ethylene pro-pylene	Perfluoro-carbon FFKM
Temperature, °F (°C)	Maximum Set Pressure, psig (bar)				
−40 (−40)					
−30 (−34)		—	—		
−10 (−23)	—				
0 (−17)				—	—
10 (−12)					
25 (−4)					
30 (−1)		6000 (413)	6000 (413)		2500 (172)
40 (4)	6000 (413)			6000 (413)	
50 (10)					6000 (413)
70 (20)					

① Outlet pressure should not exceed inlet pressure.

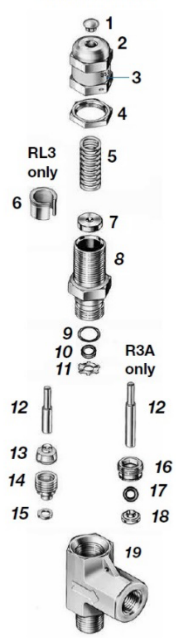
High-Pressure Valves (R3A and R4 Series)

End Connections Inlet/Outlet	Size	Ordering Number	Dimensions, in. (mm) A	B	C	D	E	H
R3A series: 0.14 in. (3.6 mm) fully open orifice								
Swagelok tube fittings	1/4 in.	SS-4R3A		1.44 (36.6)	1.60 (40.6)		4.14 (105)	
	6 mm	SS-6R3A-MM						
	8 mm	SS-8R3A-MM						
Male NPT/ Swagelok tube fitting	1/4 in.	SS-4R3A1	2.70 (68.6)	1.19 (30.2)	1.60 (40.6)	0.43 (10.9)	3.89 (98.8)	4.09 (104)
Male NPT/ female NPT	1/4 in.	SS-4R3A5		1.19 (30.2)	1.17 (29.7)		3.89 (98.8)	
Male ISO/ female ISO①	1/4 in.	SS-4R3A5-RT		1.19 (30.2)	1.17 (29.7)		3.89 (98.8)	
R4 series: 0.25 in. (6.4 mm) fully open orifice								
Swagelok tube fittings	1/2 in.	SS-R4S8		1.83 (46.5)			5.92 (150)	
	12 mm	SS-R4S12MM						
Male NPT/ Swagelok tube fitting	1/2 in.	SS-R4M8S8	4.09 (104)	1.43 (36.3)	1.83 (46.5)	0.50 (12.7)	5.52 (140)	5.37 (136)
Male NPT/ female NPT	1/2 in.	SS-R4M8F8		1.43 (36.3)	1.43 (36.3)		5.52 (140)	

Dimensions shown with Swagelok tube fitting nuts finger-tight.
① See specifications ISO 7/1, BS EN 10226-1, DIN-2999, and JIS B0203.

Materials of Construction

RL3 and R3A



Component		Material Grade/ASTM Specification
1	Plug	302 SS/ASTM 240
2	Cap	316 SS/A479
3	Label	Polyester
4	Lock nut	RL3, R3A—powdered metal 300 series SS/B783; RL4, R4—316 SS/A276
5	Spring	S17700 SS/AMS 5678
6	Sleeve	304 SS/A240
7	Spring support	RL3, R3A—powdered metal 300 series SS/B783; RL4, R4—316 SS/A276
8	*Bonnet*	*316 SS/A479*
9	*O-ring*	*Fluorocarbon FKM*
10	*Quad seal*	*PTFE-coated fluorocarbon FKM*
11	*Retainer*	*RL3, R3A—316 SS/A666; RL4, R4—316 SS/A479*
12	*Stem*	*316 SS/A479*
12a	*Bonded stem*	*Fluorocarbon FKM-bonded① 316 SS/A479*
13	*Bonded disc*	
14	*Seat*	*316 SS/A479*
15	*Gasket*	*PTFE-coated 316 SS/A240*
16	*Seat retainer*	*316 SS/A479*
17	*O-ring*	*Fluorocarbon FKM*
18	*Insert*	*316 SS/A479*
19	*Body*	*316 SS/A182*
	Lubricants	*Molybdenum disulfide-based dry film and paste; silicone-based*

Wetted components listed in *italics*.
① Material Safety Data Sheet for bonding agents available on request.

Options and Accessories

Seal Materials

Fluorocarbon FKM is the standard seal material. Buna N, ethylene propylene, and neoprene and perfluorocarbon FFKM are available. Quad seal elastomers are PTFE-coated.

To order a *valve* with an optional seal material, add a valve seal material designator to the valve ordering number.

Examples: SS-4R3A-**BU**

Seal Material	Designator Valves	Seal Kits
Buna N	-BU	BN①
Ethylene propylene	-EP	EP
Neoprene	-NE	NE
Perfluorocarbon FFKM②	-KZ	KZ
Fluorocarbon FKM	—	VI

① Use **BU** for R3A series seal kits.
② Only available for R3A series.

Set Pressure Range psig (bar)	Spring Designator	Spring Color
R3A series spring kit: basic ordering number 177-R3A-K1-		
50 to 350 (3.4 to 24.1)	A	Blue
350 to 750 (24.1 to 51.7)	B	Yellow
750 to 1500 (51.7 to 103)	C	Purple
1500 to 2250 (103 to 155)	D	Orange
2250 to 3000 (155 to 206)	E	Brown
3000 to 4000 (206 to 275)	F	White
4000 to 5000 (275 to 344)	G	Red
5000 to 6000 (344 to 413)	H	Green
R4 series spring kit: basic ordering number 177-13K-R4-		
50 to 350 (3.4 to 24.1)	A	Blue
350 to 750 (24.1 to 51.7)	B	Yellow
750 to 1500 (51.7 to 103)	C	Purple

Factory-Set Valves

R3A and R4 series valves are available with springs factory-set to a specified set pressure. Valves are set, tested, locked, and tagged with the set pressure; certificates of test are included.

To order, add **-SET** and a spring designator whose range includes the desired set pressure to the valve ordering number; specify the desired set pressure.

Example: SS-4R3A-**SETB**

Normally Open Valve

GENERAL PURPOSE VALVES

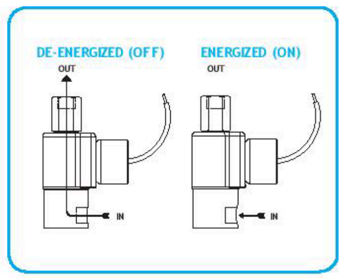
Note: This valve also available as an operator. Refer to following page.

Series 20 >> Model 21

2-Way Normally Open Valve

A complete line of valves with a great selection of options and exceptional proven performance. The standard in the field. Air, water, and other fluids compatible with standard Buna seals. Hot water, steam, gasoline, and many oils require special seal materials.

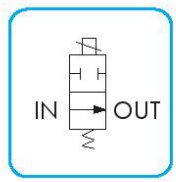
- ***The flagship valve initially created for fluid power industry.***
- ***Heavy duty and made of stainless steel.***
- ***A real workhorse with proven performance.***
- ***It has the greatest amount of options available of all the valves.***
- ***Wide range of orifice sizes from 1/32" to 1/8".***



OPERATING CONDITIONS

Media: Air, water, and other fluids compatible with standard Buna seals. Hot water, steam, gasoline, and many oils require special seal materials. (Series 20 pressure ratings may change due to the viscosity of the liquid.)*
Valve Temperature Range: Standard Valves - 0°F (-18°C) to 104°F (40°C) ambient; 0°F (-18°C) to 150°F (65°C) media. Optional Valves - can tolerate much higher or much lower ambient and media temperatures.*
Maximum Operating Pressure Differentials: See table on next page.
Burst Pressure: 5,000 PSI
Leakage: Bubble tight for standard valves.
Vacuum: To 5 Microns*

ELECTRICAL CHARACTERISTICS

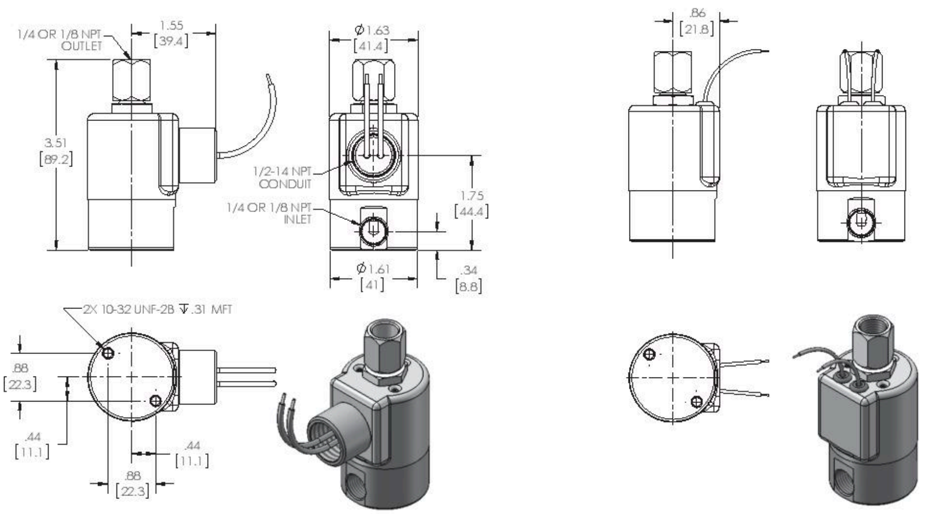


Coil Voltage: 6 to 825VAC 60 HZ. and 5 to 720VAC 50 HZ. — 1.8 to 265VDC
Nominal Power: AC — 8.7 Watts, DC — 9.5 Watts
Coil Construction: Molded (Std.), Non-molded Class A and potted Class F (Class H optional)
Typical Response Time on Air: 4 - 16 Milliseconds
Operating Speed: Up to 600 CPM
Duty Cycle: Continuous

MECHANICAL CHARACTERISTICS

Body: Stainless Steel (Std.) or Brass (Opt.)
Internal Components: Stainless Steel. Copper - AC Only.
Elastomers: Nitrile (Buna) (Std.). Many other elastomers available.*
Orifice Diameter: See table on next page.
Porting: Standard 1/8" and 1/4" NPT (other ports available).*
Housing: Grommet and 1/2" NPT conduit - many options available.*
Listings: Most valves are UL and CSA listed.*
Life Expectancy: Millions of cycles, depending on application, lubrication, etc.
Valve Weight: Grommet Valve: 1.13 lb Conduit Valve: 1.19 lb
Repair Packs: See table on next page.
Options: Alternate Port Locations, Metering, Manual Override, Alternate Elastomers, Spade Terminal Coil, European Style DIN, Explosion Proof and Magnetic Latching Coil
** Consult representative or factory for options and specifications.*

28 ››› 1-860-229-4884 ››› www.peterpaul.com



SERIES 20
MODEL 21
2WNO
CONDUIT CONNECTION

SERIES 20
MODEL 21
2WNO
GROMMET HOUSING WITH LEADS

VALVE SPECIFICATIONS

MAX. OPER. PRESS. DIFF.+		ORIFICE SIZE	CV FACTOR	VALVE NUMBER			
				GROMMET HOUSING		CONDUIT HOUSING	
AC	DC	N.O.	N.O.	1/8 NPT PORTS	1/4 NPT PORTS	1/8 NPT PORTS	1/4 NPT PORTS
400 (700)*	400 (700)*	1/32	.024	21G7XGM	21G9ZGM	21G7XCM	21G9ZCM
235 (500)	235 (500)	3/64	.053	21H7XGM	21H9ZGM	21H7XCM	21H9ZCM
150 (350)	150 (350)	1/16	.095	21J7XGM	21J9ZGM	21J7XCM	21J9ZCM
100 (150)	100 (150)	3/32	.156	21K7XGM	21K9ZGM	21K7XCM	21K9ZCM
35 (40)	35 (40)	1/8	.201	21N7XGM^	21N9ZGM^	21N7XCM^	21N9ZCM^

^ VALVES WITH 1/8 N.O. ORIFICE ARE UL LISTED ONLY
* FKM seals not recommended for pressure ratings above 500 PSI.
+ Ratings in brackets are optional extended ratings; consult factory.

ORDERING INFORMATION:

WHEN ORDERING VALVES OR REPAIR PACKS ADD VOLTAGE AND FREQUENCY TO COMPLETE VALVE NUMBER. EXAMPLES: VALVE (21J9ZGM 120/60) REPAIR PACK (K21JDX AC)

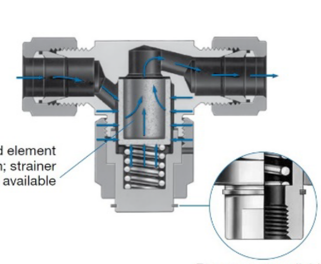
WHEN ORDERING OPERATORS ADD THE LETTER "O" TO THE FRONT OF THE VALVE NUMBER, REPLACE BODY PORT NUMBER WITH THE LETTER "D": EXAMPLE: OPERATOR (O21J9DGM 120/60)

System Filter

Filters

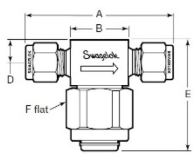
Tee-Type Filters (TF Series)

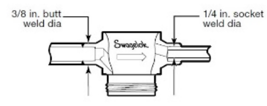
- Filter element can be replaced without removing body from system.
- Replaceable sintered elements are available in 0.5, 2, 7, 15, 60, and 90 µm nominal pore sizes; replaceable strainer elements are available in 40, 140, 230, and 440 µm nominal pore sizes.
- End connections include Swagelok tube fittings, NPT, and tube socket or tube butt weld ends.
- Select TF series filters are available with ECE R110-type approval for use in alternative fuel service. See **Options and Accessories,** page 8.



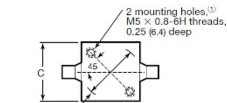
Sintered element shown; strainer element available

Bypass port available; see page 8





Tube socket and tube butt weld end connections



Bolt circle: 1.00 (25.4) for 2TF, 4TF; 1.13 (28.7) for 6TF, 8TF

End Connections Type	Size	Basic Ordering Number	Filter Series	Dimensions, in. (mm) Orifice	A	B	C	D	E	F
Swagelok tube fitting	1/8 in.	SS-2TF-	2TF	0.094 (2.39)	2.27 (57.7)	1.07 (27.2)	1.00 (25.4)	0.38 (9.7)	1.87 (47.5)	1 (25.4)
	1/4 in.	SS-4TF-	4TF	0.174 (4.41)	2.47 (62.7)	1.06 (26.9)				
	3/8 in.	SS-6TF-	6TF	0.213 (5.41)	2.84 (72.1)	1.32 (33.5)	1.13 (28.7)	0.46 (11.7)	2.20 (55.9)	1 1/8 (28.6)
	1/2 in.	SS-8TF-	8TF	0.250 (6.35)	3.04 (77.2)	1.31 (33.3)				
	6 mm	SS-6TF-MM-	4TF	0.172 (4.36)	2.46 (62.5)	1.06 (26.9)	1.00 (25.4)	0.38 (9.7)	1.87 (47.5)	1 (25.4)
	8 mm	SS-8TF-MM-	6TF	0.213 (5.41)	2.84 (72.1)	1.38 (35.1)	1.13 (28.7)	0.46 (11.7)	2.20 (55.9)	1 1/8 (28.6)
	10 mm	SS-10TF-MM-	8TF	0.250 (6.35)	2.86 (72.6)	1.32 (33.5)				
	12 mm	SS-12TF-MM-	8TF		3.04 (77.2)	1.31 (33.3)				

Pressure-Temperature Ratings

Ratings are based on standard materials of construction. Ratings for TF series filters with PCTFE gaskets are limited to 200°F and 3000 psig (93°C and 206 bar). See page 8.

Filter Series	FW, TF	2F, 4F	6F, 8F	F	TF
Material	316 SS			Brass	
Temperature, °F (°C)	Working Pressure, psig (bar)				
−20 (−28) to 100 (37)	6000 (413)	3000 (206)	2500 (172)	1000 (68.9)	2000 (137)
200 (93)	5160 (355)	2580 (177)	2150 (148)	780 (53.7)	1730 (119)
300 (148)	4660 (321)	2330 (160)	1940 (133)	680 (46.8)	1470 (101)
400 (204)	4280 (294)	2140 (147)	1780 (122)	—	—
500 (260)	3980 (274)	1990 (137)	1660 (114)	—	—
600 (315)	3760 (259)	1880 (129)	1560 (107)	—	—
650 (343)	3700 (254)	1845 (127)	1540 (106)	—	—
700 (371)	3600 (248)	1800 (124)	1500 (103)	—	—
750 (398)	3520 (242)	1760 (121)	1460 (100)	—	—
800 (426)	3460 (238)	1725 (118)	1440 (99.2)	—	—
850 (454)	3380 (232)	1690 (116)	1410 (97.1)	—	—
900 (482)	3280 (225)	1640 (112)	1360 (93.7)	—	—

Materials of Construction

Component	Filter Series	Filter Body Materials: Brass①	316 SS
		Material Grade/ASTM Specification	
Bonnet nut	TF	Brass/B16	316 SS/A479
Bonnet	*TF*	*Brass/B16*	*316 SS/A479*
Retainer screens (2)	*FW*	—	*316 SS*
Element	*FW*	—	*0.5 µm size—316L SS*
			2, 7, and 15 µm size—316 SS
	F, TF	*Sintered—316 SS*	
		Strainer—316 SS with silver solder	
Spring	*F, TF*	*302 SS*	
Gasket	*F, TF*	*Aluminum/B209*	*Silver-plated 316 SS/A240*
Body	*All*	*Brass/B16*	*316 SS/A479*
Retaining ring	TF	PH 15-7 Mo® SS	
Lubricant	*F*	*Silicone-based*	

Wetted components listed in *italics.*

Filtration Area

Filter Series	Sintered Element in.² (mm²)	Strainer Element in.² (mm²)	Pleated Element in.² (mm²)
FW	0.44 (283)	—	2.25 (1450)
2F	0.55 (350)	—	—
4F, 2TF, 4TF	1.3 (830)	1.0 (640)	—
6F, 8F, 6TF, 8TF	2.0 (1280)	1.7 (1090)	—

F and TF Series Elements

Elements remove 95 % of particles larger than the nominal pore size.

Nominal Pore Size µm	Pore Size Range µm	Element Type	Element Designator
0.5	0.5 to 2	Sintered	05
2	1 to 4		2
7	5 to 10		7
15	11 to 25		15
40①	—	Strainer	40
60	50 to 75	Sintered	60
90	75 to 100		90
140①	—	Strainer	140
230①	—		230
440①	—		440

① Not available for 2F series.

Diaphragm Pump

GAST MANUFACTURING, INC.
A Unit of IDEX Corporation
Post Office Box 97
Benton Harbor, Michigan
Ph: 269/926-6171
Fax: 269/925-8288

Product Specifications

PART NUMBER: RTD156

SHEET 1 of 2

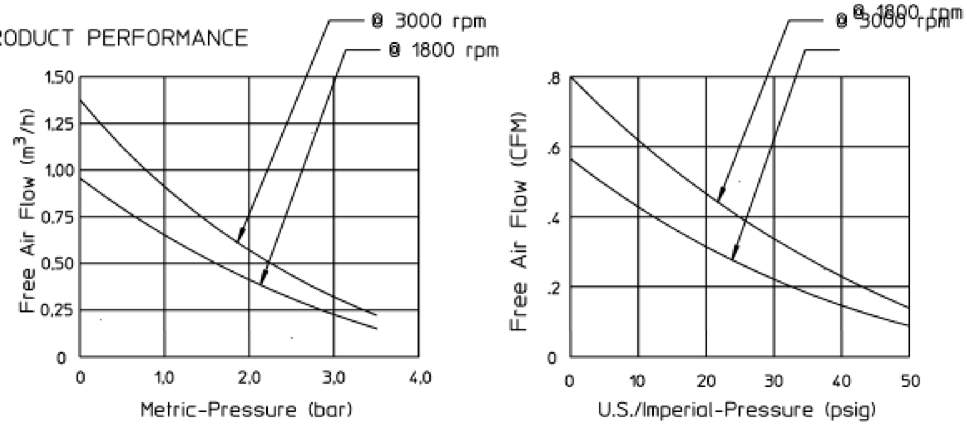
REV. E

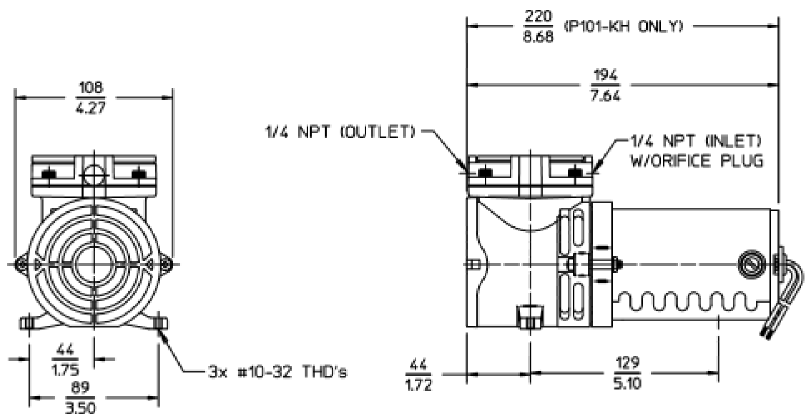
Model Number	Motor	RPM	HP	kW	Net Wt. lbs.	Net Wt. kg	AMPS	CAPACITOR mfd. - volts
MOA-P101-JH	12V DC	1800	1/16	0,05	5.3	2,4	6.8	----
MOA-P101-JK	24V DC	1800	1/16	0,05	5.3	2,4	3.2	----
MOA-P126-JK	24V DC	1800	1/16	0,05	5.3	2,4	3.2	----
MOA-P101-KH	12V DC	3000	1/8	0,09	5.3	2,4	12.2	----

SOUND LEVEL: Less than 70 dB(A) (P101-KH 69-76 dB(A))
NORMAL AMBIENT: +5 degC - +40 degC
RELATIVE HUMIDITY: 20% - 80%
ENVIRONMENT: Clean Dust Free

NOTES:
1. ALL DIMENSIONS ARE FOR REFERENCE USE ONLY.
2. PRODUCT DIMENSIONS: U.S. IMPERIAL (inches) METRIC (mm).
3. * = TECHNICAL DATA SUBJECT TO CHANGE WITHOUT NOTICE.
4. THESE MODELS REQUIRE ADDITIONAL CAPACITANCE TO BE APPLIED TO THE ELECTRICAL INPUT IN ORDER TO COMPLY WITH THE EU EMC DIRECTIVE. SEE SHEET 2 OF 2.

PRODUCT PERFORMANCE





Secondary Water Trap

In the cabinet, the bottom drain plug was removed and replaced with a ball-valve to facilitate liquid sample collection

SFR Series
Single Filter Housings with Ring Nut Closure

neo•PURE™

Residential/Commercial/Industrial Filtration Applications

Standard Features

- Manufactured in the USA
- Designed for commercial or industrial filter applications
- Heavy-duty 316L stainless steel construction for maximum durability and corrosion resistance
- Ring nut closure allow for quick cartridge change-outs
- Materials of construction include 316L stainless steel
- Available with 1/2”, 3/4”, and 1” inline connections
- Both ends of cartridge have knife-edge seals to help eliminate potential bypass
- Includes mounting bracket kit and wrench
- Uses double open end (DOE) cartridges (internal O-ring 213 cartridge optional)

Applications

- Water
- Food and Beverage
- Electronics
- Coolants
- Oil/Gas
- Paints/Inks/Coatings

Product Specifications

Maximum Operating Pressure

300 psig (20.7 bar) @ 200°F (93°C)

Connections

Inlet/Outlet: 1/2”, 3/4”, or 1” FNPT

Optional: 1” RF flange, BSP or 1” sanitary ferrules

Drain Ports: 1/4” FNPT

Materials of Construction

Head/Shell/Connections: 316L stainless steel

Drain: 316L stainless steel plug

Gaskets

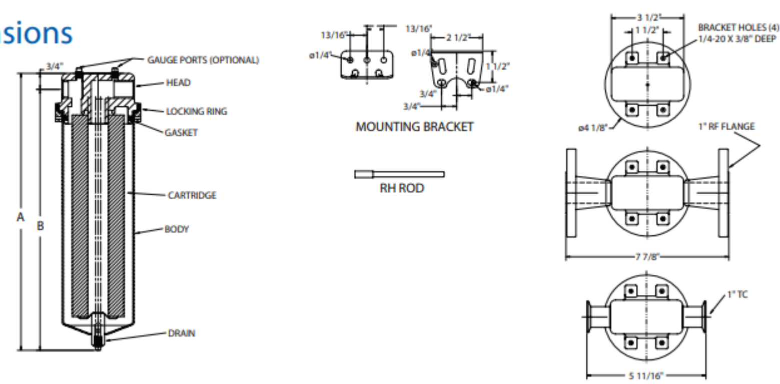
Standard: Buna N (FDA grade)

Optional: EPR, silicone, Viton

MODEL	QUANTITY (LENGTH) OF CARTRIDGES	MAXIMUM FLOW RATE* GPM (LPM)	MAXIMUM DIAMETER CARTRIDGE	DRAIN SIZE	DIMENSIONS	
					A	B
SFR1	1 (9-3/4 - 10")	7 (26.5)	2-3/4"	1/4"	13-9/16" (34.4 cm)	12-3/4" (32.4 cm)
SFR2	1 (19-1/2 - 20")	14 (53)	2-3/4"	1/4"	23-9/16" (59.8 cm)	22-3/4" (57.8 cm)
SFR3	1 (30")	21 (79.5)	2-3/4"	1/4"	33-9/16" (85.2 cm)	32-3/4" (83.2 cm)

* *Based upon 7 gpm (26.5 lpm) per 10" length with a 25 micron wound cartridge at 2 PSID clean and viscosity of 1 cps. Flow rates are approximate. Actual flow rates are based upon fluid, viscosity, cartridge type, micron ratings and other factors.*

Dimensions



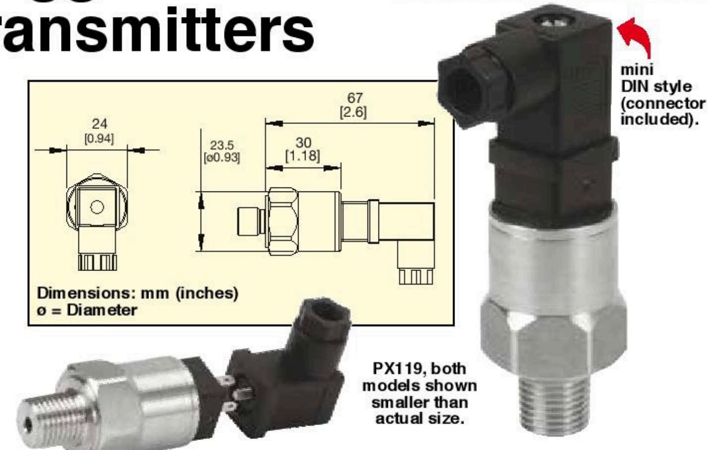
System Pressure Transducers

Compact Rugged Pressure Transmitters

15 to 5000 psi, 1 to 345 bar
4 to 20 mA Output

PX119 Series

- Low Cost
- Compact Size
- 0.50% BFSL Accuracy
- All Stainless Steel Body



The PX119 pressure transmitter series is ideally suited for material handling, industrial and mobile equipment applications where space constraints require a small body size. The body is machined from a single piece of stainless steel to provide added protection for the internal electronics. A piezoresistive ceramic sensor along with ASIC signal conditioning provide an excellent thermally compensated output.

Specifications

Accuracy: 0.50% BFSL Accuracy
Pressure Range: 15 to 5000 psi (345 bar)
Output/Supply Voltage: 4 to 20 mA: 8 to 30 Vdc
Output Connections: DIN 43650C (mini DIN)
Output Wiring: Pin 1: Supply +, Pin 2: Supply -
Long Term Drift: <0.3% FS @ 25°C (77°F)
Thermal Error:
- **7.5 psi ≥ 100 psi:** 0.01% FS/°F (0.018% FS/°C)
- **100 psi > 400 psi:** 0.009% FS/°F (0.016% FS/°C)
- **400 psi ≥ 1000 psi:** 0.011% FS/°F (0.019% FS/°C)
- **1000 psi > 3000 psi:** 0.012% FS/°F (0.021% FS/°C)
- **3000 psi ≥ 5000 psi:** 0.018% FS/°F (0.028% FS/°C)

Compensated Temperature: 0 to 85°C (32 to 185°F)
Operating Temperatures: -40 to 135°C (-40 to 257°F)
Process Connection: ¼ NPT male
Construction: 304 SS
Wetted Materials: 304 SS and Ceramic Al_2O_3, NBR Standard
Vibration: 10 g (20 to 2000 Hz) for <58 psi (4 bar); 20 g (20 to 500 Hz) for ranges >58 psi (4 bar)
Protection: Overvoltage, short circuit, reverse polarity
Response Time: 1 ms
Ingress Protection: IP65
Weight: 70 g (0.15 lb)

To Order

Ranges psi	Ranges bar	% Proof (FS)	% Burst (FS)	mini DIN Connection
Absolute Pressure				
0 to 15	0 to 1	193.4%	386.7%	**PX119-015AI**
0 to 30	0 to 2.1	193.4%	241.7%	**PX119-030AI**
0 to 100	0 to 6.9	290.1%	362.6%	**PX119-100AI**
0 to 150	0 to 10.3	193.4%	241.7%	**PX119-150AI**
0 to 300	0 to 21	193.4%	241.7%	**PX119-300AI**
0 to 600	0 to 42	241.7%	290.1%	**PX119-600AI**
0 to 1000	0 to 69	290.1%	362.6%	**PX119-1KAI**
0 to 1500	0 to 103	193.4%	241.7%	**PX119-1.5KAI**
0 to 3000	0 to 207	193.4%	241.7%	**PX119-3KAI**
0 to 5000	0 to 345	188.5%	188.5%	**PX119-5KAI**
Gage Pressure				
0 to 15	0 to 1	193.4%	386.7%	**PX119-015GI**
0 to 30	0 to 2.1	193.4%	241.7%	**PX119-030GI**
0 to 100	0 to 6.9	290.1%	507.6%	**PX119-100GI**
0 to 150	0 to 10.3	193.4%	338.4%	**PX119-150GI**
0 to 300	0 to 21	193.4%	338.4%	**PX119-300GI**
0 to 600	0 to 42	241.7%	362.6%	**PX119-600GI**
0 to 1000	0 to 69	290.1%	362.6%	**PX119-1KGI**
0 to 1500	0 to 103	193.4%	241.7%	**PX119-1.5KGI**
0 to 3000	0 to 207	193.4%	217.5%	**PX119-3KGI**
0 to 5000	0 to 345	188.5%	188.5%	**PX119-5KGI**

Ordering Examples: PX119-3KGI, *3000 psi gage pressure transmitter with 4 to 20 mA output and mini DIN termination.*
PX119-015AI, *15 psi absolute pressure transmitter with 4 to 20 mA output and mini DIN termination.*

Accessories

Model No.	Description
CA-319-4PC24-XXX-WP	Vented cable used for PX119 ≤100 psig, terminated in a clean dry area that is open to atmosphere for correct operation*
CA-319-4PC24-XXX	Standard cable for PX119 >100 psig and all absolute ranges, terminated in a dry location or sealed to prevent water from getting into the cable/sensor*
DP8PT	PLATINUM™ Series ⅛ DIN 4-digit single display panel meter

All **PX119 are vented through a hole in the connector and through the mating connector. OMEGA recommends purchase and use of ready-made Cable Assemblies using part # structure **"CA-319-4PC24-XXX-WP"** (and non-WP version) as shown above, where **"XXX"** is the length in feet of the desired cable (e.g. "030" stands for 30 ft).*

1

Relative Humidity Probe

VAISALA

HUMICAP® Humidity and Temperature Probe HMP110

Features

- Miniature-size humidity transmitter
- Low power consumption and fast start-up for battery-powered applications
- Measurement range: 0 ... 100 %RH; -40 ... +80 °C (-40 ... +176 °F)
- Cable detachable with standard M8 quick connector
- IP65 metal housing
- Optional RS-485 digital output supports Modbus RTU
- ±1.5 %RH measurement accuracy (0 ... 90 %RH)

Technical Data

Measurement Performance

Relative Humidity	
Measurement range	0 ... 100 %RH
Accuracy: [1) 2)]	
at 0 ... +40 °C (+32 ... +104 °F)	±1.5 %RH (0 ... 90 %RH) ±2.5 %RH (90 ... 100 %RH)
at −40 ... 0 °C, +40 ... +80 °C (−40 ... +32 °F, +104 ... +176 °F)	±3.0 %RH (0 ... 90 %RH) ±4.0 %RH (90 ... 100 %RH)
Factory calibration uncertainty at +20 °C (+68 °F)	±1.1 %RH (0 ... 90 %RH) ±1.8 %RH (90 ... 100 %RH)
Humidity sensor types	HUMICAP® 180R HUMICAP® 180V
Stability	±2 %RH over 2 years

Temperature	
Measurement range	−40 ... +80 °C (−40 ... +176 °F)
Accuracy (Probes with Analog Output):	
at 0 ... +40 °C (+32 ... +104 °F)	±0.2 °C (±0.36 °F)
at −40 ... 0 °C, +40 ... +80 °C (−40 ... +32 °F, +104 ... +176 °F)	±0.4 °C (±0.72 °F)
Accuracy (Probes with Digital Output):	
at +15 ... +25 °C (+59 ... +77 °F)	±0.1 °C (±0.18 °F)
at 0 ... +15 °C, +25 ... +40 °C (+ 32 ... +59 °F, +77 ... +104 °F)	±0.15 °C (±0.27 °F)
at −40 ... 0 °C, +40 ... +80 °C (−40 ... +32 °F, +104 ... +176 °F)	±0.4 °C (±0.72 °F)
Temperature sensor	Pt1000 RTD Class F0.1 IEC 60751

Mass Flow Controller
MCS-10SLPM-D-DB9M

Technical Data for Alicat MCS and MCRS Mass Flow Controllers

0 – 0.5 sccm Full Scale through 0 – 5000 slpm Full Scale

Alicat MCS and MCRS instruments are built for use with certain aggressive gases.

ALICAT SCIENTIFIC
Tel: 888-290-6060
www.alicat.com/ms

Standard Specifications (Contact Alicat for available options.)

Performance	MCS & MCRS Mass Flow Controller	
Accuracy at calibration conditions after tare	± (0.8% of Reading + 0.2% of Full Scale)	
High Accuracy at calibration conditions after tare	± (0.4% of Reading + 0.2% of Full Scale) High Accuracy option not available for units ranged under 5 sccm or over 500 slpm.	
Repeatability	± 0.2% Full Scale	
Zero Shift and Span Shift	0.02% Full Scale / ºCelsius / Atm	
Operating Range / Turndown Ratio	1% to 100% Full Scale / 100:1 Turndown	
Maximum Controllable Flow Rate	102.4% Full Scale	
Maximum Measurable Flow Rate	up to 128% Full Scale (Gas Dependent)	
Typical Response Time	100 ms (Adjustable)	
Warm-up Time	< 1 Second	

Operating Conditions	MCS & MCRS Mass Flow Controller	
Mass Reference Conditions (STP)	25ºC & 14.696 psia (standard — others available on request)	
Operating Temperature	−10 to +60 ºCelsius	
Humidity Range (Non–Condensing)	0 to 100%	
Maximum Internal Pressure (Static)	145 psig	
Proof Pressure	175 psig	
Mounting Attitude Sensitivity	**MCS:** None	**MCRS:** Mount with valve cylinder vertical & upright
Valve Type	Normally Closed	
Ingress Protection	IP40	
Wetted Materials	316LSS, 303SS, 430FRSS, FFKM (Kalrez) standard, Viton, EPDM, Buna, Neoprene as needed for some gases. If your application demands a different material, please contact Alicat.	

Communications / Power	MCS & MCRS Mass Flow Controller	
Monochrome LCD or Color TFT Display with integrated touchpad	Simultaneously displays Mass Flow, Volumetric Flow, Pressure and Temperature	
Digital Input / Output Signal[1] Options	RS-232 Serial / RS-485 Serial / Modbus RTU / PROFIBUS / EtherNet/IP / DeviceNet / Modbus TCP/IP / EtherCAT	
Analog Input / Output Signal[2] Options	0-5 Vdc / 1-5 Vdc / 0-10 Vdc / 4-20 mA	
Optional Secondary Output Signal[2]	0-5 Vdc / 1-5 Vdc / 0-10 Vdc / 4-20 mA	
Electrical Connection Options	8-Pin Mini-DIN / 9-pin D-sub (DB9) / 15-pin D-sub (DB15) / 6-pin locking / 8-pin M12	
Supply Voltage	**MCS:** 12 to 30 Vdc (15-30 Vdc for 4-20 mA outputs)	**MCRS / MCRHS:** 24 to 30 Vdc
Supply Current	**MCS**: 0.250 Amp	**MCR:** 0.750 Amp (**MCRHS**: 2.0 Amp)

1. The **Digital Output Signal** communicates Mass Flow, Volumetric Flow, Pressure and Temperature
2. The **Analog Output Signal** and **Optional Secondary Analog Output Signal** communicate your choice of Mass Flow, Volumetric Flow, Pressure or Temperature

Range Specific Specifications

Full Scale Flow Mass Controller	Pressure Drop[1] at FS Flow (psid) venting to atmosphere	Mechanical Dimensions[2]	Process Connections[3]
MCS 0.5 sccm to 50 sccm	1.0	4.4"H x 3.4"W x 1.1"D	M-5 (10-32) Female Thread[4]
MCS 100 sccm to 500 sccm	1.0	4.6"H x 3.6"W x 1.1"D	1/8" NPT Female
MCS 1 slpm	1.5		
MCS 2 slpm	3.0		
MCS 5 slpm	2.0		
MCS 10 slpm	5.5		
MCS 20 slpm	20.0		

1. Lower Pressure Drops Available, please see our **WHISPER-Series** mass flow controllers at ***www.alicat.com/whisper***.
2. See drawings for metric equivalents.
3. Compatible with Swagelok® tube, Parker®, face seal, push connect and compression adapter fittings. VCR and SAE connections upon request.
4. Shipped with 316SS M-5 (10-32) Male Chemraz O-ring face seal to 1/8" Female NPT fittings

Corrosive Gases (MCS series)

Instruments in the standard MC series are also available with an optional "S" configuration (MCS) for use with corrosive gases. In this configuration, we upgrade the valve to 303 stainless steel, the sensor to 316L stainless steel and the elastomers to FFKM.

General Chemical Resistance Guide

Start typing a chemical name in the box below

Chemical	DuPont Elastomers	Rating
Ammonia Gas (cold)	Perfluoroelastomer (Kalrez® FFKM)	1
Ammonium Hydroxide (conc.)	Perfluoroelastomer (Kalrez® FFKM)	1

Large Mass Flow Controller
MCHQ-50SLPM-D-M12-485-PCV30

Technical Data for MCQ-Series Mass Flow Controllers

50 SLPM full scale through 3000 SLPM full scale

Standard specifications. Consult Alicat for available options.

ALICAT SCIENTIFIC
+1 (888) 290-6060
alicat.com/mcq

CONTROL AND SENSOR PERFORMANCE	
Mass Flow Accuracy at Calibration Conditions[1]	±2% of full scale
Repeatability	±0.2% of full scale
Steady State Control Range	0.5–100% of full scale
Valve Function	Normally Closed
Temperature Sensitivity	**Mass flow zero shift:** ±0.01% of full scale per °C from tare temperature, per atm **Mass flow span shift:** ±0.01% of reading per °C from 25°C, per atm
Pressure Sensitivity	**Mass flow zero shift:** ±0.01% of full scale per atm from tare pressure **Mass flow span shift:** ±0.1% of reading per atmosphere from calibration conditions
Operating Temperature Range	−10–60°C
Temperature Accuracy	±0.75°C
Operating Pressure Full Scale	320 PSIA
Pressure Accuracy above 1 atm	±0.5% of reading
Pressure Accuracy below 1 atm	±0.07 PSIA
Totalizer Volume Uncertainty	±0.5% of reading additional uncertainty
Sensor Response Time	<1 ms
Typical Indication Response Time	<10 ms, flow rate dependent
Typical Control Response Time	As fast as 100 ms (T_{63}), flow rate dependent, user adjustable
Typical Warm-Up Time	<1 s

1 Stated accuracy is after tare under equilibrium conditions, includes repeatability and linearity.

MECHANICAL	
Minimum Operating Pressure	11.5 PSIA common mode pressure (consult Alicat for lower operating pressures) Differential pressure must exceed model pressure drop, see below for details
Maximum Operating Pressure	Damage possible above 400 PSIA common mode pressure Damage possible above 75 PSI differential pressure
Ingress Protection	IP40 (consult Alicat for weatherproofing options)
Humidity Range	0–95%, non-condensing
Wetted Materials	302, 303, 304, 316L, 410 and 430FR stainless steel; FKM, alumina ceramic, brass, glass, gold, heat-cured epoxy, heat-cured silicone rubber, polyamide, silicon

CONTROL AND COMMUNICATIONS	
Analog I/O Options	4–20 mA, 0–5 VDC, 1–5 VDC, 0–10 VDC
Digital I/O Options	RS-232 Serial by default RS-485 Serial, Modbus RTU (over RS-232 or RS-485), Modbus TCP/IP, DeviceNet, EtherCAT, EtherNet/IP, PROFIBUS
Electrical Connection Options	6-pin locking, 8-pin mini-DIN, 8-pin M12, DB-9, DB-15
Power Requirements[2]	24 VDC, 1 A Add 40 mA if equipped with 4–20 mA output
Serial Data Update Rate[2]	40 Hz at 19200 baud
Analog Data Update Rate	1 kHz
Display Update Rate	10 Hz
Analog Signal Accuracy	±0.1% of full scale additional uncertainty

2 Consult the individual operating bulletins for specific industrial protocol power requirements and data transmission specifications.

Large 480V Pump

N 630.15 SERIES
PROCESS VACUUM PUMPS AND COMPRESSORS

N 630.15 SP.9 E

ADVANTAGES

- High chemical resistance
- Durable even with difficult operating conditions
- High level of gas tightness
- Ambient temperatures of up to 60 °C possible with water cooling
- High operating pressure of max. 12 bar rel.
- The pump can start against the entire pressure and vacuum range

POSSIBLE AREAS OF USE

- Environmental monitoring
- Process industry
- Chemical industry
- Energy technology – e.g. pressure increase for natural gas
- Gas recovery

Please visit our website www.knf.com to get more information

PERFORMANCE DATA				
Series model	**N 630.15 - 50 Hz Version**		**N 630.15 - 60 Hz Version**	
Material design	**ST.9 E / ST.13 E**	**SP.9 E / SP.13 E**	**ST.9 E / ST.13 E**	**SP.9 E / SP.13 E**
Pump head	Stainless steel			
Diaphragm	PTFE-coated	EPDM	PTFE-coated	EPDM
Valves	Stainless steel			
Flow rate at atm. pressure (l/min)	30.0		35.0	
Ultimate vacuum (mbar abs.)	70			
Max. operating pressure (bar rel./psig)	12.0/174.0			
Permissible ambient temperature (°C)	+5 ... +60 (+40 without water cooling)			
Permissible media temperature (°C)	+5 ... +60 (+40 without water cooling)			
Level of gas tightness (mbar x l/s) .9 | .13	$6 \times 10^{-3} / 5 \times 10^{-5}$			
Weight (kg/lbs)	55.0/121.0			

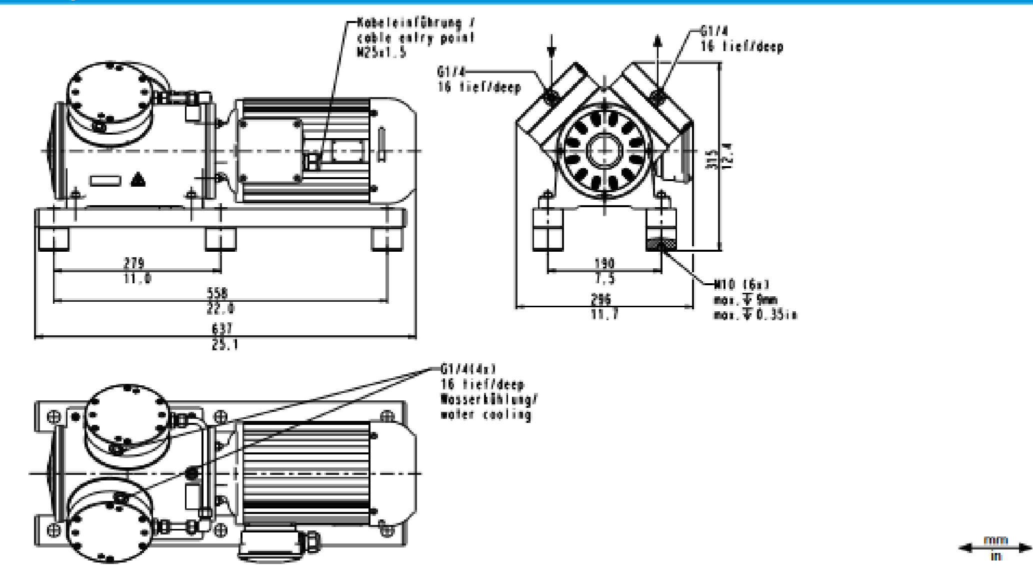
ELECTRICAL DATA				
Voltage (V)	230/400	200/346	220/380	277/480
Motor	Three-phase motor			
Protection class motor	IP 55			
Protection class pump	IP 20			
Frequency (Hz)	50	50/60	60	
Power P_2 (W)	1500			
I_N (A), 50 Hz	6.15/3.55	7.0/4.05	-	
I_N (A), 60 Hz	-	7.1/4.1	6.5/3.75	5.2/3.0

N 630.15 SP.9 E | SP.13 E

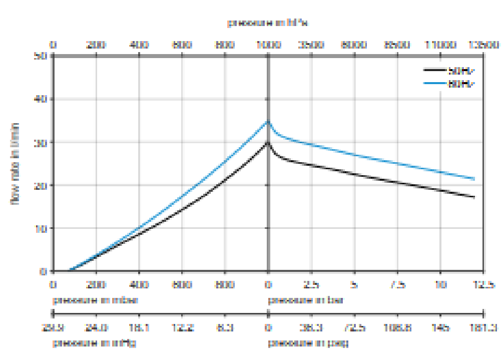
PERFORMANCE DATA			
Series model	**Flow rate at atm. pressure (l/min)[1]**	**Max. operating pressure (bar rel./psig)**	**Ultimate vacuum (mbar abs.)**
N 630.15 SP.9 E - 50 Hz	30.0	12.0/174.0	70
N 630.15 SP.13 E - 50 Hz	30.0	12.0/174.0	70
N 630.15 SP.9 E - 60 Hz	35.0	12.0/174.0	70
N 630.15 SP.13 E - 60 Hz	35.0	12.0/174.0	70

[1] Flow rate determined at 20 °C, 1013 mbar abs.
(Pressure 0 to 1013 mbar abs. in accordance with ISO 21360-1/2)

N 630.15 SP.9 E | SP.13 E



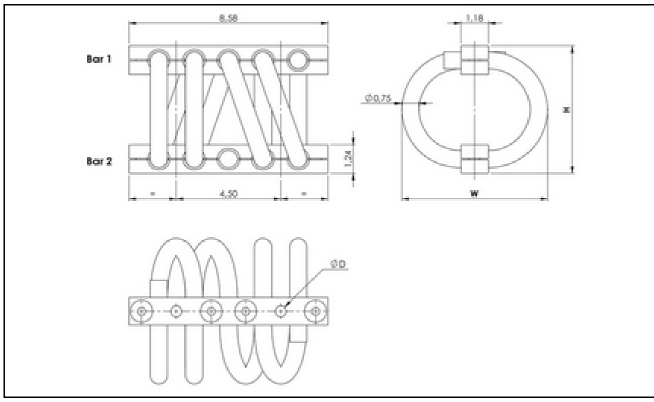
N 630.15 SP.9 E | SP.13 E



Gas Cabinet Shock Isolators

WIRE ROPE ISOLATOR

DEFINITION
series HH64



- All metal multidirectional anti-vibration/shock mounts
- Exceptional reliability and long life
- High damping
- No aging
- Corrosion resistant
- Unequalled temperature range : - 180°C to 300°C (-290°F to 570°F)
- Great adaptability/versatility

Specials on request
(material size and number of loops, etc.)

Dimensions are in inches. For reference only

SERIES

Materials and finishes (meets RoHS requirements)

HH64

Cable:
stainless steel
galvanized available: HHG

Retainer bars:
aluminium alloy/
SurTec

Screws:
alloy steel/zinc plate

Inserts:
stainless steel

All stainless steel: HHSS

Other materials on request

MODEL

	height H (in)	width W (in)	weight (lbs)
-24	3.9	4.5	5.4
-28	4.1	4.9	5.8
-32	4.3	5.3	6.1
-34	4.6	5.7	6.5
-36	4.9	6.3	6.9
-44	5.3	6.9	7.5
-46	5.7	7.3	7.9
-48	6.3	7.9	8.5
-50	6.9	8.5	9.1

INTERFACES

fixtures holes D	Bar 1		
Bar 2	ø 0.53 in through holes	ø 0.53 in through holes countersunk 82°	1/2 - 13 inserts
ø 0.53 in through holes	T2	not standard	not standard
ø 0.53 in through holes countersunk 82°	TC	C2	not standard
1/2 - 13 inserts	TI	CI	I2

H	H	6	4	-	2	4	0	4	C	I

SERIE: HH64
'Half-Helical' mount from the HH64 series

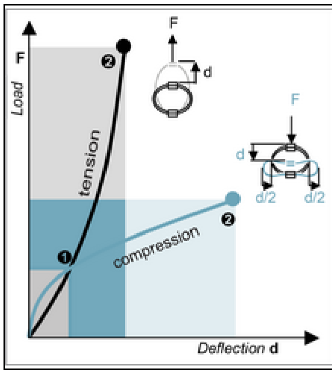
MODEL: -24
height: 3.9in
width: 4.5in
weight: 5.4lbs

LOOPS: 04
Serie standard is 04 loops

INTERFACE: CI
ø 0.53 in through holes countersunk 82° in bar 1,
1/2 - 13 inserts in bar 2

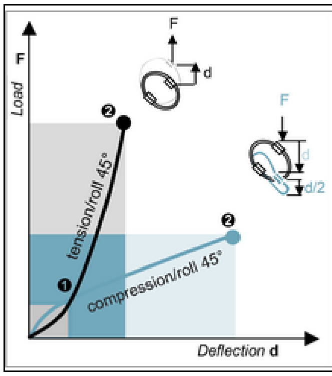
WIRE ROPE ISOLATOR

PERFORMANCE DATA
series HH64



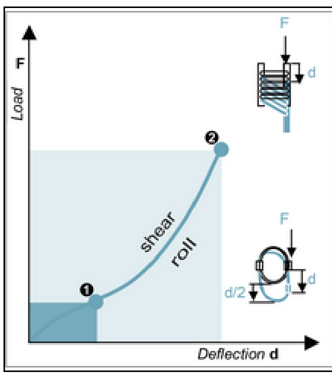
COMPRESSION AND TENSION

HH64 Series	Model	-24	-28	-32	-34	-36	-44	-46	-48	-50
1.Max Static	F lbf	1400	1200	980	840	680	570	520	450	390
	d in	0.23	0.27	0.31	0.35	0.41	0.47	0.54	0.63	0.73
2.Max Shock	F lbf	4200	3500	2900	2500	2000	1700	1500	1300	1200
	d in	1.2	1.5	1.7	1.9	2.2	2.6	2.9	3.4	4.0
3.Max Vibration	2a in	0.14	0.16	0.18	0.21	0.24	0.28	0.32	0.38	0.44
	f Hz	7.0	6.5	6.1	5.7	5.3	5.0	4.6	4.2	3.9
1.Max Static	F lbf	1400	1200	980	840	680	570	520	450	390
	d in	0.20	0.24	0.28	0.32	0.38	0.44	0.49	0.55	0.61
2.Max Shock	F lbf	16000	13000	12000	10000	8500	7200	6200	5100	4300
	d in	0.94	1.2	1.4	1.6	2.0	2.3	2.5	2.7	2.9
3.Max Vibration	2a in	0.10	0.13	0.15	0.18	0.22	0.26	0.27	0.29	0.32
	f Hz	9.1	8.2	7.6	7.1	6.5	6.0	5.7	5.4	5.1



COMPRESSION/ROLL 45° - TENSION/ROLL 45°

HH64 Series	Model	-24	-28	-32	-34	-36	-44	-46	-48	-50
1.Max Static	F lbf	1000	860	730	630	510	430	390	340	290
	d in	0.36	0.43	0.50	0.57	0.67	0.78	0.87	1.0	1.1
2.Max Shock	F lbf	2800	2300	2000	1700	1400	1200	1000	900	780
	d in	1.9	2.2	2.5	2.9	3.3	3.8	4.4	5.2	6.0
3.Max Vibration	2a in	0.20	0.24	0.27	0.32	0.36	0.42	0.48	0.57	0.65
	f Hz	5.9	5.4	5.1	4.8	4.5	4.2	3.9	3.5	3.2
1.Max Static	F lbf	1000	860	730	630	510	430	390	340	290
	d in	0.26	0.31	0.36	0.42	0.50	0.58	0.64	0.72	0.81
2.Max Shock	F lbf	7800	6700	5800	5000	4300	3600	3100	2600	2200
	d in	1.1	1.3	1.6	1.8	2.3	2.7	2.8	3.1	3.3
3.Max Vibration	2a in	0.12	0.15	0.18	0.20	0.25	0.29	0.31	0.34	0.36
	f Hz	8.1	7.4	6.8	6.3	5.8	5.4	5.1	4.8	4.6



SHEAR OR ROLL

HH64 Series	Model	-24	-28	-32	-34	-36	-44	-46	-48	-50
1.Max Static	F lbf	690	580	490	420	340	280	260	220	200
	d in	0.29	0.35	0.41	0.48	0.56	0.66	0.76	0.91	1.1
2.Max Shock	F lbf	4500	3700	3200	2700	2200	1800	1600	1300	1100
	d in	1.3	1.6	1.8	2.1	2.5	3.0	3.2	3.6	4.0
3.Max Vibration	2a in	0.14	0.17	0.20	0.23	0.28	0.32	0.35	0.40	0.45
	f Hz	6.7	6.1	5.7	5.3	4.9	4.5	4.3	4.0	3.8

1. Max static load (F) with corresponding deflection (d)
2. Max shock load (F) with corresponding deflection (d)
3. Uncoupled resonant frequency (f) under max static loading 1. and max peak to peak sinusoidal vibration input (2a)

*IMPORTANT: Performance characteristics are given here for reference only. They can be increased under specific conditions. Contact us

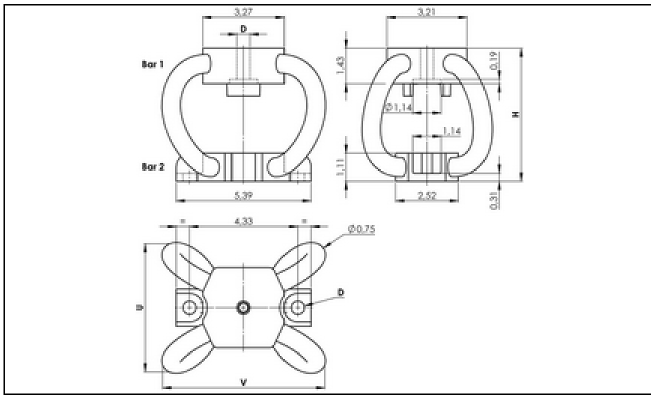
TYPICAL SHOCK/VIBRATION SPECIFICATIONS:

Air	AIR 7306, MIL-E-5400, MIL-C-172, MIL-STD-810
Ground Forces	GAM EG13A, SEFT 001, MIL-STD-810, VG 9533
Marine	GAM EG13C, IT25-21/96-31/15-86, MIL-S-167, MIL-S-901, STANAG 042, BV 043.73, BV 044
Others	GAM EMB1, GAM EMBT4, DEF STAN 07-55, IEC 571, FINABEL 2C

Water Trap Shock Isolators

WIRE ROPE ISOLATOR: 'POLYCAL'

DEFINITION
series MP64



- All metal multidirectional anti-vibration/shock mounts
- Exceptional reliability and long life
- High damping
- No aging
- Corrosion resistant
- Unequalled temperature range:- 180°C to 300°C (- 290°F to 570°F)
- Great adaptability/versatility

Dimensions are in inches. For reference only

SERIES
Materials and finishes (meets RoHS requirements)
MP64 **Cable:** stainless steel **Retainer bars:** aluminium alloy **Inserts:** stainless steel

MODEL	height H (in)	width U (in)	width V (in)	weight (lbs)
-78	5.1	5.4	6.9	4.9
-84	5.9	5.9	7.7	5.1
-86	6.5	6.3	8.0	5.4
-90	7.6	7.2	8.6	6.0
-92	8.8	8.1	9.3	6.7

INTERFACES	
fixtures holes D	
no suffix	1 through hole ø 0.53 in (optional 5/8 - 11 insert)
	2 through holes ø 0.53 in

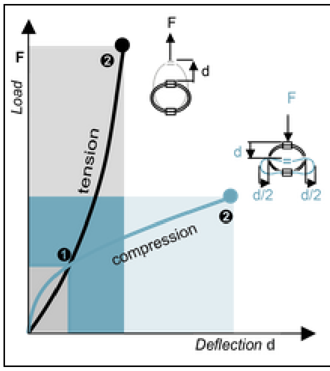
M	P	6	4	-	7	8

SERIE: MP64
'Polycal' mount from the MP64 series

MODEL: -78
height: 5.1in
width: 5.4in
weight: 4.9lbs

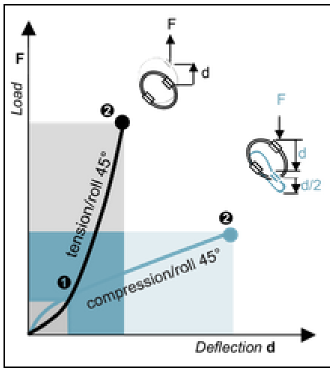
WIRE ROPE ISOLATOR: 'POLYCAL'

PERFORMANCE DATA
series MP64



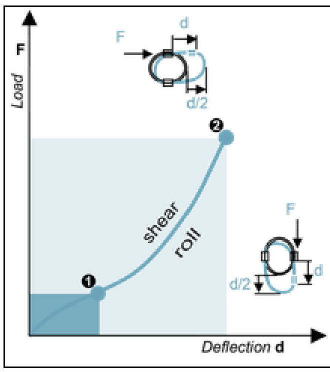
COMPRESSION AND TENSION

MP64 Series	Model	-78	-84	-86	-90	-92
1.Max Static	F lbf	380	310	270	210	160
	d in	0.38	0.56	0.67	0.87	1.1
2.Max Shock	F lbf	1100	920	810	640	490
	d in	2.3	3.1	3.5	4.6	5.7
3.Max Vibration	2a in	0.26	0.34	0.39	0.51	0.62
	f Hz	5.2	4.4	4.0	3.4	3.0
1.Max Static	F lbf	380	310	270	210	160
	d in	0.38	0.46	0.51	0.61	0.74
2.Max Shock	F lbf	4400	3300	2800	2000	1600
	d in	1.9	2.1	2.3	2.6	3.1
3.Max Vibration	2a in	0.21	0.23	0.25	0.28	0.34
	f Hz	6.5	6.0	5.7	5.2	4.7



COMPRESSION/ROLL 45° - TENSION/ROLL 45°

MP64 Series	Model	-78	-84	-86	-90	-92
1.Max Static	F lbf	280	230	200	160	120
	d in	0.68	0.86	0.98	1.2	1.5
2.Max Shock	F lbf	760	610	530	410	310
	d in	3.5	4.6	5.3	6.9	8.5
3.Max Vibration	2a in	0.38	0.51	0.58	0.76	0.93
	f Hz	4.3	3.7	3.4	2.9	2.6
1.Max Static	F lbf	280	230	200	160	120
	d in	0.49	0.60	0.67	0.81	1.00
2.Max Shock	F lbf	2200	1600	1400	1000	770
	d in	2.1	2.4	2.6	2.9	3.5
3.Max Vibration	2a in	0.23	0.26	0.28	0.32	0.39
	f Hz	5.8	5.3	5.1	4.6	4.2



SHEAR OR ROLL

MP64 Series	Model	-78	-84	-86	-90	-92
1.Max Static	F lbf	190	150	140	110	81
	d in	0.70	0.84	0.98	1.3	1.6
2.Max Shock	F lbf	1100	780	660	470	350
	d in	2.5	3.0	3.4	4.1	5.0
3.Max Vibration	2a in	0.27	0.33	0.37	0.45	0.55
	f Hz	4.9	4.3	4.1	3.6	3.3

1. Max static load (F) with corresponding deflection (d)
2. Max shock load (F) with corresponding deflection (d)
3. Uncoupled resonant frequency (f) under max static loading 1. and max peak to peak sinusoidal vibration input (2a)

*IMPORTANT: Performance characteristics are given here for reference only. They can be increased under specific conditions. Contact us

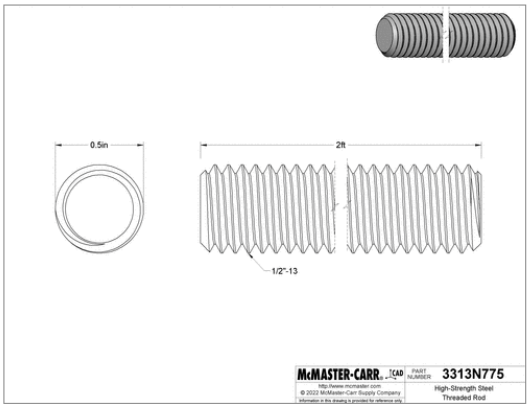
TYPICAL SHOCK/VIBRATION SPECIFICATIONS:

Air	AIR 7306, MIL-E-5400, MIL-C-172, MIL-STD-810
Ground Forces	GAM EG13A, SEFT 001, MIL-STD-810, VG 9533
Marine	GAM EG13C, IT25-21/96-31/15-86, MIL-S-167, MIL-S-901, STANAG 042, BV 043.73, BV 044
Others	GAM EMB1, GAM EMBT4, DEF STAN 07-55, IEC 571, FINABEL 2C

Water Trap Anchor bolts
Cut to 16" length

High-Strength Steel Threaded Rod

Zinc Yellow-Chromate Plated, 1/2"-13 Thread Size, 2 Feet Long



Material	Zinc Yellow-Chromate Plated Steel
Fastener Strength Grade/Class	ASTM Grade BD
Thread Size	1/2"-13
Length	2ft.
Tensile Strength	150,000 psi
Hardness	Rockwell C33
Thread	
Direction	Right Hand
Type	UNC
Spacing	Coarse
Fit (External)	Class 2A
Threading	Fully Threaded
Specifications Met	ASTM A354BD
RoHS	RoHS 3 (2015/863/EU) Compliant
REACH	REACH (EC 1907/2006) (06/10/2022, 224 SVHC) Compliant
DFARS	Specialty Metals Compliant (252.225-7009)
Country of Origin	United States
USMCA Qualifying	No
Schedule B	731815.5000
ECCN	EAR99

Comparable to Grade 8 steel, these threaded rods have a tensile strength of 150,000 psi, making them about 25% stronger than medium-strength steel rods.

Zinc yellow-chromate plated steel threaded rods resist corrosion in wet environments.

Appendix C – Water Trap Design and Installation

The primary water trap collects water that may be coming out of the borehole sampling zone. The trap will have an internal volume of 9.4 L. Since the amount of water potentially coming out of the borehole is unknown, a self-contained, self-powered drain system will allow near infinite water collection. A pair of float switches will trigger the drain to open when the trap is 80% full and drain until 15% full. The draining functionality is only enabled for two boreholes (GS-1 and GS-2). The other six boreholes are all single fill containers.

The table below shows the parts that make up the water trap, including the inlet and outlet fittings for gas and liquid, and the frame. Some parts are labeled with a number, those parts are called out by their number in the corresponding Figure (C1).

Table C1. Water trap parts list.

Part	Supplier: part number
Frame	Custom
Cushion clamps (1)	Grainger: 4MWA2
Screw	McMaster-Carr: 92865A724
Nut	McMaster-Carr: 95462A033
Washer	McMaster-Carr: 92141A033
Lock washer	McMaster-Carr: 91102A770
Water trap body (2)	McMaster-Carr: 4804T222
Float insert fitting (3)	McMaster-Carr: 1424N22
Gas in/gas out (4)	McMaster-Carr: 4565T322
Top and bottom cap (5)	Pipe Fittings Direct: KCXH6SS
Liquid drain fittings (6)	McMaster-Carr: 4565T312
Manual drain	McMaster-Carr: 45395K216
Enclosure	Polycase: SB-34-02
Battery	Universal Battery: UB12150
Mechanical relay	Automation Direct: AD-PR40-2A-12D
Float switch	Dwyer: L10-S-3-O
Float switch extension	Custom
Auto drain	Peter Paul: 72K9DGM

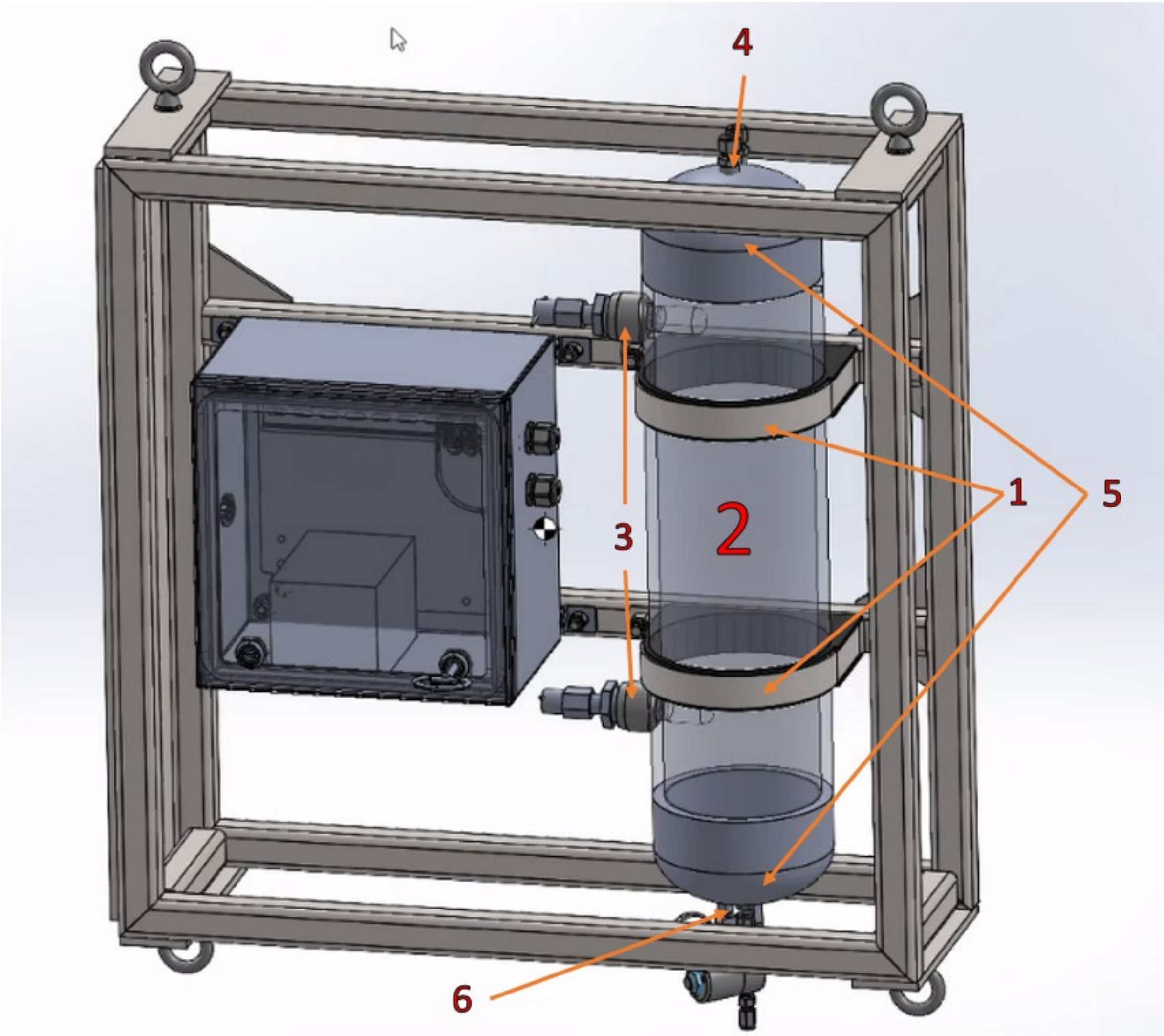


Figure C1. Water trap.

C.1 Drain Valve Control

When water trap fills to high level float, the solenoid valve opens to drain the resevoir (Figure C2). The solenoid remains open until water drains to height of low level float. At that point the solenoid drain valve will close, leaving ~1.3 L of water in the trap (Figure C3).
Circuit function -

1. Water begins to fill water trap. Water level triggers low float switch (Switch goes from normally open to closed position).
2. Water level fills and triggers high float switch (switch goes from normally open to closed position). DPST mechanical relay is activated.
3. Solenoid valve opens releasing water. Water drops below high level float switch. (float switch goes from closed back to normally open). Relay remains latched.
4. Water drops below the low level float. Low float switch opens (goes from closed back to normally open). DPST relay latch is broken the solenoid closes.

Dual Float Water System Circuit

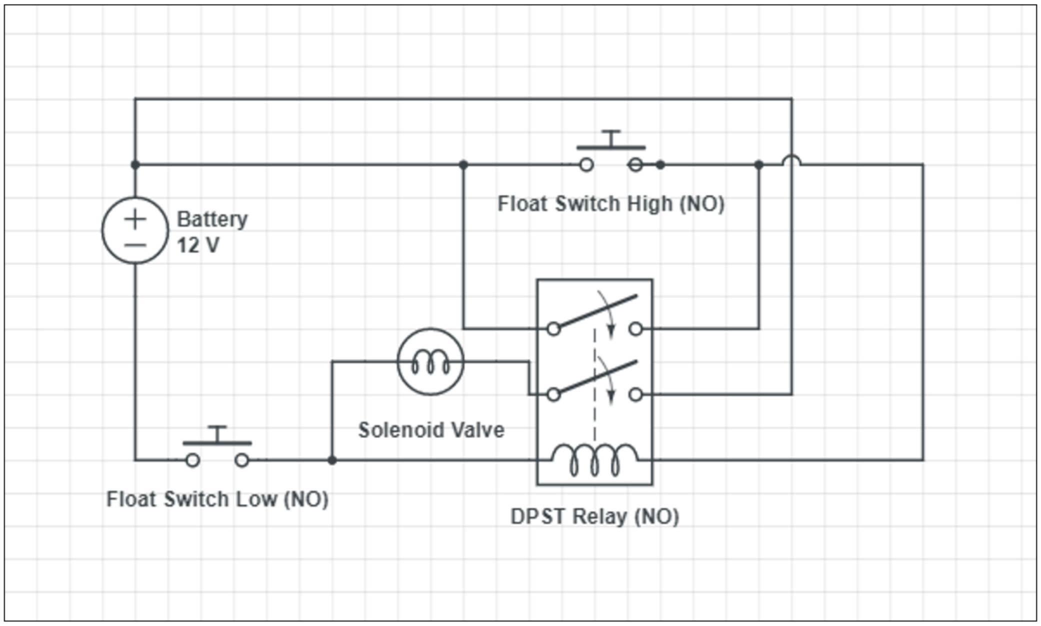


Figure C2. Water trap float switch circuit diagram.

Discharge times 1.7 gallons through 3/64" orifice		
Differential (PSI)	Flow Rate (GPM)	Full drain time (Min)
1	0.0414	52
2	0.0585	33
5	0.0729	17
10	0.1881	9
20	0.3501	4.8
30	0.5121	3.4

Water trap volumes

Total volume = 2.48 gal 9.4 L
Volume to high float = 2.103 gal 7.69 L
Volume between floats= 1.69 gall 6.40L
Volume below low float = 0.338Gal 1.28 L

Figure C3. Water trap volumes and calculated drain times.

In order to drain the water trap, a battery is necessary to maintain the solenoid in the open position. Battery size is determined by the amount of time the solenoids need to remain in the open position. The power consumption for the solenoid valve is 9.5 Watts. Based on the drain times above (Figure C3), a 12 amp-hour battery was chosen, allowing for at least 2 full trap volumes to be drained.

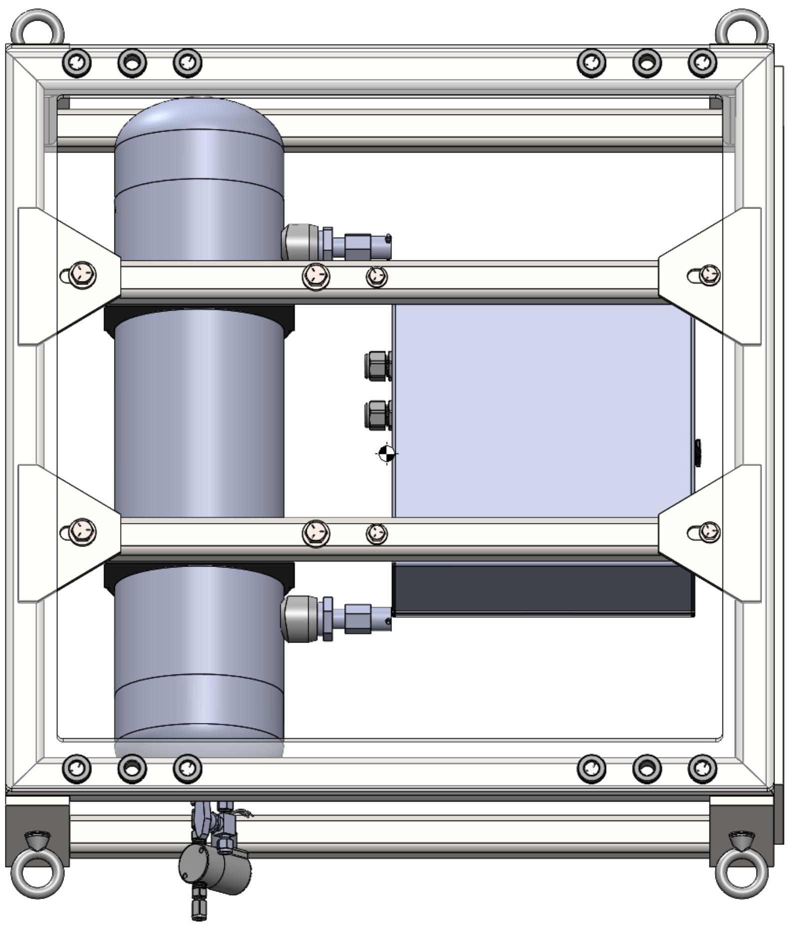


Figure C4. Figure showing the back of the water trap frame. Shows the holes at each corner used for shock mounting.

C.2 Water Trap Installation Instructions

1. Align template with edges of existing water trap frame
2. Clamp template to the frame using quick clamps or equivalent
3. Drill (2) 9/16” holes at each of the corners through the square beam. Skip middle hole in pattern.
4. Align template with edges of existing water trap frame
5. Attach MP64-86 wire rope isolators to water trap frame (using 3.5” ½-13 bolts)
6. Place template against the rib
7. Mark rib for the anchor bolts locations using center holes on template
8. Drill 3/4” anchor holes at least 13” deep at marked locations
9. Inject Hilti HY 200-R into drilled holes
10. Install ½-13 x 16” anchor bolts
11. Rotate anchor one revolution to insure uniform epoxy coverage
12. Drill 9/16” anchor holes for D-ring attachment points

13. Inject Hilti HY 200-R into drilled holes
14. Install ½” x 16” anchor bolts
15. Allow epoxy to cure per package instructions
16. Use chain hoist to raise water trap into position.
17. Align the water trap isolators with the anchor bolts
18. Secure with ½” hex nuts and washers
19. Loosely attach ratchet straps between eye bolt at top of frame and D-ring.
20. Maintain slack as shown in illustration
21. Secure excess webbing

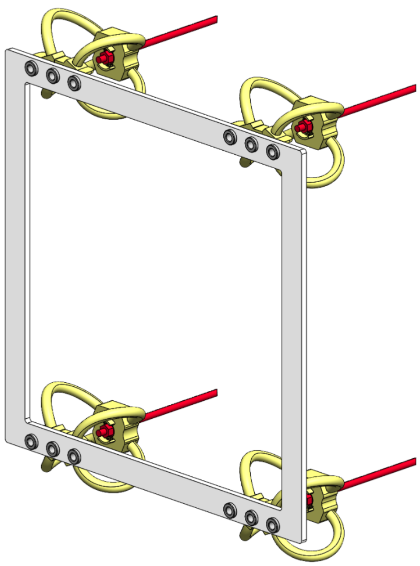


Figure C5. Water trap isolators and template.

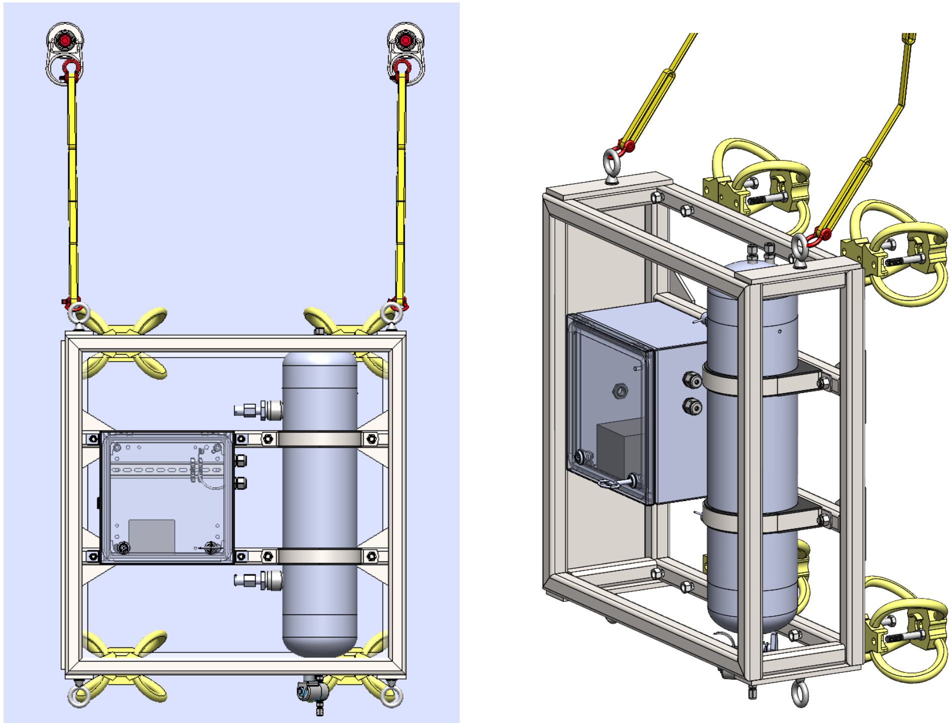


Figure C6. Water trap installation diagram.

Figure C7. Water trap installed in tunnel.

Appendix D – Electrical Power Description

The borehole gas sampling system will be used to move gas from the boreholes, through tubing, to the 650 facility. The sample gas will be distributed to other analytical systems and then returned to the boreholes. This is a closed loop system with flow being driven by pumps. The system has two primary electrical components; a 24VDC system and two 480V pumps. The majority of the system (small pumps, instrumentation, control, etc.) operates on 24VDC which is provided by two 1000W power supplies connected to 120 VAC power in 650. The 480V power is used to power two large diaphragm pumps which are controlled through independent VFDs. The sketch below (Figure D1) provides an overview of the electrical power distribution on the gas sampling system.

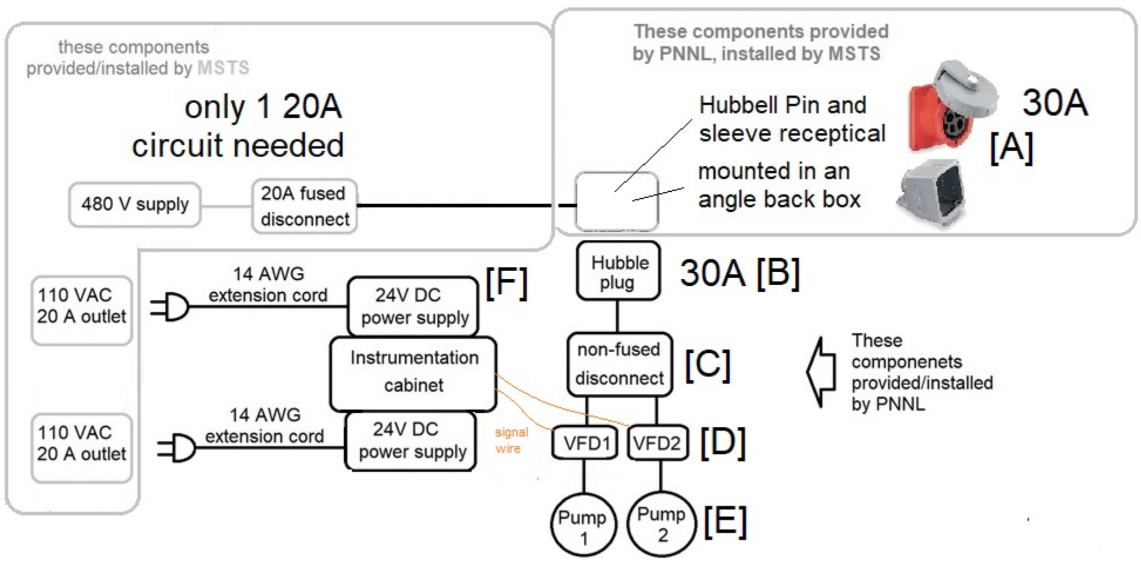


Figure D1. Description of power needed for the Gas Sampling System.

D.1 120 Volt Supply

The DC power supplies are UL listed, 1000 Watt supplies ganged together in a parallel output configuration. The 24 volts is routed from the DC supplies (mounted outside the electronics enclosure) to a 24 V bus inside of the electronics enclosure (Figure D2). The power supplies will be connected to 120 V, 10A outlets in the 650 facility with 25-foot 14AWG extension cords with locking plugs. Additional cord locks will be used to prevent accidental disconnection of the power supplies.

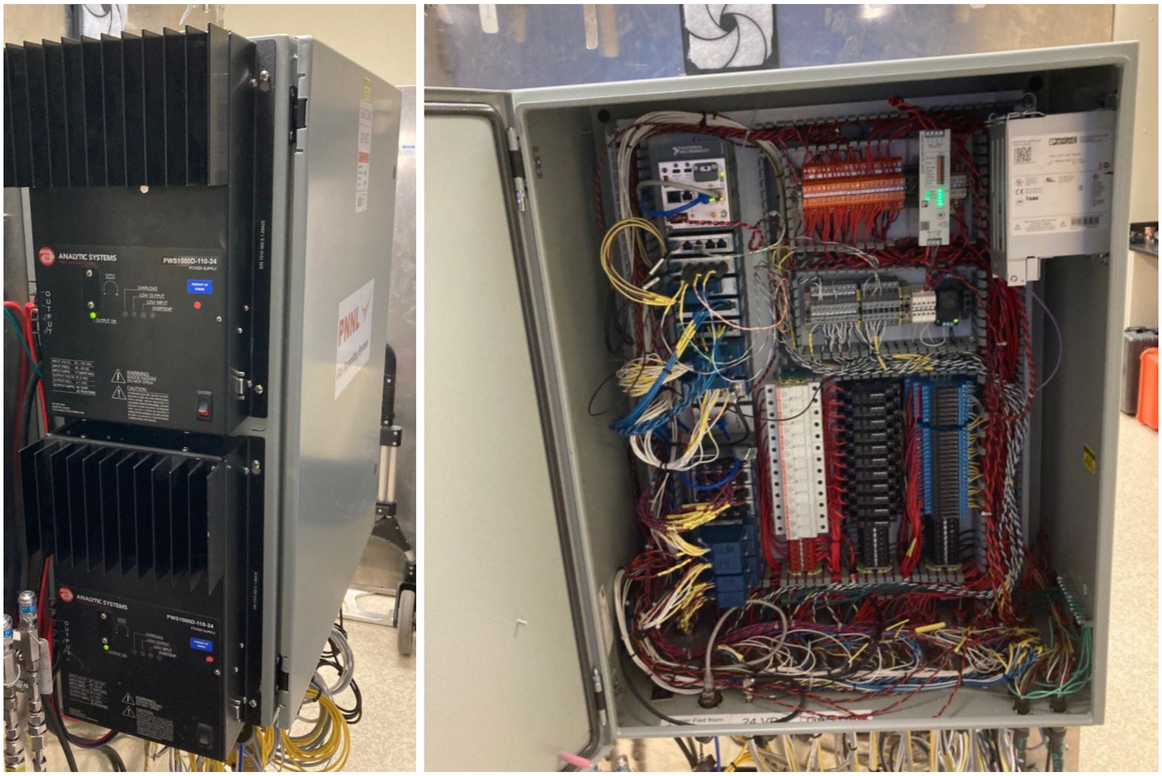


Figure D2. 24 VDC power supplies mounted to the electronics cabinet.

D.2 480 Volt Supply

Large diaphragm pumps are necessary to recirculate gas within the system if the formation pressures (post explosion) are higher than the small pumps can handle. Only two of these pumps are installed (for the boreholes closest to the working point). These pumps are driven by 1500W, 480 Volt, 3-phase motors. The motors and controlled (on/off and speed) by VFDs connected to the system control inside of the electronics cabinet. In this manner the large pump operation will be controlled remotely by an operator on the apron. The incoming 480V power is split inside of a local non-fused disconnect mounted to the gas sampling system. The disconnect is connected to power with a pin-and-sleeve plug. Inclusion of a local plug on the system provides a means to de-energize the system and conduct work using exclusive control (rather than lock-and-tag). Additionally, the local disconnect provides an local emergency stop mechanism for the motors. The 480V equipment ground is also connected, through the equipment chassis, to the 120 VAC ground. All internal and external panels are bonded with jumpers.

Figure D3. 480 V VFDs and local disconnect.

Figure D4. 480V pumps installed in the gas cabinet, and motor plate.

D.3 PNNL inspection of non-NRTL equipment

Per PNNL policy, the custom fabrication of a system using electrical components greater than 50V requires inspection and approval by an AHJ. The AHJ inspection report is included and coved a number of important system aspects, including grounding and labeling (Figure D5). The gas sampling system passed the PNNL AHJ inspection, and was marked as such (Figure D5).

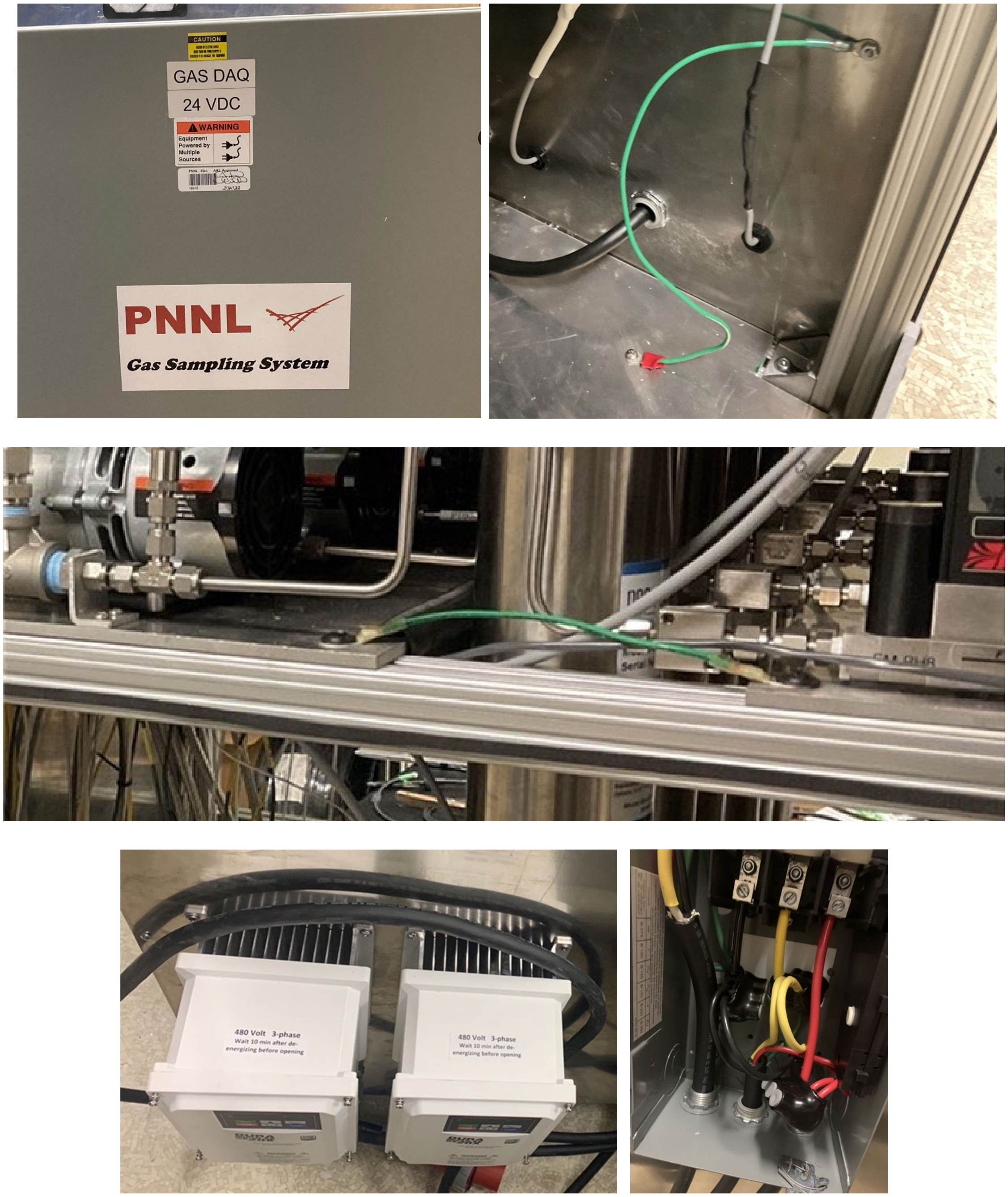


Figure D5. Additional pictures of the gas sampling system electrical system.

D.4 Cut sheets for major electrical components

[A] 30 A Hubbell receptacle
This receptacle will be mounted to the 650 floor and provide 480V power for the two 480V gas pumps

IEC Pin and Sleeve

30A, 3 Phase 480V, 3 Pole, 4 Wire

HUBBELL

Watertight Receptacle

Features

- UL Type 4X, 12 and IP69k environmental ratings
- Super tough insulated non-metallic housing
- Self-closing gasketed cover
- Sequential contact engagement to prevent a momentary over-voltage
- Market leading UL witnessed HP ratings

Ordering Information

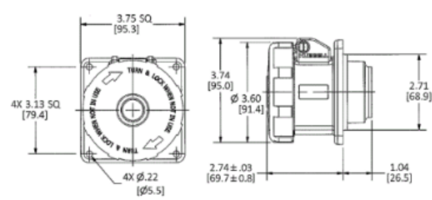
Description	UPC	Catalog Number
Watertight IEC Pin and Sleeve Receptacle	783585404639	**HBL430R7W**

Listings

UL Classified, File E146032
CSA Certified File LR285C
UL Classified to IEC 60309-1 IEC 60309-2

Specifications

Housing	PBT
Closure Covers	PBT
Sealing Gasket	Solid Neoprene
Retainer	High-Impact Thermoset
Gaskets	Santoprene
Terminal Screws	Stainless Steel



Performance

Electrical	
Current Interrupting	Certified for current interrupting at full rated current
Dielectric Voltage	Withstand 3000V AC
Max. Working Voltage	600V AC RMS
Mechanical	
Impact Resistance	Per CSA C22.2 No. 182.1 / UL1682
Product Identification	Identification and ratings are a permanent part of the device housing
Terminal Identification	Terminals identified in accordance with North American and IEC conventions
Environmental	
Flammability	V-0
Ingress Protection	TYPE 3R,3RX,4X and IP68,IP69K
Moisture Resistance	IEC 60309-1
Operating Temperatures	Maximum Continuous 75°C; Minimum - 40°C w/o impact

Complementary Products

Cover Assemblies

[B] 30 A Hubbell plug
This plug will be attached to a short (~6 foot) length of SO cord (SOOW 10AWG) and a disconnect switch mounted to the gas sampling cabinet

IEC Pin and Sleeve

30A, 3 Phase, 480V, 3 Pole, 4 Wire

HUBBELL

Watertight Plug

Features

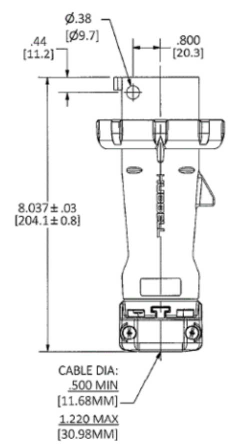
- UL Type 4X, 12 and IP69k environmental ratings
- One piece non-metallic housing provides impact and chemical resistance in an insulated body
- Watertight neoprene gland seal to prevent water ingress from entering at cable entrance
- Solid one-piece pins for reliable electrical contact
- Sequential contact engagement to prevent a momentary over-voltage

Ordering Information

Description	UPC	Catalog Number
Watertight IEC Pin and Sleeve Mating Plug	783585404585	**HBL430P7W**

Listings

UL Listed, File E146033
CSA Certified File LR280C
UL Classified to IEC 60309-1
IEC 60309-2



Specifications

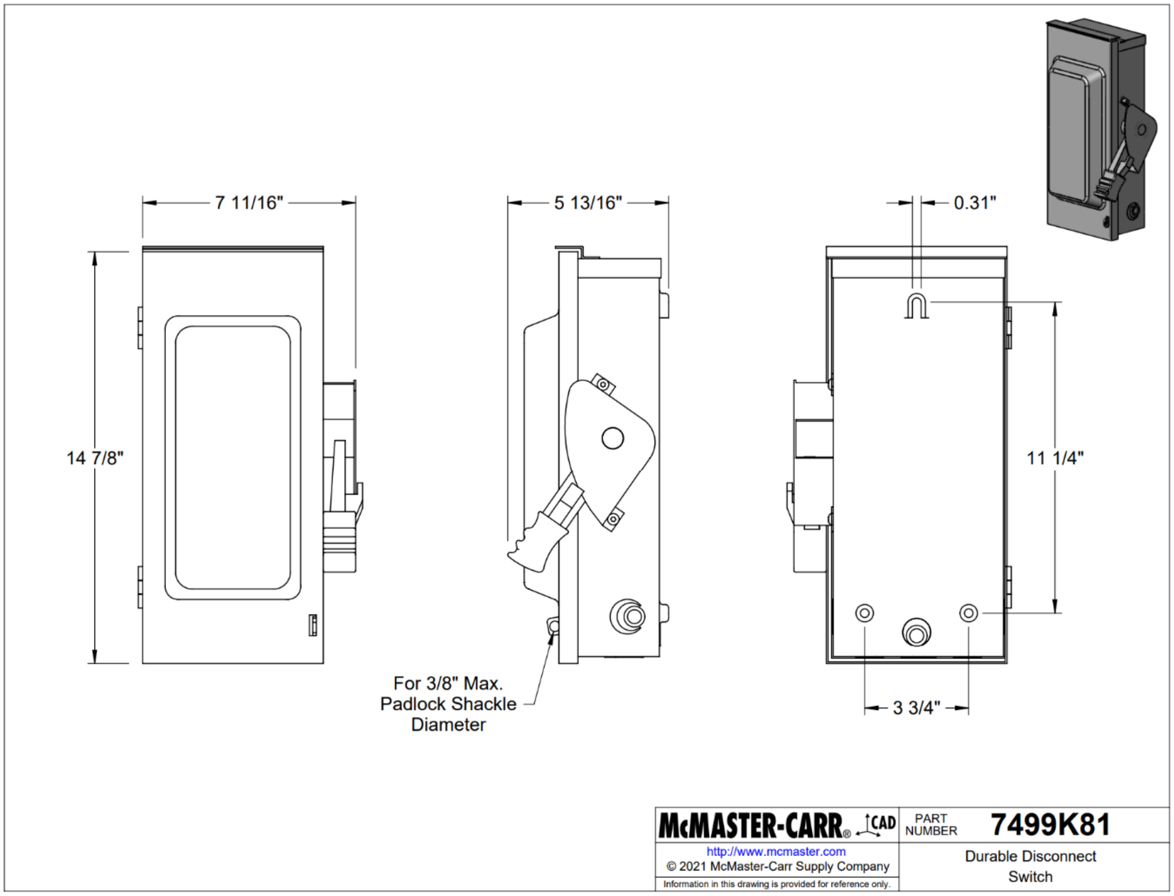
Housing	PBT
Locking Ring	PBT
Sealing Gasket	Solid Neoprene
Contact Carrier	High-Impact Thermoset
Glands	Santoprene
Terminal Screws	Stainless Steel
Cord Clamps	PBT

Performance

Electrical	
Current Interrupting	Certified for current interrupting at full rated current
Dielectric Voltage	Withstands 3,000V AC
Max. Working Voltage	600V AC RMS
Mechanical	
Impact Resistance	Per CSA C22.2 No.182.1 /UL1682
Product Identification	Identification and ratings are a permanent part of the device housing.
Terminal Identification	Terminals identified in accordance with North American and IEC conventions
Environmental	
Flammability	V-0
Ingress Protection	Type 3R,3RX,4X and IP68,IP69K
Moisture Resistance	IEC 60309-1
Operating Temperature	Maximum Continuous 75°C; Minimum - 40°C w/o impact

[C] Disconnect Switch

This disconnect switch will be mounted to the gas sampling cabinet. It will have 480V power coming in and 2 480V legs going out, feeding two VFD pump controllers. Power plug is attached with 10 AWG SOOW cord. The VFDs are connected with 12 AWG SOOW cord.



Switch Type	Disconnect
Number of Circuits Controlled	3
Switching	
Current	30 A
Voltage	600V AC/ 600V DC
Switch Action	Stays Switched (Maintained)
Industry Designation	3PST
Maximum Voltage	600V AC/600V DC
Electrical Phase (hp)	Single (10 hp @ 240 V AC) Three (30 hp @ 600 V AC)
For Number of Wires	3
Actuator Color	Black/Red
For Maximum Padlock Shackle Diameter	3/8"
Number of Mounting Holes	3

Mounting Hole Diameter	0.31"
Mounting Fasteners Included	No
Wire Connection Type	Lug Terminals
Knockout Trade Size	1/2, 3/4, 1, 1 1/4
Environment	Splashing Water
Environmental Rating	NEMA 3R
Features	Lockout, Safety Interlock
Specifications Met	UL Listed, Fed. Spec. WS-865C
RoHS	Not Compliant
REACH	Not Compliant
DFARS	Specialty Metals COTS-Exempt
Country of Origin	United States
USMCA Qualifying	No
Schedule B	853650.9065
ECCN	EAR99

[D] Variable Frequency Drive
The variable frequency drives are DURApulse model GS23X-42P0. The drives are connected to the pumps with 14 AWG VFD cable (specs below).
https://www.automationdirect.com/adc/shopping/catalog/drives_-a-_soft_starters/ac_variable_frequency_drives_(vfd)/washdown_(nema_4x)/gs23x-42p0

GS20X 460V[1] 3-Phase Specifications – Frame Sizes A, B, C

				GS23X-40P5	GS23X-41P0	GS23X-42P0	GS23X-43P0	GS23X-45P0	GS23X-47P5	GS23X-4010
Model Name				GS23X-40P5	GS23X-41P0	GS23X-42P0	GS23X-43P0	GS23X-45P0	GS23X-47P5	GS23X-4010
Price				$300.00	$309.00	$355.00	$394.00	$479.00	$657.00	$741.00
Frame Size				A	A	A	A	B	C	C
Output Rating	Max Motor Output		hp	1/2	1	2	3	5	7 1/2	10
			kW	0.4	0.75	1.5	2.2	3.7	5.5	7.5
	CT	Rated Output Capacity	kVA	1.1	2.1	3.2	4.2	6.9	9.9	13
		Rated Output Current	A	1.5	2.7	4.2	5.5	9	13	17
		Carrier Frequency[3]	kHz	2–15 (default 4)						
	VT	Rated Output Capacity	kVA	1.4	2.3	3.5	5	8	12	15.6
		Rated Output Current	A	1.8	3	5.6	6.5	10.5	15.7	20.5
		Carrier Frequency[3]	kHz	2–15 (default 4)						
Input Rating[2]	CT	Rated Input Current	A	2.1	3.7	5.8	6.2	9.9	14.3	18.7
	VT	Rated Input Current	A	2.5	4.2	6.4	7.2	11.6	17.3	22.6
	Rated Voltage/Frequency			Three-phase 380–480 VAC (-15% to +10%), 50/60 Hz						
	Operating Voltage Range (VAC)			323–528						
	Frequency Tolerance (Hz)			47–63						
Weight (kg [lb])				2.35 [5.18]	2.6 [5.73]	2.8 [6.17]	3.6 [7.94]	3.45 [7.61]	4.25 [9.37]	4.25 [9.37]
Cooling Method				Convective				Fan		
IP Rating				IP66 / NEMA 4X						

1 - For Use With Three-Phase Motors Only.
2- If 3-phase power source is non-symmetrical, refer to "Circuit Connections – RFI Jumper" in the GS20(X) AC Drives User Manual, Chapter 2. Please refer to "GS20(X) DURApulse Accessories – Fusing" (pg.tGSX-41) for input fusing information.
3 - The value of the carrier frequency is a factory default. Decrease the current value if you need to increase the carrier frequency. Refer to "Derate Output Current Based on Carrier Frequency (if neccessary)".

Environmental Conditions for GS20X AC Drives

Condition	Operation	Storage	Transportation
Installation Location	PCB design is compliant with IEC 60364-1 / IEC 60664-1 Pollution Degree 2. The outer case meets IP66 standard for indoor use. If the drive is for outdoor application, avoid direct sunlight.	n/a	n/a
Ambient Temperature	IP66 / NEMA 4X / UL Type 4X: -20–40°C (-20–50°C w/derating)	-40–85°C	-20–70°C
	Non-condensing, non-freezing		
Relative Humidity	0-100%, no water condensation	95%, no water condensation	
Air Pressure	86–106 kPa	70–106 kPA	
Pollution Level	IEC 60721-3, concentrate prohibited		
	Class 3C2; Class 3S2	Class 2C2; Class 2S2	Class 1C2; Class 1S2
Altitude	<1000m (For altitudes > 1000m, derate to use it.)		
Package Drop	n/a	ISTA procedure 1A (according to weight) IEC 60068-2-31	
Vibration	1.0 mm, peak to peak value range from 2–13.2 Hz; 0.7–2.0 G range from 13.2–55 Hz; 2.0 G range from 55–512 Hz; complies with IEC 60068-2-6.	2.5 G peak, 5 Hz–2 kHz 0.015" maximum displacement	
Impact	15G, 11ms Compliance with IEC/EN60068-2-27	30G	

DO NOT expose the GS20X AC Drive to harsh environments such as direct contact with chemical substance and solvent, and exposure to direct sunlight.

Use For	Motors, Interference Shielding
Wire Type	Stranded
Flexibility	Flexible
Power Wire	
Number of	4
Gauge	14
Cable AWG	14/4
Shielding	Double Shielded
Shield Type	Braid, Foil
Current	15 A @ 86° F
Voltage	1,000V AC/1,500V DC
Temperature Range	-40° to 220° F
OD	0.52"
Outer Insulation Material	PVC Plastic
Outer Insulation Color	Black
Inner Insulation Material	Nylon Plastic, PVC Plastic
Inner Insulation Color	Black, Green/Yellow
Industry Designation	VFD, WTTC

[E] Large Diaphragm Pumps
KNF diaphragm pump, model N630.15ST.9E.

PERFORMANCE DATA				
Series model	**N 630.15 - 50 Hz Version**		**N 630.15 - 60 Hz Version**	
Material design	**ST.9 E / ST.13 E**	**SP.9 E / SP.13 E**	**ST.9 E / ST.13 E**	**SP.9 E / SP.13 E**
Pump head	316 Stainless Steel			
Diaphragm	PTFE-coated	EPDM	PTFE-coated	EPDM
Valves	Superflex Stainless Steel			
Flow rate at atm. pressure (l/min)	30.0		35.0	
Ultimate vacuum (mbar abs.)	70			
Max. operating pressure (bar g/psig)	12.0/174.0			
Permissible ambient temperature (°C/ °F)	5 - 60 / 40 - 140 (40/104 without water cooling)			
Permissible media temperature (°C/ °F)	5 - 60 / 40 - 140 (40/104 without water cooling)			
Level of gas tightness (mbar x l/s) .9 / .13	$6 \times 10^{-3} / 5 \times 10^{-5}$			
Weight (kg/lbs)	55.0/121.0			

ELECTRICAL DATA				
Voltage (V)	230/400	200/346	220/380	277/480
Motor	Three-phase motor			
Motor protection class	IP 55			
Pump protection class	IP 20			
Frequency (Hz)	50	50/60	60	
Power P_2 (W)	1500			
I_N (A), 50 Hz	6.15/3.55	7.0/4.05	-	
I_N (A), 60 Hz	-	7.1/4.1	6.5/3.75	5.2/3.0

[F] 24V DC power supplies
This system uses two 1000 Watt DC power supplies to provide the 24V DC used by the small pumps and instrumentation. The power supplies are connected in a parallel output configuration. The power supplies will be connected with 14 AWG extension cords with locking plugs and additional cord locks to prevent disconnection.


ANALYTIC SYSTEMS
Power Conversion Solutions

AC SOURCE POWER SUPPLIES | PWS1000

3 YEAR WARRANTY

PWS1000 AC SOURCE POWER SUPPLY

The PWS1000 series of Power Supplies provides 1000 watts of continuous power at 12, 24, or 48 volts DC from a 110 or 220 volt AC source.

The newly updated single-board design is ultra-quiet and features the latest generation of current-mode PWM control. Modern switch-mode technology coupled with powerful IGBT switching transistors allow for maximum efficiency and reliability while maintaining compactness. New circuit innovations reduce output ripple to levels previously only available from bulky and inefficient linear power supplies.

Designed for ease of use the PWS1000 has a four contact output terminal (two positive and two negative contacts) for easy connection of devices, covered output voltage adjust and a bright LED display panel for at-a-glance indication of the operational status.

Reliability features include an input fuse, thermal shutdown, and output short circuit shutdown with automatic recovery. While the devices powered by the unit are protected from excessive voltage and current by an output over voltage crowbar circuit and current limiting.

Available models

Input

110V	220V

Output

12V	24V	48V	72V

Applications

An ISO9001 Registered Company   www.AnalyticSystems.com

PWS1000 | AC SOURCE POWER SUPPLY

INPUT

Nominal Voltage	110VAC	220VAC
Actual Voltage	90-130VAC	180-260VAC
Input Amps (Max)	13.2A(12V) 17A (24/32/48V)	6.6A (12V) 8.5A (24/32/48V)
Input Fuse (MDA)	20A (12V) 25A (24/32/48V)	10A(12V) 15A (24/32/48V)
Input Frequency	45 -65Hz	
Noise on Input	<50mV	

OUTPUT

Nominal Voltage	12VDC	24VDC	48VDC	72VDC
Actual Voltage	13.6 ± 0.05VDC	27.2 ± 0.05VDC	54.4 ± 0.1VDC	81.6 ± 1.5VDC
Output Current	60A Cont./ 70A Peak	40A Cont./ 45A Peak	20A Cont./ 22.5A Peak	13.3A Cont./ 15A Peak
Output Crowbar	16.0 ± 0.5V	32.0 ± 1.0V	63.9 ± 2.0V	96 ± 3.0V
Output Adjustment	± 1.0 V			
Output Ripple & Noise	<50 mV			
Transient Response	<1V for 50% Surge			
Regulation (Line & Load)	< +/- 0.5%			
Duty Cycle	Peak 20% for 10 minutes maximum Continuous 100% for 24 hours per day			
Efficiency	> 80% @ Maximum Output			

MECHANICAL

Dimensions	14.5 in (36.8 cm) Long x 9.9 in (25.1 cm) Wide x 5.5 in (14.0 cm) High
Clearance	1.0 in / 2.5 cm all around
Weight	12 lb / 5.5 kg
Material and Finish	Marine Grade Black Anodized Aluminum with 18-8 Stainless Fasteners
Mounting	Wall or shelf mount
Connections	Four contact output terminals

OPTIONS

GMDSS - Digital Voltmeter/Ammeter & Remote control kit.

Parallel Output Diodes for multiple unit connection

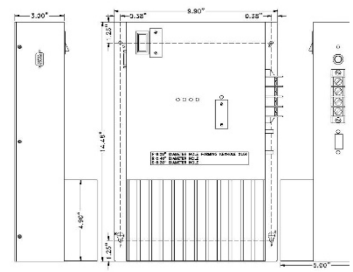
Safety Special Inspection (CSA/UL)

Integrated Digital Voltmeter/Ammeter

Heavy Duty Ruggedization with Wide OperationalTemperature range

Custom Input/Output Voltages available

DIMENSIONS



ENVIRONMENTAL AND SAFETY

Operating Temperature Range	-25°C to +40°C @ maximum output. Derate Linearly 2.5% per °C from 40°C (Optional -40°C to +55°C wide operational temperature range available)
Humidity	0 - 95% Relative Humidity (non-condensing) with standard conformal coating
Audible Noise	NONE 0db @ 3ft
Typical Service Life	> 10 years (87,600 hrs)
Isolation	Input-Case, Input-Output: 1500 VDC. Output-Case:500 VDC (1500V for 48 V Output)
Warranty	Three Years Parts and Labor
Safety	Certified to CSA C22.2 No.107.1 and UL 458

Note: Specifications are subject to change without notice.

ANALYTIC SYSTEMS
Power Conversion Solutions

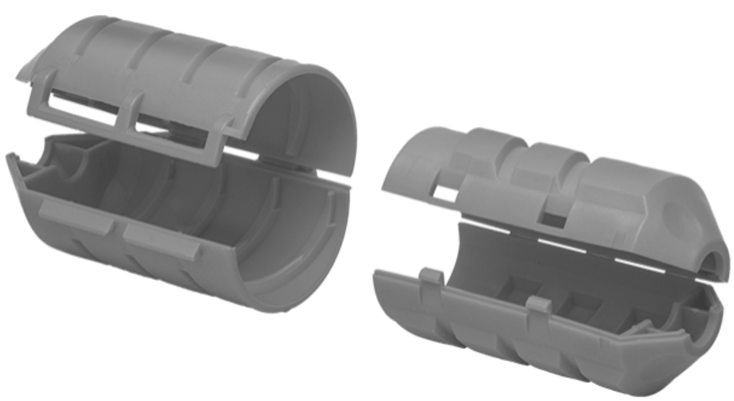
AnalyticSystems.com
sales@analyticsystems.com
604.946.9981 800.668.3884

8128 River Way
Delta BC V4G 1K5

Locking Extension Cord

25 Feet Long, Yellow

Length	25 ft.
Wire Gauge	14
Current	15 A
Voltage	125V AC
Connections	Straight-Blade Male Plug × Straight-Blade Female Socket
Straight-Blade Male Plug	
NEMA Style	5-15
End Shape	Straight
Number of Blades	3
Straight-Blade Female Socket	
NEMA Style	5-15
End Shape	Straight
Number of Slots	3
Number of Outlets	1
Power-Indicating Light	With Power-Indicating Light
Cord	
OD	0.36"
Insulation Material	PVC Plastic
Flexibility	Flexible



Appendix E – Calibration of Sensors

The gas sampling boreholes and the gas circulation cabinet have a number of sensors and devices. Not all instruments were, or will be, calibrated. Only measurements that may be directly used in post-explosion analysis were deemed necessary for calibration. For example, each borehole circulation loop includes a mass flow controller; these were not calibrated. While the data may be useful to provide interpretation of concentration measurements, the circulation flow rate will not be used directly by models and was therefore not deemed necessary for calibration. Similarly, the process flow pressure measurements are useful for verifying system operation, but will not be used in any quantitative analysis, and were not calibrated. While these instruments will not be calibrated, system checks will be used to verify function and response prior to the experiment. Only two instruments in the borehole and borehole gas circulation system need to have calibration checks performed. These are the borehole pressure transducers and the humidity probes. The humidity probes measure the relative humidity and temperature of the gas circulating from the borehole. Since the temperature is the temperature inside the cabinet at 650, not the temperature in the formation, the relative humidity is converted to absolute humidity using the RH probe's integral temperature measurement. All instruments included manufacturer's calibration equations to convert analog signals to engineering units. A calibration check was conducted to demonstrate that the sensors were providing data of appropriate quality.

Humidity sensor calibration checks were done with a two-point approach; one check at near saturated conditions and one in a desiccated environment. Similarly, the temperature probe calibration was checked against a single reference measurement since the temperature in the cabinet will vary by less than 10 degrees C.

The calibration checks of the pressure transducers used a calibrated reference sensor (Druck DPI 611) to perform a multi-point (5 to 8) check across the full range of the transducer (Figure E1). All sensors were checked after installation and verified to be within both the manufacturer's stated accuracy and the total uncertainty of the reference sensor (Table E1).

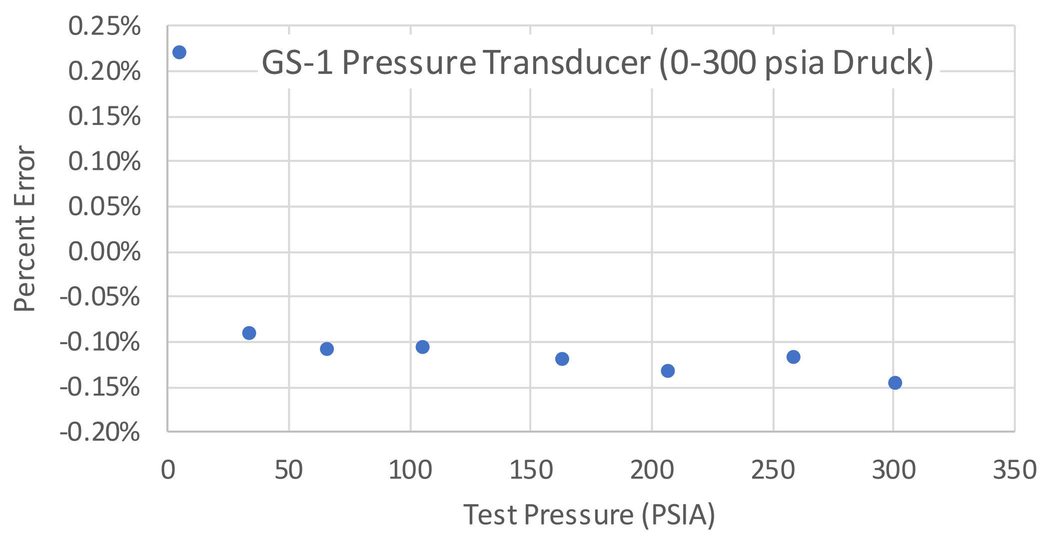


Figure E1. Example of calibration check measurements across full-range of GS-1 pressure transducer.

Table E1. Average error of pressure measurements relative to reference sensor.

Location	Sensor Brand	Average Error
GS-1	Druck	-0.07%
GS-2	Druck	0.03%
GS-3	Druck	-0.02%
GS-4	No-Shok	0.06%
GS-5	No-Shok	0.26%
GS-6	Druck	-0.22%
GS-7	No-Shok	0.20%
GS-8	Druck	-0.07%
TE-1	Omega	0.09%
TE-2	Omega	-0.02%
TE-3	Omega	0.03%

Appendix F – Tubing Installation Procedure

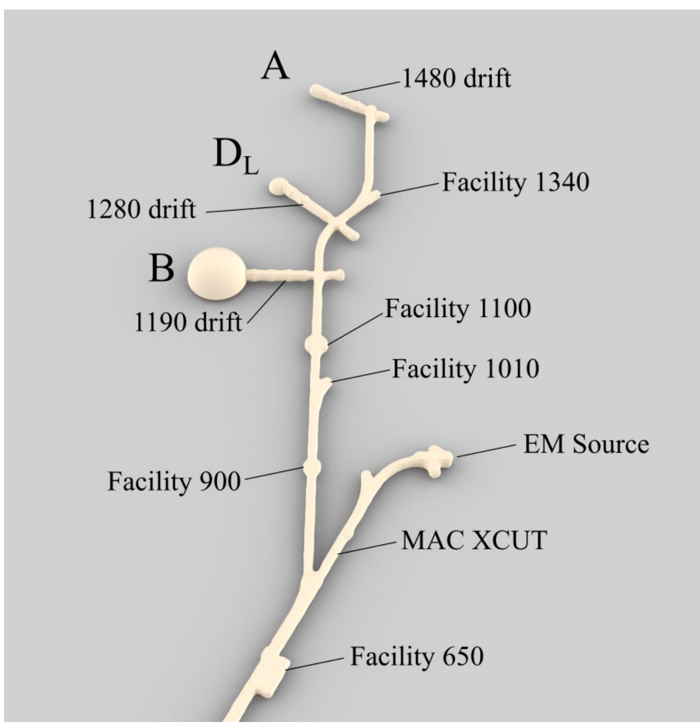
The tubing installation procedure was completed, approved and used as a standalone document prior to the installation of tubing in the tunnel for PE1.

F.1 Introduction

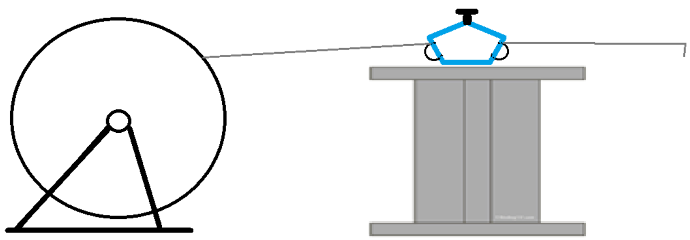
A primary objective of the Low Yield Nuclear Monitoring (LYNM) Physics Experiment 1 (PE1), conducted in P-Tunnel at the Nevada National Security Site (NNSS), is measurement of radioisotope tracer transport through the formation. To this end, gas measurement boreholes were installed along with gas monitoring equipment. The sample gas will be transported from the boreholes, as well as the tunnel, to a central location for monitoring and collection, and then returned to the collection point. The gas will be transported through stainless steel tubing. In total, 28 stainless steel tubing runs accounted for all the sampling lines; 8 sample lines for boreholes, 8 sample return lines for boreholes, 3 tunnel environment sample lines, 3 tunnel environment sample return lines, and 6 tubes for the AWE sample system. These tubing runs will be attached to the rib as specified in the cable plan. The following field guide outlines the method used to install the tubing within the tunnel.

F.2 Tubing Installation Field Guide

1. Have 2 or more tubing spools moved into the .06 bypass drift, depending on room available.
    a. There is nominally 13,000 feet of tubing needed for the boreholes.
    b. The spools each contain 5000 feet of tubing; at least 3 spools will be needed just for the boreholes. Run these first.
    c. The TE/AWE locations require an additional 8000 feet of tubing. Short lengths of tubing left on spools used for boreholes can be used for these locations.
2. Spools should be unloaded and deployed at the 1190 drift and forklift alcove.



3. Remove one spool from pallet (see Spool Set-up guide)
4. Position spool such that another tubing spool is between the active spool and the direction the tubing will be pulled. Be sure that the spool is oriented such that the tubing is coming off the top of the spindle.
5. Lift the active spool up on the spool jacks (see Spool Set-up guide)
6. Un-spool 10-15 feet of tubing
7. Pass the tubing through the tube straightener and screw the tube straightener to the other spool. This will secure the straightener so that it does not move.



8. Using a tube bender, put a 90-degree bend at the end of the tube to provide a handle.
9. Adjust the tension on the tube straightener- manually pull some tubing through the straightener to check tension. Adjust as necessary.
10. Affix nametag to tube. Either pre-engraved brass tag or tape/magic marker.
    a. Tube should be identified with BH or TE # and sample (S) or return (R) designator.
11. Connect an electric drill to the tube straightener. Begin to deploy tubing.
    a. One person will walk the tubing down the tunnel. One person will operate the electric drill, driving the tubing through the tube straightener. One person will spin the spool on the jacks to keep the spool unwinding evenly.
    b. The electric drill may make tube deployment more difficult initially. It may be best to only pull manually until several hundred feet have been pulled off the spool.
12. Pull tube past desired end-point (650 facility). Pull and additional 30 feet past the tube bundle that goes under the invert; extra length is needed to go up-and-over alcoves and branch tunnels.
13. Cut tubing from spool. Affix temporary nametag to tube on spool end (tape/magic marker).
14. Lay tubing on invert near the rib.
15. Repeat steps 9 – 12 for all boreholes and TE locations.
    a. Each location has a sample and return line.
    b. There are 24 tubes run south of 1190.
16. Once tubing is pulled, it can be hung on the rib. This should be done in bundles of 4 or 8 tubes (2 or 4 pairs of sample/return lines).
    a. Zip ties may be used to hold bundles together if it makes the task easier.
    b. Use cable hangers to attach the tubes to the rib. If the cable hangers are not large enough for all 24 tubes, hang the TE tubes separately on the rib.

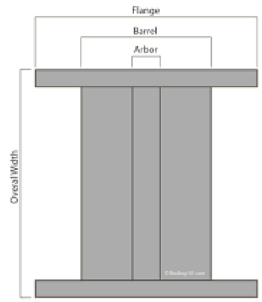
17. Measure and spool out 4 tube lengths of tubing 450 feet long (each). This is nominally the distance from the 1190 drift to the Mac cross-cut
18. Walk these tube bundles past 650 and attach to the rib (following TE3 data cable). Do not connect to anything yet.
19. Reposition the tubing spools to run tubing north (farther into the tunnel) from 1190.
20. Following steps 9-15, pull all tubing necessary for boreholes and TE locations north of the 1190 drift.
    a. Pull an additional 30 feet of tubing to allow excess for going up and over alcoves and branch drifts.

F.3 Data Cable Deployment Guide

1. Once the tubes have been installed, the data cables should be deployed
    a. Data cables are currently stored in the mechanics alcove
    b. Cables are not borehole specific
    c. Cables have a mil-spec connector on one end
2. Unspool ~30 feet of data cable with the connector on the free end
3. Use a fish tape to pull the connector through the conduct runs
    a. Pull the connector from the far rib over to the 650 alcove
    b. Leave slack to connect to the DAQ box on the gas sampler
4. Affix a pre-engraved brass tag to the cable near the connector.
5. Use a pipe (or rod) (or chunk of tubing) through the center of the spool to facilitate deployment
6. Run the cable down the shaft to the corresponding borehole, laying the cable on the invert near the rib, similar to the tubing.
7. DO NOT CUT THE CABLE. Leave spool on invert.
8. Affix another pre-engraved brass tag to the cable near the borehole.
9. Repeat for all borehole cables and 1 remaining TE cable.
    a. Note that the TE cable has sensors attached.
10. Hang all data cables on the rib using cable hangers.

F.4 Spool Set-Up Field Guide

1. Use 2 or 3 people to get the tubing spool off the pallet
    a. Use pry bars to scoot the spool part-way off the pallet.
    b. Lift and flip the spool so that it is standing on the flanges

2. Slide the spool rod through the arbor
3. Unfold jacks
    a. Remove front pin

4. Place a jack underneath each side of the spool rod
5. Open the roller cage
6. Lift each jack up so that the front rod is close to vertical

7. Lift the jack lever and ensure that roller assembly collapses on the side with the jack

8. Remove front support pin and lift roller assembly until rollers engage spool rod. Try to get the spool rod to the top of the arbor.
9. Replace front support pin
   a. May need to adjust the front support placement to get optimal height
10. Repeat for other side
11. Close roller cage assembly and latch with pin
12. Depress jack levers simultaneously to lift spool. This should only create a small amount of clearance from ground (less than 1”). If necessary, use shovels to create additional separation between flanges and ground.

Appendix G – Gas Cabinet Functionality Check

This checklist is used to verify operation of the gas cabinet. It verifies both operation and leaks by triggering actions and monitoring corresponding system response. For instance, the pumps are verified to be working by looking at the flow rate when they are turned on.

	BH1	BH 2	BH 3	BH 4	BH 5	BH 6	BH 7	BH 8	TE1	TE2	TE3
Small pumps turn on?											
Solenoid Valves Close?									NA	NA	NA
T/RH probes working?											
PTs working correctly?											
Flow peaks at >5 L/min											
If inlet valve closed, pressure drops?										Do manually	
If outlet capped, pressure increases?											
Snoop check at pump outlet											
Rotameter check of MFC											
Sample loop pressure decay rate*											
Decay rate acceptable											
Three Way valves work?			NA	NA	NA	NA	NA	NA	NA	NA	NA
TWVs oriented correctly?			NA	NA	NA	NA	NA	NA	NA	NA	NA

***Leak Check Procedure**

For checking gas cabinet and sample loop tubing within the 650 alcove

- Configure system so that pump is flowing air through sample loop.
- Close outlet solenoid valve and ball valve
- Allow system pressure (pressure at outlet of MFC) to increase to (nominally) 25 psi.
- Close inlet solenoid valve and ball valve
- Stop pump. Pressure should slowly equilibrate at all transducers
- Once system pressure has equalized, watch pressure for decay
- Record the pressure decay rate (psi/min) and the pressure at the time of measurement
- Determine if the pressure decay rate is acceptable. For reference, the system volume at 650 is approximately 7L, meaning that a pressure decay rate of 0.15 psia per minute is about 0.07 L/min, or less than 2% of the total flow.

Appendix H – Dual Packer Assessment

During grouting of the practice boreholes, a concern was raised about the potential for grouting to impact the connectivity of the sampling zone to the formation. Several mitigation ideas were considered. After discussions and review, installation of a second packer as part of the packer string was identified as the easiest solution to implement while still meeting confinement requirements.

H.1 Summary of Change

A second packer (identical to the primary packer) was installed 5 feet up-hole from the primary packer (Figure H1). The primary and secondary packers are connected by lengths of pipe, with stainless tubing connecting the pass-through and inflation ports of each packer. All other connections and hardware were as originally planned, just connected to the secondary packer rather than the primary. Grout was injected into the borehole as originally planned, but grout was held back by the secondary packer, creating a void space between the two packers.

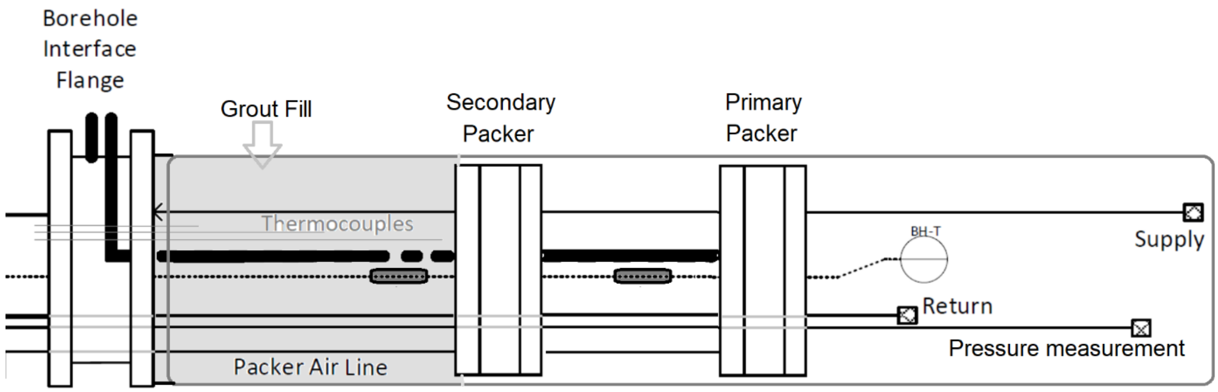


Figure H1. Diagram of proposed secondary packer approach

H.2 Modifications Required

This solution required very few modifications from the original plan. The secondary packers had to have a Swagelok adaptor added to the downhole side to accommodate extension of the inflation line from the secondary to the primary packer (Figure H2). In this configuration, both packers were inflated to the same pressure. The air inflation line connecting the two packers was poly tubing to provide flexibility in assembly. The sample, return and pressure measurement lines were extended between the primary and secondary packers using pre-cut lengths on tubing and Swagelok fittings. The center rod connecting the primary and secondary packers was ½” stainless steel pipe; a union was used to facilitate installation. The thermistor data cable was extended using two 20AWG wires, and spliced to the data cable extension with the gas block splice technique. The thermistor and the data cable extension also included a plug located between the two packers, facilitating faster installation. This dual packer package was tested in a horizontal practice borehole (PH-2) in April (2022).

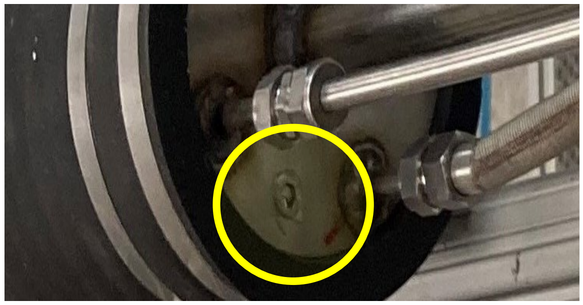


Figure H2. Packer air fill port on downhole side of packer (plugged).

H.3 Impacts

One impact of the dual packer approach is related to the packer inflation requirement. With the original single packer there were not expected to be any air gaps in the borehole, meaning that packer deflation would not have a significant impact on sample representativeness. However, with the dual packer solution, the effective sampling area could include the large air gap between the two packers if the packers are deflated.

Appendix I – Remote Permeability Test Description

Permeability tests can be conducted on the gas sampling boreholes remotely. This allows for an assessment of the in-situ permeability without requiring tunnel access of any plumbing changes. This approach employees a closed loop, but the water trap is used to provide air storage for the test (Figure I1). A brief description of the procedure and results is provided here. In general, the remote closed loop testing approach resulted in measured permeability similar to the permeabilities measured at the borehole collars.

Remote Permeability Testing Procedure

1. Set MFC flow rate to zero (yellow arrow)
2. Turn pump on (orange arrow). This stores pressurized air in the water trap between the MFC and the pump (blue arrow).
3. Allow pressure to build to approximately 40 psia
4. Stop Pump and close isolation valve (purple arrow)
5. Let interval recover (allow formation pressure to equalize to pressure before pumping began)
6. Set MFC flow rate (1 LPM is a good starting point)
7. Allow air flow to continue, and sample interval pressure to stabilize, until water trap is back to ambient pressure.
8. Use steady-state solution, or other analytical techniques, to determine formation permeability.

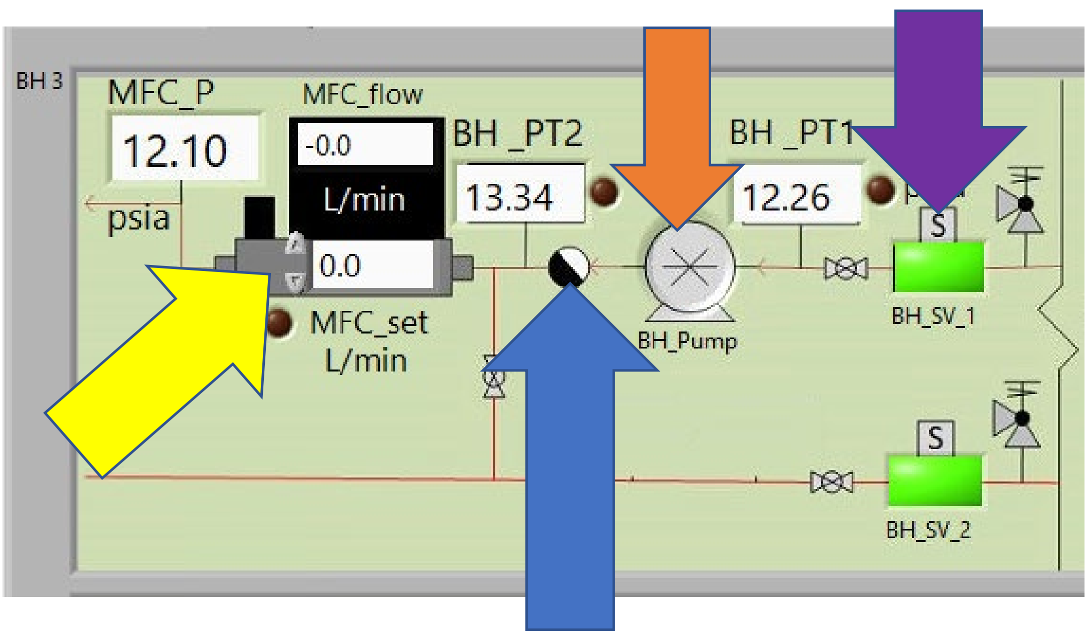


Figure I1. Gas cabinet GUI controls used to conduct remote permeability test

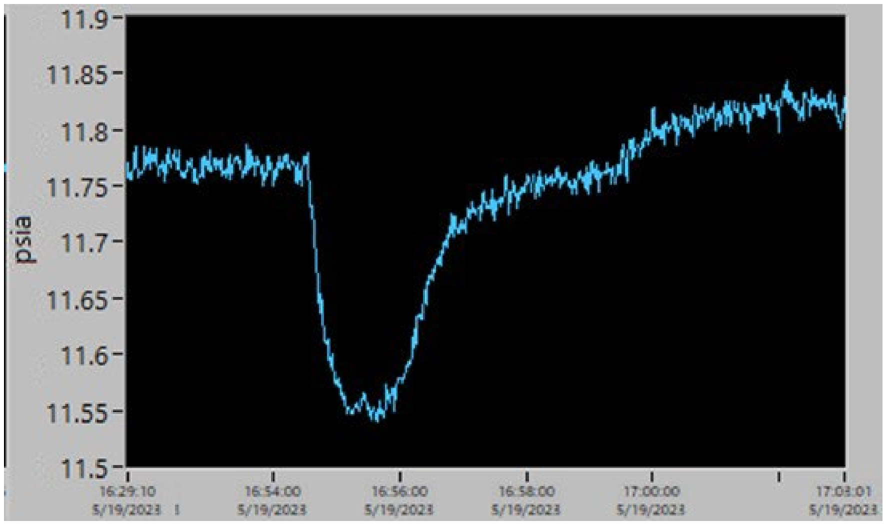


Figure I2. Example of borehole pressure response during permeability test.

Table I1. Results from remote closed loop permeability testing compared to previous permeability measurements

	Before Grouting		After Final Grout		Closed Loop Test	
Borehole	Date	Perm. (Darcy)	Date	Perm. (Darcy)	Date	Perm. (Darcy)
GS-1	8/24/2022	0.156	11/15/2022	0.146	6/13/2023	0.147
GS-2	8/24/2022	0.485	11/15/2022	0.145[a]	6/26/2023	0.189[a]
GS-3	8/24/2022	0.0373[b]	11/15/2022	0.0461	6/26/2023	0.049
GS-4	8/23/2022	0.364	11/15/2022	0.348	6/26/2023	0.384
GS-5	8/23/2022	0.0024[c]	11/15/2022	0.0006[d]	6/26/2023	0.018
GS-5	8/23/2022	0.0024[c]	11/15/2022	0.0189[e]	6/26/2023	0.018
GS-6	8/23/2022	0.688	11/15/2022	0.794	6/29/2023	0.798
GS-8	8/24/2022	1.55	11/15/2022	2.36	8/25/2023	1.64

[a] Packer deflated due to packer failure
[b] Average of 3 pre-grout measurements
[c] Result suspected to be biased high due to leak
[d] Gurgling noises observed. Bottom half of borehole assumed to be filled with water
[e] Test repeated with packer deflated

Chapter 2 – Gas Production Boreholes: *Installation and Completion Report*

1.0 Introduction

One objective of the PE-1 experiment is to measure gas transport in rock. To accomplish this, tracer gas will be introduced in the chambers, and gas sampling boreholes will be used to measure concentrations of gases within the formation. Instrumentation and grouting are a critical aspect of ensuring that the samples collected are representative of the larger formation gas composition. Sampling equipment was designed to allow sampling from a moderate sized interval with minimal perturbation of the formation. Grouting was done to provide confinement of the borehole, as well as to isolate the sampling interval. The intent of this report is to capture relevant details of the borehole grouting and demonstrate that the boreholes will provide scientifically meaningful gas samples for the experiment. More comprehensive borehole equipment information can be found in the final as-built documentation, while additional grouting details are captured in the final grout report.

2.0 Borehole Cleaning

Prior to installation, boreholes were thoroughly cleaned. A wire-bristle brush and a shop-vac with a long hose were the most useful cleaning tools. The brush and vacuum hose were attached to conveyance pipe to clean the entire length of the borehole. The level of cleanliness was evaluated and approved using a sewer camera before and after cleaning.

3.0 Equipment Design Overview

The hardware installed into gas sampling boreholes was designed to allow the interval between the rib and the sampling zone (at the end of the borehole) to be filled with grout. While the final as-built documentation captures all of the design details, an overview of the design is provided here.

3.1 Sample Zone Isolation

The sampling zone was isolated from the rest of the borehole with a packer or packers. Up going boreholes used a single packer while down going boreholes used a dual packer arrangement (Figure 19). All packers were Aardvark environmental packers (fixed mandrel) with a 24-inch inflation section. Each packer had 4 pass-through tubes which allowed air sample lines and a temperature probe to reach into the sampling interval. Each packer also had a pair of custom-built centralizers to minimize rubbing the packer on the bottom of the borehole during installation (Figure 20).

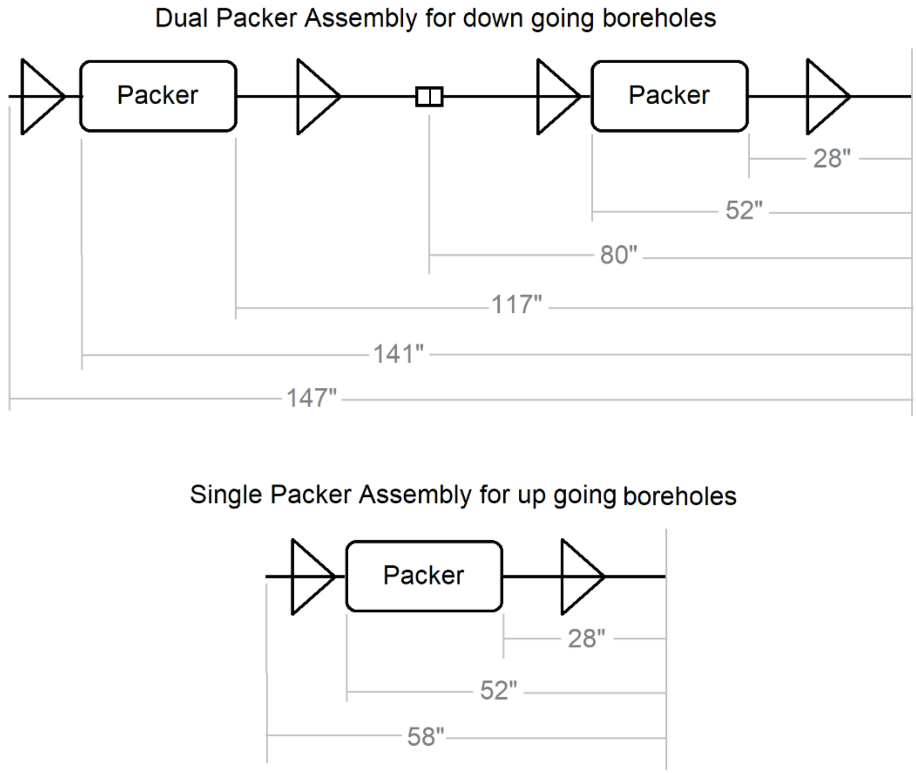


Figure 19. Diagram and dimensions for single and dual packer borehole assemblies (triangles represent the custom packer centralizers).

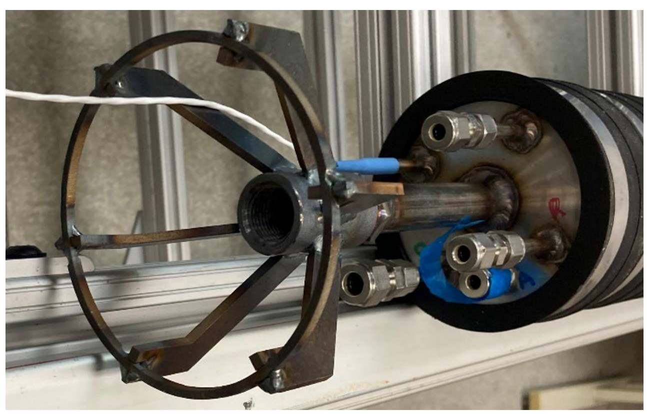


Figure 20. Custom packer centralizer attached to the back of a packer.

3.2 Gas block and tubing encasement

Several design elements were used to ensure that the grout adhered to the tubing and did not provide a fast path for gas transport through the grout plug. First, a gas block was built into the data cable near the packer. This gas block was put at a natural splice location, where the two-wire thermistor cable which passed through the packer was spliced to the Cat-5 cable used within the borehole. While the thermistor was swaged to the packer pass-through tube, preventing gas from migrating around the packer through the thermistor pass-through tube, it was necessary to add a gas block at the splice location to prevent high-pressure gas from the formation pushing through the grout (or fractures in the grout), and down the Cat-5 cable jacket. The gas-block was achieved by splicing the wires together using heat-shrink butt-splice connectors. A larger heat-shrink tube was then pulled over the entire splice and sealed against the Cat-5 cable. The majority of the heat-shrink tube was left open and was filled with a quick-set epoxy. Once the tube was mostly full, the top of the heat-shrink was closed, and the middle was shrunk until epoxy pushed out of the top. The result was some pressure was applied to the liquid epoxy, pushing it into the Cat-5 cable jacket, into the butt-splice connectors and into the thermistor wire jacket. This gas block design was tested and demonstrated to provide a gas tight seal.

In addition to the gas block, other measures were taken to prevent fast paths through the grout plug. Custom spacer rings were designed and cut from acrylic sheet (Figure 21). These spacer rings were put on the conveyance pipe every 5 feet. The tubing (both SS and the poly tremie pipe for upgoing holes) was generally secured to the conveyance pipe using electrical tape. At each spacer, the tubing was flared out and around the spacer, with tubes separated from each other by the notches in the spacer.

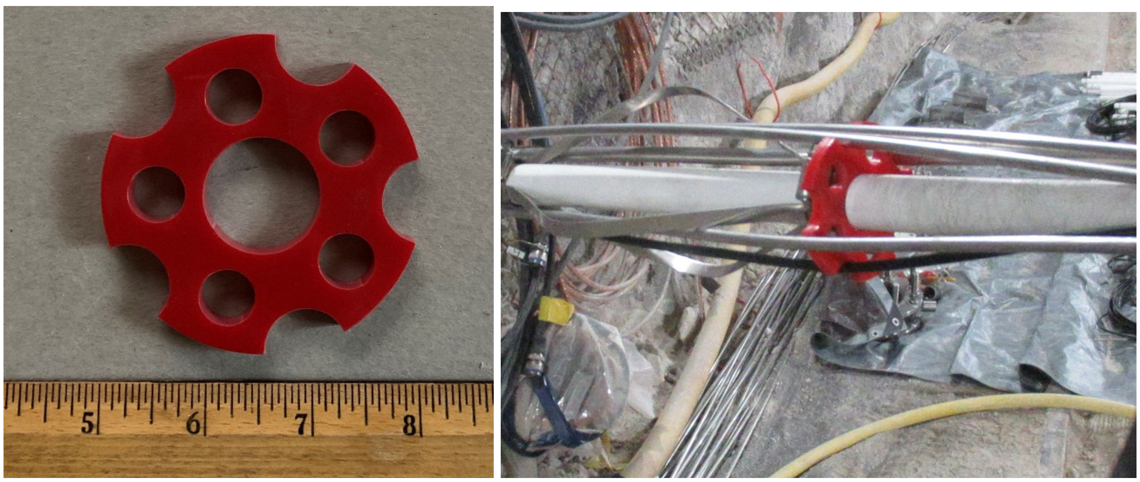


Figure 21. Custom spacer used to create separation between conveyance pipe and tubing.

In order to keep the conveyance pipe and tubing from laying on the bottom of the borehole, and creating a fast path, centralizers were used to keep the conveyance pipe elevated above the borehole (Figure 22). The centralizers were flared such that each of the three fins was touching the borehole. For down going holes the conveyance pipe was perforated (4 holes every 5 feet) to allow grout to fill the interior of the conveyance pipe. Finally, all tubing grouted in place in the borehole was roughed up to promote grout adhesion to the tubing wall. All tubing was sanded by hand with 80-grit sandpaper (Figure 23).

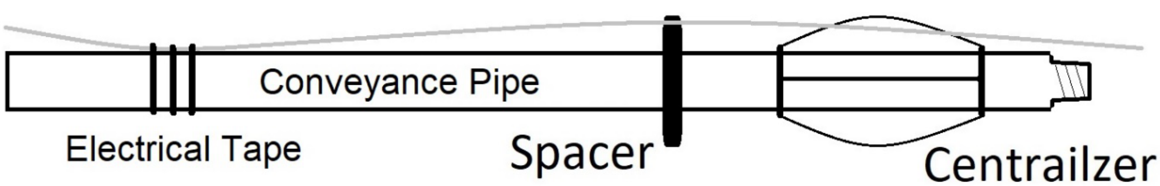


Figure 22. Conveyance pipe schematic showing spacer and centralizer.

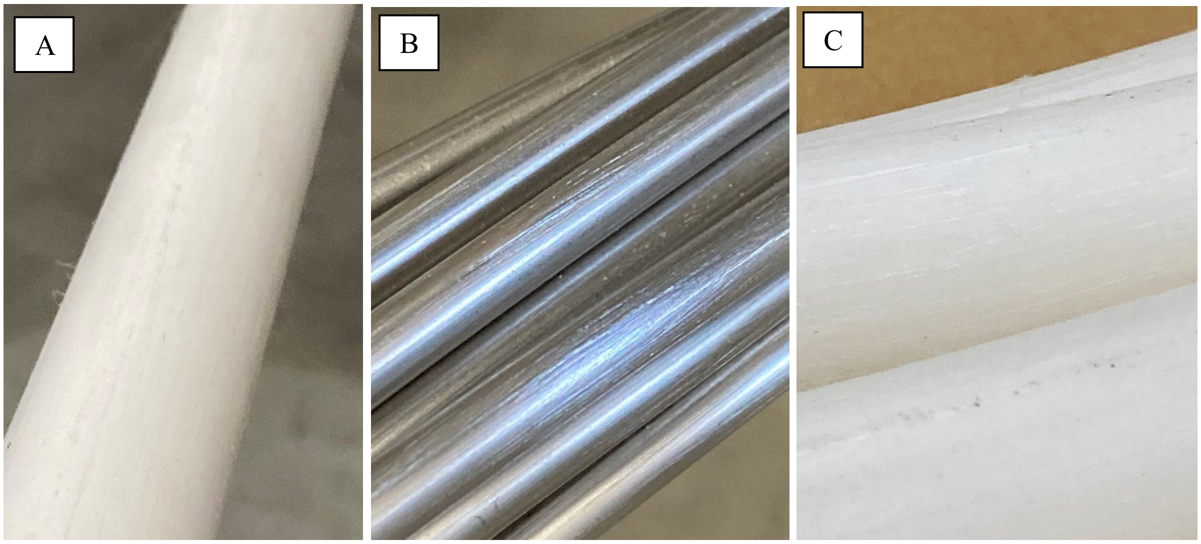


Figure 23. Surface roughness of tubing and pipe installed in gas sampling boreholes. A = conveyance pipe, B = stainless steel tubing, C = tremie pipe.

3.3 Grout Delivery

Detailed grouting procedures were developed and followed during gas borehole grouting activities. For both up and down going holes, grout was delivered through a tremie pipe from the collar toward the packer. Down going holes were instrumented with a removable tremie pipe, allowing the tremie pipe to be gradually removed during grout pumping. After emplacement of each grout lift, compressed air was used to clean the tremie pipe out. Up going holes on the other hand used a fixed tremie pipe and a sealed collar. In this configuration the grout was pumped to the top of the hole through the tremie pipe and allowed to run back down to the collar end. Additionally, up going holes used the conveyance pipe as a vent/return line. Perforations near the packer allowed displaced gas to vent out of the conveyance pipe and out through the collar assembly. Similarly, the vent line provided a return line for gout during grouting of the up going holes. Once grout return was observed, the grout was allowed to drain from the vent and tremie lines and compressed air was used to clear both lines. On the final grout lift of up going holes, both the vent and tremie line were filled with grout and shut in, eliminating any open conduits in the grout plug.

3.4 Collar

The borehole collars were completed differently for up going and down going boreholes. Down going boreholes could be grouted with no collar hardware in place or vent line. On the other hand, up going boreholes had to have a sealed collar for grouting to occur. In addition to the tremie pipe and vent line, 2 sampling tubes, a pressure monitoring tube, a packer inflation tube and a data cable had to pass through the collar and be liquid tight. The tubing and tremie pipe passed through the faceplate and were sealed using bore through compression fittings. The tubing fittings were reamed out an extra 1/64-in to make sliding the faceplate on easier. The data cable was sealed using a standard liquid tight cord grip. Because the tremie pipe delivery method was decided on after fabrication of the collar hardware, an unused threaded port on the faceplate was used to adapt the tremie pipe and pass through the collar assembly (Figure 24). The vent line (conveyance pipe) was connected to a flange adaptor as originally designed (Figure 25).

For the down going boreholes, once the final grout lift was done, the tremie pipe was removed and the collar faceplate slid over the sample tubes and data cable and secured to the flange with threaded rod (Figure 26). While the face plate was not necessarily required, it provides an added layer of confinement and protection for the tubing. For both up and down going boreholes, once the faceplates were secured a grounding cable was connected between the collar and the instrumentation ground. This was to prevent ground loops between instrumentation along the instrumentation tubing runs.

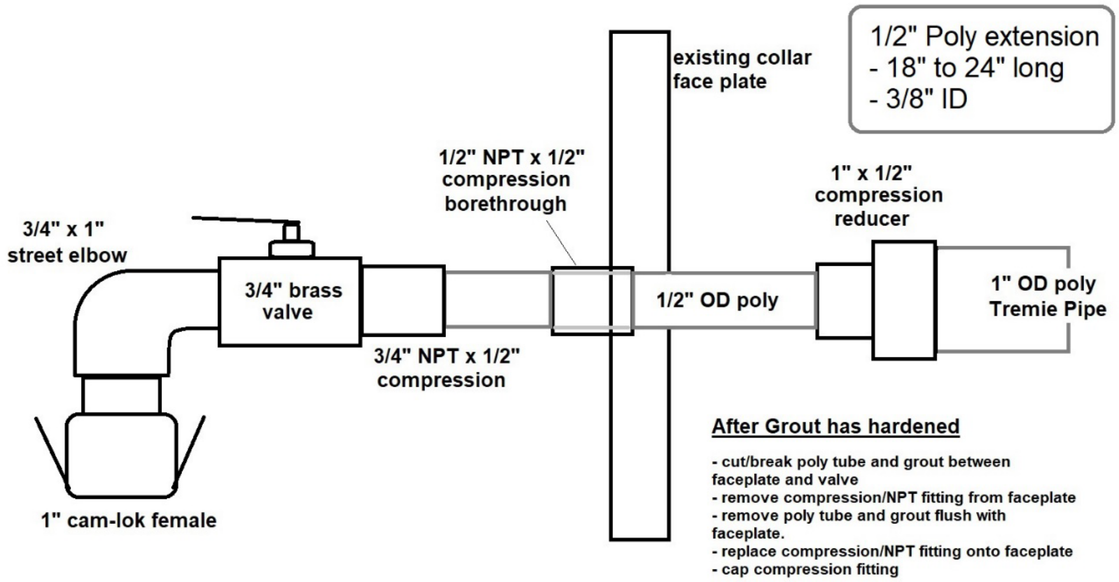


Figure 24. Collar faceplate modification to adapt tremie pipe grout delivery in up going holes.

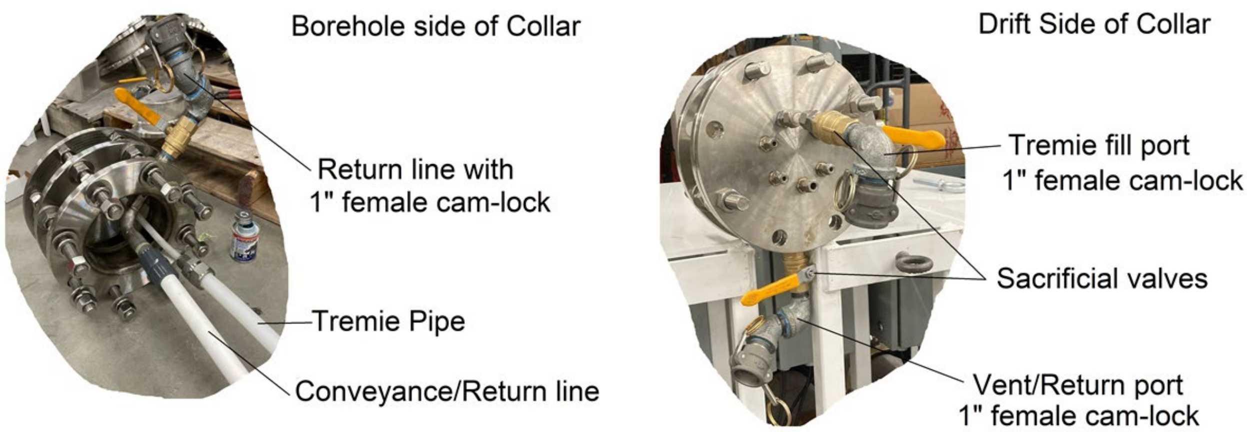


Figure 25. Front and back view of up going borehole collar assembly.

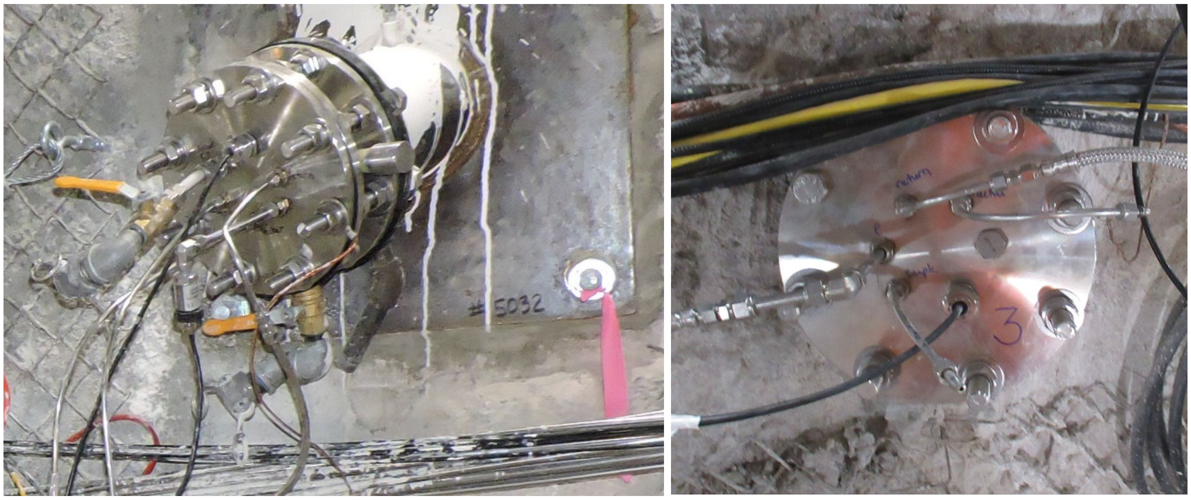


Figure 26. Pictures of final collar completion for GS-4 (up going) and GS-3 (down going).

4.0 Equipment Installation

The borehole equipment was fabricated in Richland, WA, and/or purchased and delivered to Richland, WA. To facilitate ease of installation inside the tunnel, as much preparation as possible was done prior to shipping equipment to the NNSS. This included pre-cutting tubing to length, sanding the tubing and pipe, attaching centralizers to the conveyance pipe, marking conveyance pipe for the appropriate centralizer spacing, threading nuts and washers onto the threaded rod, attaching all of the sampling zone hardware to the packer, splicing and gas-blocking the data cables, etc. (see Figure 27). The borehole equipment was shipped to NNSS in three shipping crates; one contained the 1” OD poly tube used for tremie pipe while the other two crates contained everything else. All parts were labeled and color coded as necessary to ensure that components were installed in the correct borehole.

Figure 27. Pre-assembled borehole components prior to packing for shipment.

5.0 Grouting Plan

In general, the plan for grouting was to install grout in multiple lifts. The down going boreholes (GS-1, GS-3, GS-5) were to receive 5 gallons of grout, followed by nominally 25 gallons of grout. Both of these first two lifts were planned to emplace the 0.5% plasticizer recipe. Following the initial two lifts in down going holes, a final lift of the 1% recipe would be emplaced up to the collar, and a final top-off would be added if necessary. The up going holes were only planned to receive the 1% plasticizer mix, in three stages. The first stage was targeted for 15 gallons, with the second stage going until grout came out of the return line. The final lift was then to fill the void between the packer and the return line.

6.0 Grout Emplacement

While the grouting plan was generally followed, there were some in-field changes to the grouting schedule and plan. These changes were made by the confinement scientist and the instrumentation team representative working together and resulted in a more efficient order of operations (Table 6). The NNSS grout team took and maintained official records on grout volumes, batch QA measurements, injection volumes and times, etc. Below is an unofficial compilation of grout volumes, mixes and nominal injection times, as recorded by the instrumentation team during grout emplacement. This information is intended to provide a general summary of the order of operations and performance, not a comprehensive description of the grout emplacement. Note that GS-7 was not grouted; due to the shallow depth of GS-7, the confinement team determined that grout was not necessary for GS-7.

Overall, the boreholes required more grout than the empty volume being grouted (Table 7). The amount of extra grout appeared to be a function of the permeability of the formation (Figure 28). The permeability is known to vary with depth, so the ratio of grout emplaced to the expected volume also varied as a function of the angle of the borehole (Figure 28). This would indicate that there were no major losses to fractures, or that losses to fractures were generally consistent between boreholes. It is also an indication that the grout properties were consistent between batches.

Table 6. Summary of the individual grout lifts emplaced in each borehole and the total volume emplaced.

Borehole	First Lift	Second Lift	Third Lift	Top-off	Total volume
GS-1	5 gal, 0.5%, Afternoon 9/20	31.4 gal, 0.5% Afternoon 9/21	19.1 gal, 1% Morning 9/26	NA	~55 gallons
GS-2	15 gal, 1% Morning 9/20	22.6 gal, 1% Morning 9/21	19.6 gal, 1% Morning 9/21	16.6 gal, 1% Morning 9/26	~74 gallons
GS-3	5 gal, 0.5%, Morning 9/19	25 gal, 0.5% Afternoon 9/20	21.4 gal, 1% Morning 9/21	8.8 gal, 1% Morning 9/21	~60 gallons
GS-4	15 gal, 1% Morning 9/19	35.4 gal, 1% Morning 9/20	22.5 gal, 1% Morning 9/20	10.8 gal, 1% Morning 9/21	~84 gallons
GS-5	5 gal, 0.5%, Morning 9/19	27.2 gal, 0.5% Afternoon 9/20	17 gal, 1% Morning 9/21	2 gal, 1% Morning 9/21	~51 gallons
GS-6	15 gal, 1% Morning 9/19	26.4 gal, 1% Morning 9/20	39 gal, 1% Afternoon 9/20	15.4 gal, 1% Morning 9/21	~96 gallons
GS-8	18 gal, 1% Morning 9/20	5 gal, 1% Afternoon 9/20	29.8 gal, 1% Morning 9/21	11.6 gal, 1% Morning 9/26	~64 gallons

NA- because GS-1 was grouted behind a sulfa-set dam rather than an open collar, a top-off was not necessary

Table 7. Comparison of the expected grout volume and the emplaced grout volume for gas sampling boreholes.

Borehole	Calculated Grout Volume (gallons)	Emplaced Grout Volume (gallons)	Ratio	Formation Permeability (Darcy)
GS-1	43	55	1.29	0.156
GS-2	51	74	1.45	0.485
GS-3	47	60	1.29	0.0373
GS-4	56	84	1.51	0.364
GS-5	46	51	1.12	0.0012
GS-6	57	96	1.69	0.688
GS-8	47	64	1.35	1.55

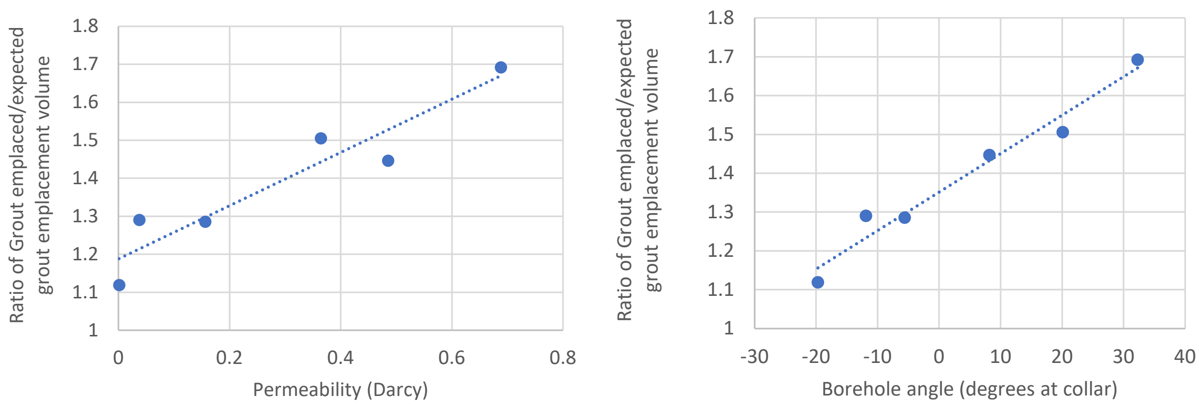


Figure 28. Comparison of the relative amount of extra grout needed for each borehole relative to the measured permeability and borehole angle for boreholes GS-1 through GS-6. GS-8 not included.

7.0 Borehole Collar Completion

Boreholes were completed with the custom flange faceplate. Up going boreholes were grouted with this plate in place. Down going holes (except GS-1 and GS-7) had the plate installed after grouting was complete. The faceplate provides a secondary confinement seal as the tubing and cables were all sealed with gas tight fittings (see Figure 26). One borehole, GS-1, was drilled at a shallow angle (5.6 degrees below horizontal). During grouting activities, the confinement and instrumentation representatives agreed that the shallow angle represented a risk if grouted according to the original plan as the grout would meet the top of the borehole too far into the formation and provide a potential gas pathway. In the field, it was decided to plug the opening of the borehole with a sulfa-set dam. The sample tubing, data cable and tremie pipe were routed out of the borehole through an opening at the top of the dam. This allowed the grout level to reach a greater height within the borehole and improve confinement. This also meant that no grout top-off was necessary, or possible, for GS-1.

8.0 Pneumatic isolation

During completion of the practice boreholes there were concerns about grout impacting the permeability or connectivity of the gas sampling zone with the formation. While the extent of this possible impact was never fully quantified, mitigation steps were put in place to ensure that the gas sampling zones were well connected to the formation and provided representative samples. There were more concerns about grout impacting the down going holes as gravity contributed to potential grout movement into or around the sampling zone. However, mitigation steps were put in place for the up going holes also.

These mitigation steps were applied in three primary mechanisms: modification of the packer design for down going holes, the use of a thicker and faster setting grout closest to the packer for down going holes, completing the boreholes in a series of grout lifts rather than a single lift and pneumatic isolation of the sampling zone during grout emplacement close to the borehole.

As described above, down going boreholes were instrumented with a dual packer assembly. This kept the first grout pour ten feet from the gas sampling zone and created a cavity between the packers where any grout bypassing the first packer would collect before reaching the sampling zone.

The grout emplacement sequence was planned to help mitigate impact to the sampling zone. The first grout lift in the down going holes was limited to 5 feet with the faster setting grout. This lowered the head pressure pushing grout into the formation and reduced the time available for the grout to move into or through the formation. The second lift of grout in down going holes was larger, but still the thicker 0.5 % recipe. For up going holes, the initial lift was limited to 15 feet while the second lift brought grout within 2 feet of the packer. This allowed the final grout lift, next to the packer, to be relatively small and controlled, reducing the chance of pushing grout past the packer and into the sampling zone.

The final measure put in place to help mitigate sample zone impact from grouting was pneumatic isolation of the sampling zone during grout lifts close to the packer. For down going holes, this meant that during the first two lifts, air was pumped into the sampling interval during grouting and for several hours after. Similarly, for up going holes, air was pumped into the sampling interval during emplacement of the final grout lift. For up going holes air flow was not necessarily maintained beyond the emplacement phase as there was no driving force to move grout towards the sampling zone once pumping was complete. There were some changes in pressure and flow observed during or shortly after grouting for a few of the boreholes (Figure 29), however, those were largely attributed to transient conditions rather than actual permeability changes.

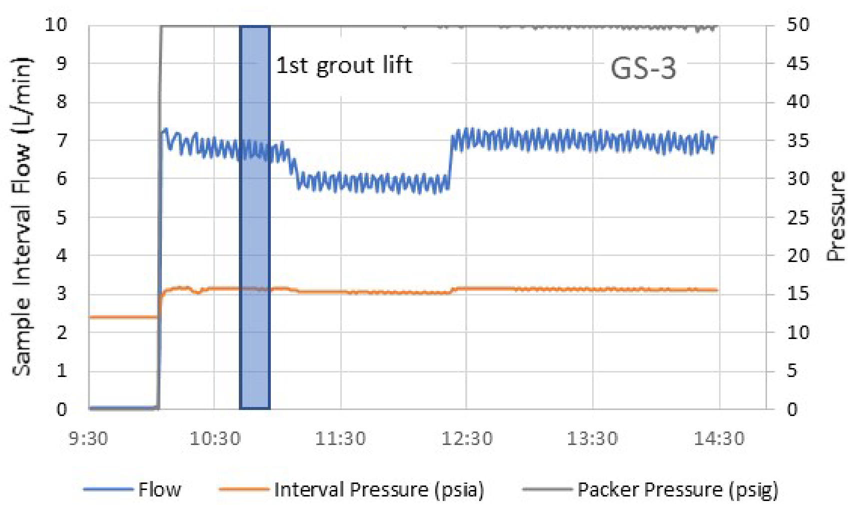


Figure 29. Sample interval flow and pressure and packer pressure measured before, during and after emplacement of the first lift of grout in GS-3.

9.0 Permeability Testing

Formation permeability was calculated as the change in pressure caused by gas flow into the sampling interval (Zeigler, 1976). Permeability was measured after instrumentation installation (before grouting), in-between some of the grout lifts, and immediately after the final grout lift for some boreholes (Table 8). A final series of permeability measurements were made several weeks after completion of grouting. For most of the boreholes there was less than a 25% difference between the maximum and minimum permeability measured before, during and immediately after grouting (Table 8). This level of variability can be attributed to measurement variability rather than actual changes in permeability. There appeared to be a large decrease in permeability in GS-5; however, the permeability measurements made prior to 9/20/22 were biased high due to equipment failure. On 9/20/22, a leak was identified on a cap covering a tube connected to the GS-5 sampling zone. The result of this is that some of the gas being pumped into the sampling zone was leaking out of the cap and not going into the formation, resulting in the calculated permeability being biased high.

Following grout emplacement, the grout was allowed to cure for 3 weeks before final permeability testing was completed. The results of the final permeability testing, when compared with the initial permeability results (Table 9) indicated that there was no significant impact to the borehole permeability as a result of grouting. Four of the boreholes had no significant difference in the permeability measured before and after grouting. One borehole showed an increase in permeability while the other two boreholes had other issues that made a valid comparison impossible. The packer in GS-2 failed after grouting, preventing a 1:1 comparison with pre-grout measurements. The borehole GS-5 appeared to have significant standing water in the borehole, as evidenced by gurgling noises coming from the sample lines during gas sample collection efforts. The relative saturation of the formation around the GS-5 sampling zone likely change significantly between the initial and final permeability measurements.

Table 8. Permeability measured in the gas sampling boreholes before, during, and immediately after grouting.

	Before Grouting		During Grouting			After Final Grout lift		
Borehole	Date	Perm. (Darcy)	Date	Stage	Perm. (Darcy)	Date	Perm. (Darcy)	% diff. (max-min)
GS-1	8/24/22	0.156	9/19/22	after 1st lift	0.14	9/26/22	0.14	14%
GS-2	8/24/22	0.485				9/26/22	0.37	26%
GS-3	8/24/22	0.0369	9/19/22	after 1st lift	0.039	9/21/22	0.041	15%
GS-3	8/24/22	0.0376	9/21/22	after 2nd lift	0.042			
GS-3	9/19/22	0.0373						
GS-4	8/23/22	0.364				9/21/22	0.33	11%
GS-5	8/23/22	0.0024*	9/19/22	after 1st lift	0.0025*	9/21/22	0.0012	73%
GS-6	8/23/22	0.688						
GS-8	8/24/22	1.55	9/21/22	after 2nd lift	1.43	9/26/22	1.86	26%

* Result biased high due to leak

Table 9. Borehole permeability measured before grouting and after grout cured for 3 weeks.

	Before Grouting		After Final Grout		
Borehole	Date	Permeability (Darcy)	Date	Permeability (Darcy)	Relative change in permeability pre to post grouting
GS-1	8/24/22	0.156	11/15/22	0.146	No change
GS-2	8/24/22	0.485	11/15/22	0.145[a]	Not a valid comparison
GS-3	8/24/22	0.0373[b]	11/15/22	0.0461	No change
GS-4	8/23/22	0.364	11/15/22	0.348	No change
GS-5	8/23/22	0.0024[c]	11/15/22	0.0006[d]	Not a valid comparison

Borehole	Before Grouting: Date	Before Grouting: Permeability (Darcy)	After Final Grout: Date	After Final Grout: Permeability (Darcy)	Relative change in permeability pre to post grouting
GS-6	8/23/22	0.688	11/15/22	0.794	No change
GS-8	8/24/22	1.55	11/15/22	2.36	Increase

a- Packer deflated due to packer failure
b- Average of 3 pre-grout measurements
c- Result suspected to be biased high due to leak
d- Gurgling noises observed. Bottom half of borehole assumed to be filled with water.

10.0 Impact of Packer Inflation

For some of the boreholes, post-grout permeability tests were conducted with the packer deflated. This provided data to evaluate how well the grout plug sealed the borehole; if the permeability measured with the packer deflated is larger than measured with the packer inflated (after accounting for the difference in geometry), it could be an indication that the grout plug did not seal well against the borehole wall. However, there are other possible explanations, such as an indication that the zone isolated by the packer contained a fracture or some other discontinuity. This is particularly problematic for the down-going holes where the exposed interval (with the packers deflated) is 11.75 feet long.

Based on the comparison of the permeability test results for packers inflated and deflated (Table 10), it appears that for the upgoing boreholes there isn't a significant difference between inflating and deflating the packers. For the two down going boreholes with viable tests conducted, there is a notable difference between the permeability measured with the packer inflated and the packer deflated. For GS-5, it is assumed that the higher measured permeability is associated with less saturated rock being exposed when the packers are deflated. Based on this assessment, a recommended packer inflation scheme would be to inflate the packers in boreholes GS-1, -3, -4, -6, -7, -8 while leaving the packers in GS-5 and GS-2 uninflated.

Table 10. Comparison of permeabilities measured in gas sampling boreholes with packers inflated and deflated.

Borehole	Packer Inflated	Packer Deflated	Difference
GS-1	0.146	no data	NA
GS-2	no data	0.145	NA
GS-3	0.0461	0.14	Different
GS-4	0.348	0.301	No difference
GS-5	0.0006	0.0189	Different
GS-6	0.794	0.893	No difference
GS-8	2.36	5.46	No difference

11.0 Conclusion

The borehole grouting effort was successful. All eight gas sampling boreholes should provide gas samples that are representative of the formation. Additionally, it appears that the gas sampling boreholes are isolated from the drift. While there were concerns about grout impacting the connectivity of down going boreholes, the before and after permeability testing indicated that there was not a significant impact from grouting.

12.0 References

Zeigler, T.W. 1976. DETERMINATION OF ROCK MASS PERMEABILITY

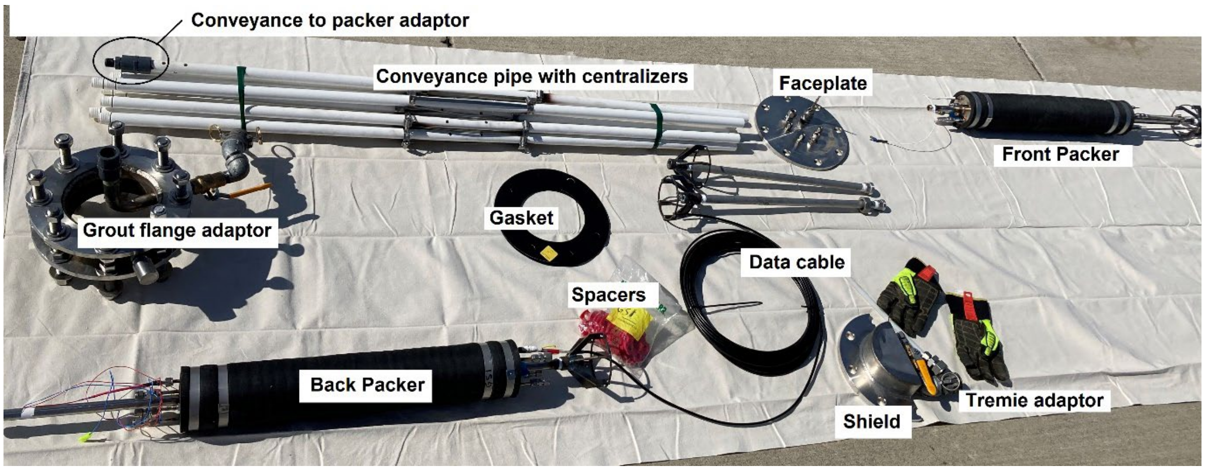
U.S. Army Corps of Engineers Technical Report S-76-2, U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

Appendix A – Borehole Installation Field Guides

These field guides were used to guide the field team on installation of gas sampling instrumentation into the boreholes and to ensure that no critical steps were missed.

A.1 Up-going Borehole: Installation Field Guide

Primary components used in Borehole Completion



A.1.1 Initial Preparation

1. Open shipping crate. Each crate contains all components for 4 boreholes, except 3/8" tubing. 3/8" tubing length needs to be cut from spools already onsite.
2. Lay out tarp/drop clothes to keep parts clean(ish).
3. Unpack components for current borehole (see packing/unpacking list)
4. Spread out centralizers on all conveyance pipes.
   a. Spacing between the clamps is pre-marked on the pipe; one clamp is already tightened.
   b. Slide second clamp down, flaring centralizer, until outside edge of clamp is even with the straight side of the mark.
   c. Secure clamp tightly with nut-driver. Double check tightness of both clamps.
   d. Check fit of one within borehole
5. Verify Borehole
   a. Double check borehole number/location.
   b. Identify TD of borehole from drilling records and borehole spec table.
   c. Tag end of borehole with PVC conveyance rod. Will need 1 or 2 extra sticks of conveyance pipe to reach.
      i. Measured borehole depth should match drilling log (±12"). This is from end of hole to the face of the flange on the collar.
6. Packer

a. Set packer aside. Review connections, ensure everything came pre-assembled correctly and are tight

Insert into borehole this direction

b. Slide packer into borehole to ensure that fit looks appropriate

c. Perform quality checks on packer and cables

i. Using resistance setting (Ω) of voltmeter, measure the resistance of the thermistor. Measure blue and blue/white wires of extension cable. Resistance should be between 11 and 15 kΩ. Record.

10K Thermistor Output Table

°F	°C	Ohms	°F	°C	Ohms
59	15.00	15714	69	20.56	12182
61	16.11	14925	71	21.67	11590
63	17.22	14180	73	22.78	11030
65	18.33	13478	75	23.89	10501
67	19.44	12814	77	25.00	10000

ii. Use scrap poly tubing and compressor to inflate packer to 40 psi. Turn off compressor, close valve and watch gage to confirm packer does not leak.

iii. Deflate packer.

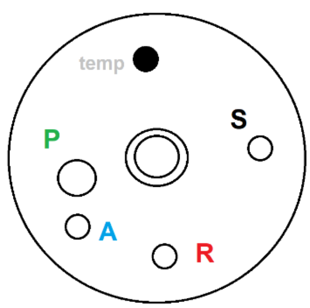
d. Verify which ports are the Sample, Return, Inflation (air) and Pressure ports.

i. Sample = Black

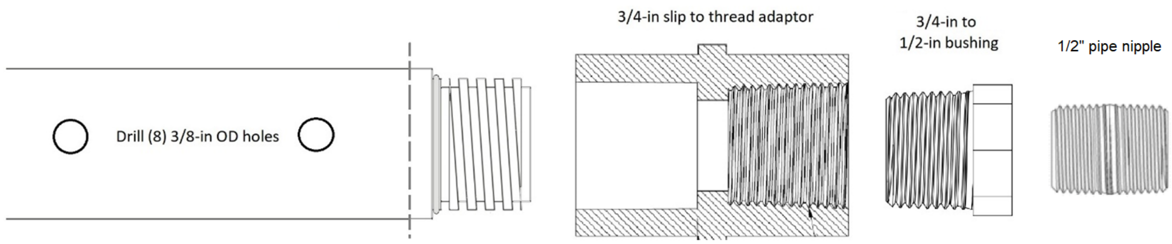
ii. Return = Red

iii. Air = Blue

iv. Pressure = Green



e. Connect first stick of conveyance pipe (perforated with reducer assembly attached) to packer. This adapts the internal flush thread pipe to the ½" MNPT center port on the packer.



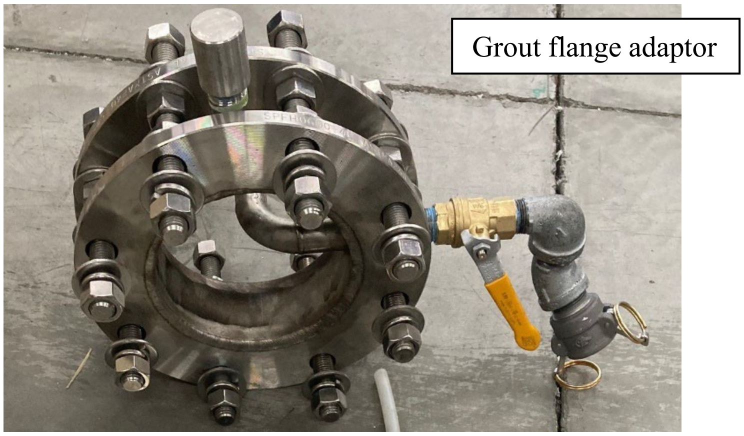
Conveyance to packer adaptor comes pre-assembled

   f. Unspool some of the data cable.
   g. Measure and record lengths of packer assembly.
      i. Tip to packer
      ii. Tip to back of packer
      iii. Tip to flush thread adaptor

7. Connect Tubing
   a. Unspool some of the bundle of ¼” tubing; nominally 15 feet. No tubing straightener required. Make every effort to keep tubing straight and unkinked near the ends to facilitate sliding through faceplate bore-through fittings.
   b. Unspool some of the bundle of 3/8” tubing; nominally 15 feet. Use of tubing straightener may be necessary. Determine in field.
   c. Place protective rubber caps over tube ends (collar side).
   d. Label tag end of tubing (collar side) with corresponding packer port (S, R, A, P)
   e. Arrange tubing in tunnel on tarp/drop cloth. The sequence will be to insert 5 feet of the package, unspool material for the next 5 feet, attach everything and then insert that 5-foot section.
   f. Attach all four tubes to back of packer. Mark both ends with color coded label according to color scheme above. Double check that the labels match on both ends.
8. Slide a spacer onto the back of the first stick of conveyance pipe.
9. Attach tremie pipe to conveyance pipe with electrical tape. It should be located 2 feet behind back of packer.
10. Arrange tubing, thermistor cable and tremie pipe around spacer. Use zip-ties or electrical tape in front and behind the spacer (~6”) to secure the tubes, cable, conveyance pipe and tremie pipe. The spacer should be firmly held in place by the tension of the tubes.
11. Push package into borehole until end of conveyance pipe is just outside of the collar. Be careful not to break the spacer on the collar during insertion.
12. Connect the next stick of conveyance pipe to the first stick.
13. Repeat steps 9-13.
14. Repeat this pattern until the packer tip bumps the bottom of the borehole. Confirm insertion depth is consistent with the reported and measured TD.
15. Do not attach any zip-ties within the last 4 to 6 feet of the borehole; this leaves flexibility in getting tubing and cables through the collar faceplate.

A.1.2 Grout Collar Adaptor connection

1. Retrieve the collar assembly; this includes the grout flange adaptor, 2 gaskets, the face plate, the tremie pass-through adaptor and the hood.



2. Remove the exterior nuts and washers from the flange adaptor. Leave the internal nuts so that threaded rod remains in place.
3. The conveyance pipe must be cut and glued to the slip-to-thread adaptor on the flange assembly; there are two ways to measure where the cut should occur. With either method, the vent port should be oriented down to allow grout to drain.
   a. Method A: Direct mark
      i. Slide a gasket around the tubing, cable, tremie and conveyance pipe. Place against the collar with holes aligned. A piece of tape can be used to hold it in place temporarily.
      ii. Thread the conveyance pipe, SS tubing and cables through the grout flange adaptor.
      iii. Hold the collar adaptor up to the collar flange, or use bolts to hold it in place.
      iv. Reach in and mark the conveyance pipe at the end of the slip-to-thread adaptor.
      v. Remove the grout adaptor and pull the conveyance pipe, tubing and entire packer assembly back just enough to allow work near the mark on the conveyance pipe.
      vi. From the mark on the conveyance pipe, measure back (away from the collar) 1.5”. Cut the pipe here using a PVC pipe cutter.
      vii. Apply PVC primer and glue to both the outside of the conveyance pipe and the inside of the adapter.
      viii. Slide the grout flange adaptor over the pipe and tubing and attach the slip-to-thread adaptor to the conveyance pipe.
      ix. Re-insert the package and collar adaptor; this should leave the tip of the packer assembly ½” short of the end of the borehole.
      x. Use 2 nuts to temporarily hold the adaptor in place.
   b. Method B: Measure and mark
      i. Using a straight-edge, measure the distance from the collar flange to the tip of the slip-to-thread adaptor.

ii. Similarly, using a straight-edge, mark the conveyance pipe at the point where at straight-edge laid across the collar flange intersects the conveyance pipe.

iii. Pull the conveyance pipe, tubing and entire packer assembly out of the hole ~6-12".

iv. From the mark on the conveyance pipe, measure forward (toward the collar) the distance measured in (i). Mark, then measure 1.5" back (away from the collar) and mark. Cut the pipe here using a PVC pipe cutter.

v. Slide a gasket around the tubing, cable, tremie and conveyance pipe. Place against the collar with holes aligned. A piece of tape can be used to hold it in place temporarily.

vi. Thread the conveyance pipe, SS tubing and cables through the center of the grout flange adaptor.

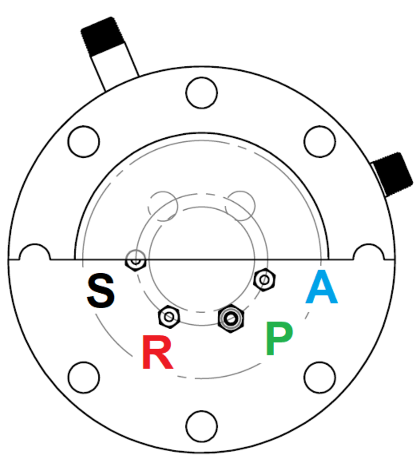
vii. Apply PVC primer and glue to both the outside of the conveyance pipe and the inside of the adapter and attach the slip-to-thread adaptor to the conveyance pipe.

viii. Re-insert the package and collar adaptor; this should leave the tip of the packer assembly ½" short of the end of the borehole.

ix. Use 2 nuts to temporarily hold the adaptor in place.

A.1.3 Face Plate Attachment

1. The tubing, tremie pipe and data cable should now protrude out of the grout collar adaptor several feet. Cut excess tubing back if necessary, leaving at least 24" beyond the collar. Do not trim data cable unless absolutely necessary.
2. Get the adaptor faceplate. Remove the nuts and ferrules from the Swagelok fittings.
3. Slide a gasket around the tubing, cable, tremie and conveyance pipe. Place against the grout adaptor flange with holes aligned. A piece of tape can be used to hold it in place temporarily.
4. Insert the tremie pass-though adaptor though the ½" Swagelok fitting.
5. Cut the Tremie pipe to allow connection of the ½" to 1" Swagelok pass-through adaptor. The 12" of ½" tubing allows for imprecise measurements of this cut- field fit as necessary.
6. Align all tubing with the pass-through holes on the faceplate. The tubing holes should be along the bottom with the cable holes on top. The sample and return lines should be to the left of the 3/8" tube, with the packer inflation line to the right of the 3/8" tube. This is preferred, but not required if tubing alignment makes this difficult.



7. Slide the faceplate on, passing tubes and data cable through the bore-through fittings (from the inside of the faceplate).
8. Continue to slide the faceplate on until it reaches the gasket and grout adaptor flange.
9. Attach nuts along the bottom half of the faceplate. The top half will need the hood attached later.
    a. Attach with a nut, lock washer and flat washer on the outer-most edges, and with nuts and flat washers on the face plate and borehole collar flange.
10. Using Teflon or nylon ferrules, slide nuts and ferrules onto tubing and secure to faceplate. Also slide cable glands and nuts onto data cable and thermocouple wire and tighten.

A.1.4 Quality Control Testing

1. Plug in and turn on pressure response testing kit. Two power outlets are needed.
2. Use a voltmeter to check voltage/resistance of the thermistor
    a. Using resistance setting (Ω) of voltmeter, measure the resistance of the thermistor. Resistance should be between 11 and 15 kΩ. Compare to value recorded at beginning of installation.

10K Thermistor Output Table

°F	°C	Ohms	°F	°C	Ohms
59	15.00	15714	69	20.56	12182
61	16.11	14925	71	21.67	11590
63	17.22	14180	73	22.78	11030
65	18.33	13478	75	23.89	10501
67	19.44	12814	77	25.00	10000

3. Using plastic ferrules, connect pressure response testing kit to borehole tubes
    a. Pump outlet connected to 'Sample' tube
    b. Pressure transducer connected to 3/8" line
    c. Air compressor to packer inflation line
4. Initiate air flow into sample zone. Ensure that 10 L/min of air can be pushed through the line. Turn flow off.
5. Cap return line (using plastic ferrules) and inflate packer to 60 psi. Turn off compressor, close valve on packer inflation assembly and watch gage to confirm packer does not leak.
6. Initiate flow test. Pressure response should be observable using the CR1000 keypad. However, viewing with CSI Loggernet software makes visualization easier.
7. Test should go at least 5 minutes, or until pressure and flow have stabilized. Test duration is a function of permeability. Once complete, turn off pump and watch pressure decay.
8. Once pressure has returned to the initial conditions, switch connections so that flow is into the return line and the sample line is capped.
9. Repeat flow test. Results should be nearly identical.
10. Disconnect packer inflation assembly; allow packer to deflate.
11. Repeat flow test. There should be no measurable pressure response.

A.1.5 Completion

1. Once the packer assembly has passed the quality control checks it is time to complete the borehole installation.
2. Using a tube bender, bend each tube such that the excess tube is vertical (pointed towards the invert) or slightly pointing towards the rib.
3. Remove any nuts on the top half of the faceplate.
4. Place protective hood over the top half of the faceplate.
5. Attach nuts and washers in same arrangement as before
6. Tighten all nuts on all 8 threaded rod (32 nuts). They should be as tight as possible using 12-inch wrenches.
7. Place rubber caps on ends of tubes to protect ends until connection to water trap and tunnel tube runs occurs.

A.1.6 Connection to Water Trap and Tunnel Tube Runs

1. Use 3/8" tubing to connect sample line to water trap inlet. This will be a field fit process as water trap locations are not specified yet. Use sections of flex lines to accommodate movement of components.
2. Connect tunnel tube runs to water trap outlet (sample line) and to borehole tubing (return line). This will be a field fit process as water trap locations are not specified yet. Use sections of flex lines to accommodate movement of components. This step will use adaptors to reduce from 3/8" (tunnel tubing runs) to ¼" (borehole and water trap).

A.2 Down-going Borehole: Installation Field Guide

A.2.1 Initial Preparation

1. Open shipping crate. Each crate contains all components for 4 boreholes, except 3/8" tubing. 3/8" tubing length needs to be cut from spools already onsite.
2. Lay out tarp/drop clothes to keep parts clean(ish).
3. Unpack components for current borehole (see packing/unpacking list)
4. Spread out centralizers on all conveyance pipes.
   a. Spacing between the clamps is pre-marked on the pipe (11-1/8"); one clamp is already tightened.
   b. Slide second clamp down, flaring centralizer, until outside edge of clamp is even with the straight side of the mark.
   c. Secure clamp tightly with nut-driver. Double check tightness of both clamps.
5. Verify Borehole
   a. Double check borehole number/location.
   b. Identify TD of borehole from drilling records and borehole spec table.
   c. Tag end of borehole with PVC conveyance rod.
      i. Measured borehole depth should match (±6"). This is from end of hole to the face of the flange on the collar.

6. Packer
   a. Set packers aside. Review connections, ensure everything on the front of the first packer came pre-assembled correctly and tight

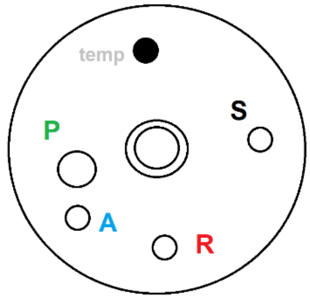
   b. Slide first packer into borehole to ensure that fit looks appropriate
   c. Connect stainless tube extensions to back of front packer. Tubes and fittings are color coded. Be sure to go through the fins of the centralizers
   d. Connect the second packer to the first packer
      i. Hold the second packer up outside the hole.
      ii. Align the stainless tubes so that they go through the fins of the centralizer and align with the matching color-coded port.
      iii. Slide stainless extension tubes into Swagelok fittings and align union connection in the middle
      iv. Tighten Swagelok fittings and central union,
      v. Connect the thermistor cable near the back of the first packer.
      vi. Secure thermistor cable connection securely with electrical tape
   e. Insert dual packer assembly into borehole, leaving back of second packer nominally even with the collar flange
   f. Perform quality checks on packer and cables
      i. Using resistance setting (Ω) of voltmeter, measure the resistance of the thermistor. Resistance should be between 11 and 15 kΩ. Record.

10K Thermistor Output Table

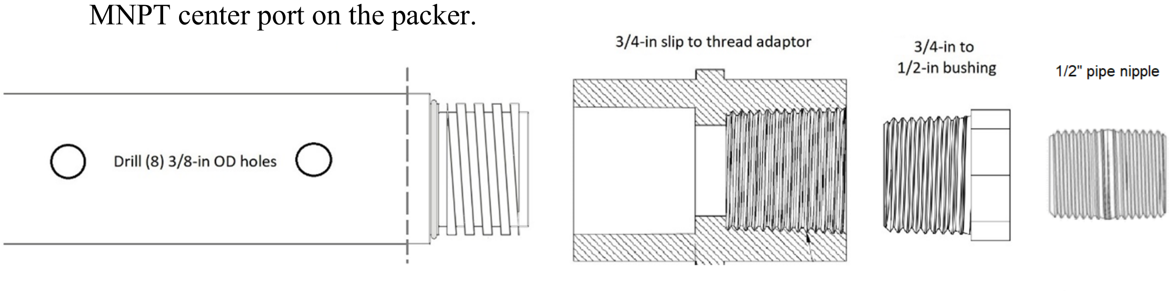
°F	°C	Ohms	°F	°C	Ohms
59	15.00	15714	69	20.56	12182
61	16.11	14925	71	21.67	11590
63	17.22	14180	73	22.78	11030
65	18.33	13478	75	23.89	10501
67	19.44	12814	77	25.00	10000

      ii. Use scrap poly tubing and compressor to inflate packers to 40 psi. Turn off compressor, close valve and watch gage to confirm packers do not leak.
      iii. Deflate packers.
   g. Verify which ports are the Sample, Return, Inflation (air) and Pressure ports.
      i. Sample- Black
      ii. Return- Red
      iii. Air- Blue

iv. Pressure- Green



h. Connect perforated PVC section to packer. This adapts the internal flush thread pipe to the ½" MNPT center port on the packer.



Conveyance to packer adaptor comes pre-assembled

i. Unspool some of the data cable.

j. Measure and record lengths of packer assembly.

   i. Tip to packer

   ii. Tip to back of packer

   iii. Tip to flush thread adaptor

7. Tubing

   a. Unspool some of the bundle of ¼" tubing; nominally 15 feet. No tubing straightener required. Make every effort to keep tubing straight and unkinked near the ends to facilitate sliding through faceplate bore-through fittings.

   b. Unspool some of the bundle of 3/8" tubing; nominally 15 feet. Use of tubing straightener may be necessary. Determine in field.

   c. Place protective rubber caps over tube ends (collar side).

   d. Arrange tubing in tunnel on tarp/drop cloth. The sequence will be to insert 5 feet of the package, unspool material for the next 5 feet, attach everything and then insert that 5-foot section.

   e. Attach all four tubes to back of packer. Mark both ends with color coded label according to color scheme above. Double check that the labels match on both ends.

8. Identify the first stick of conveyance pipe; it has the reducer assembly and perforations on one end of the pipe. Attach this stick to the packer.

9. Slide a spacer onto the back of the first stick of conveyance pipe.

10. Attach tremie pipe to conveyance pipe with a single wrap of electrical tape. It should be located 2 foot behind back of the second packer.
11. Arrange tubing, thermistor cable and tremie pipe around spacer. Use zip-ties or electrical tape in front and behind the spacer (~6") to secure the tubes and cable. DO NOT SECURE tremie pipe on down-going holes. The spacer should be firmly held in place by the tension of the tubes.
12. Push package into borehole until end of conveyance pipe is just outside of the collar. Be careful not to break the spacer on the collar during insertion.
13. Connect the next stick of conveyance pipe to the first stick.
14. Repeat steps 9-13.
15. Repeat this pattern until the packer tip bumps the bottom of the borehole. Confirm insertion depth is consistent with the reported and measured TD.
16. Do not attach any zip-ties within the last 4 to 6 feet of the borehole; this leave flexibility in getting tubing and cables through the collar cap.

A.2.2 Quality Control Testing

1. This testing will be completed before attaching the borehole faceplate, and before grouting. It will be repeated after grouting.
2. Plug in and turn on pressure response testing kit. Two power outlets are needed.
3. Use a voltmeter to check voltage/resistance of the thermistor
   a. Using resistance setting (Ω) of voltmeter, measure the resistance of the thermistor. Resistance should be between 11 and 15 kΩ. Compare to value recorded at beginning of installation.

10K Thermistor Output Table

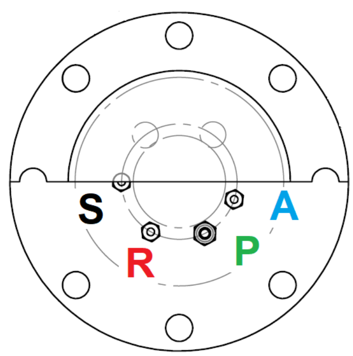
°F	°C	Ohms	°F	°C	Ohms
59	15.00	15714	69	20.56	12182
61	16.11	14925	71	21.67	11590
63	17.22	14180	73	22.78	11030
65	18.33	13478	75	23.89	10501
67	19.44	12814	77	25.00	10000

4. Using plastic ferrules, connect pressure response testing kit to borehole tubes
   a. Pump outlet connected to 'Sample' tube
   b. Pressure transducer connected to 3/8" line
   c. Air compressor to packer inflation line
5. Initiate air flow into sample zone. Ensure that 10 L/min of air can be pushed through the line. Turn flow off.
6. Cap return line (using plastic ferrules) and inflate packer to 60 psi. Turn off compressor, close valve on packer inflation assembly and watch gage to confirm packer does not leak.
7. Initiate flow test. Pressure response should be observable using the CR1000 keypad. However, viewing with CSI Loggernet software makes visualization easier.
8. Test should go at least 5 minutes, or until pressure and flow have stabilized. Test duration is a function of permeability. Once complete, turn off pump and watch pressure decay.
9. Once pressure has returned to the initial conditions, switch connections so that flow is into the return line and the sample line is capped.

10. Repeat flow test. Results should be nearly identical.
11. Disconnect packer inflation assembly; allow packer to deflate.
12. Repeat flow test. There should be little to no pressure response.

A.2.3 Face Plate Attachment

1. For down-going holes there is no grout adaptor. Grouting will be done with the tremie pipe. The face plate will be attached after grouting is complete.
2. The tubing, data cable, and conveyance pipe should now protrude out of the borehole collar adaptor several feet. Cut excess tubing back to 24" if necessary. Do not trim data cable unless absolutely necessary. Cut the conveyance pipe as close to the cured grout as possible.
3. Get the adaptor faceplate. Remove the nuts and ferrules from the Swagelok fittings and remove the glands from the cable cord grips.
4. Slide a gasket around the tubing, cable and conveyance pipe. Place against the grout adaptor flange with holes aligned. A piece of tape can be used to hold it in place temporarily.
5. Align the tubing with the pass-though holes on the faceplate. The tubing holes should be along the bottom with the cable holes on top. The sample and return lines should be to the left of the 3/8" tube, with the packer inflation line to the right of the 3/8" tube. This is preferred, but not required if tubing alignment makes this difficult.



6. Slide the faceplate on, passing tubes through the bore-through fittings (from the inside of the faceplate).
7. Before sliding the faceplate all the way on, remove the nuts from the threaded rod holding the grout adaptor in place. Be careful that the completion string does not shift out of the hole when the nuts are removed.
8. Continue to slide the faceplate on until it reaches the gasket and collar flange.
9. Attach several of the threaded rod assemblies along the bottom half of the faceplate. The top half will need the hood attached later.
   a. Attach with nuts, lock washers and flat washers.
10. Using Teflon or nylon ferrules, slide Swagelok nuts and ferrules onto tubing and secure to faceplate. Also slide cable glands and nuts onto data cable and tighten.

A.2.4 Completion

1. After grouting, repeat the quality control checks. Once the packer assembly has passed the quality control checks it is time to complete the borehole installation.

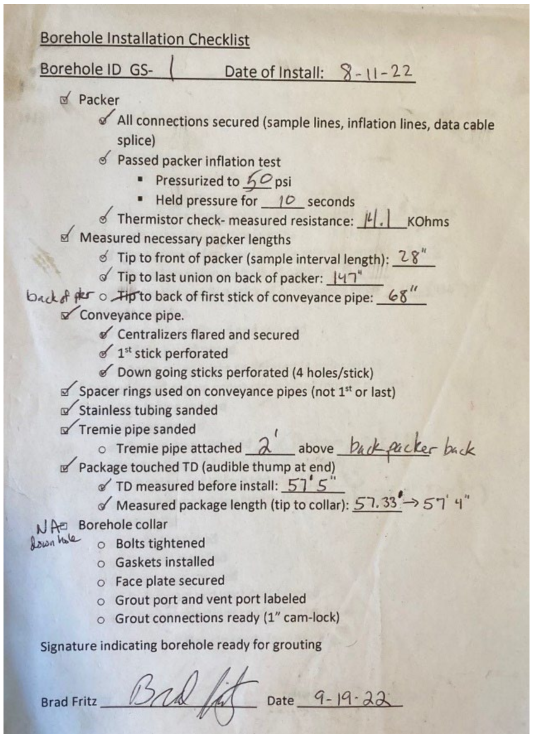
2. Using a tube bender, bend each tube such that the excess tube is vertical (pointe down) or slightly pointing towards the rib.
3. Remove any nuts on the top half of the faceplate.
4. Place protective hood over the top half of the faceplate.
5. Insert threaded rod, nuts and washers in same arrangement as before
6. Tighten all nuts on all 8 threaded rod (16 nuts). They should be as tight as possible using 12-inch wrenches.
7. Place rubber caps on ends of tubes to protect ends until connection to water trap and tunnel tube runs occurs.

A.2.5 Connection to Water Trap and Tunnel Tube Runs

1. Use 3/8” tubing to connect sample line to water trap inlet. This will be a field fit process as water trap locations are not specified yet.
2. Connect tunnel tube runs to water trap outlet (sample line) and to borehole tubing (return line). This will be a field fit process as water trap locations are not specified yet. This step will use adaptors to reduce from 3/8” (tunnel tubing runs) to ¼” (borehole and water trap).

Appendix B – Borehole Installation Checklists

These checklists were developed by the project and used in the field to document and verify that the equipment was installed correctly, that the equipment passed all QA checks and to document the as-installed lengths of equipment.



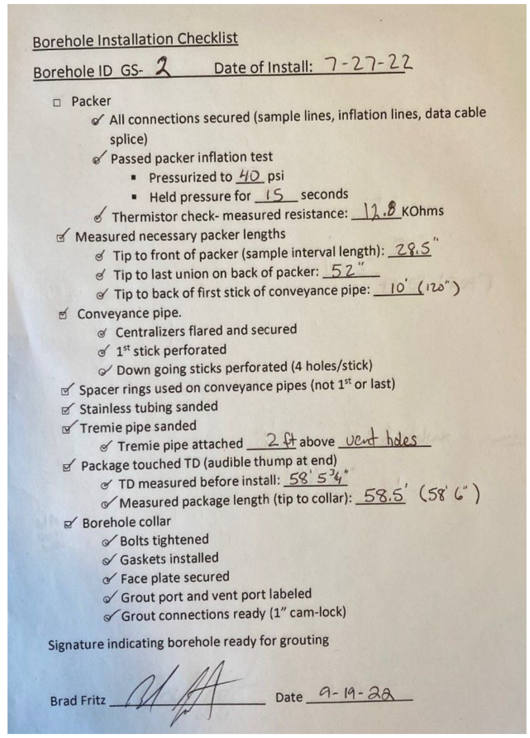
Borehole Installation Checklist

Borehole ID GS- 1 Date of Install: 8-11-22

- ☑ Packer
  - ✓ All connections secured (sample lines, inflation lines, data cable splice)
  - ✓ Passed packer inflation test
    - Pressurized to 50 psi
    - Held pressure for 10 seconds
  - ✓ Thermistor check- measured resistance: 11.1 KOhms
- ☑ Measured necessary packer lengths
  - ✓ Tip to front of packer (sample interval length): 28"
  - ✓ Tip to last union on back of packer: 147"
  - back of pkr ~~Tip~~ to back of first stick of conveyance pipe: 68"
- ☑ Conveyance pipe.
  - ✓ Centralizers flared and secured
  - ✓ 1st stick perforated
  - ✓ Down going sticks perforated (4 holes/stick)
- ☑ Spacer rings used on conveyance pipes (not 1st or last)
- ☑ Stainless tubing sanded
- ☑ Tremie pipe sanded
  - Tremie pipe attached 2' above back packer back
- ☑ Package touched TD (audible thump at end)
  - ✓ TD measured before install: 57' 5"
  - ✓ Measured package length (tip to collar): 57.33' → 57' 4"
- NA down hole ☐ Borehole collar
  - Bolts tightened
  - Gaskets installed
  - Face plate secured
  - Grout port and vent port labeled
  - Grout connections ready (1" cam-lock)

Signature indicating borehole ready for grouting

Brad Fritz [signature] Date 9-19-22



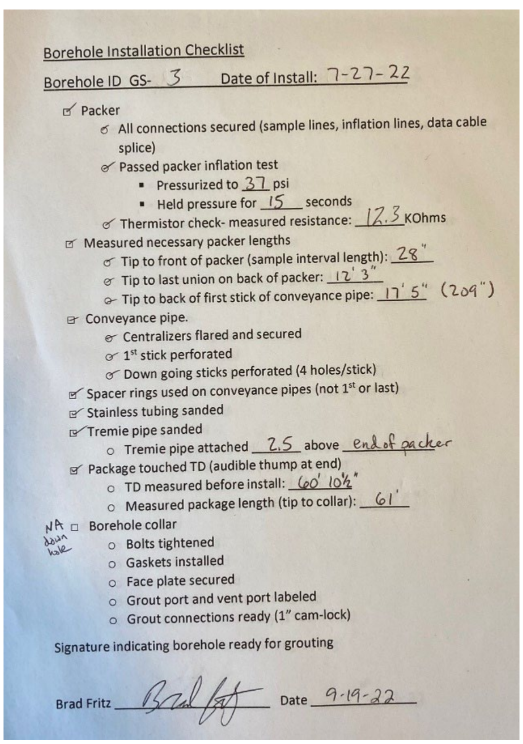
Borehole Installation Checklist

Borehole ID GS- 2 Date of Install: 7-27-22

- ☐ Packer
  - ✓ All connections secured (sample lines, inflation lines, data cable splice)
  - ✓ Passed packer inflation test
    - Pressurized to 40 psi
    - Held pressure for 15 seconds
  - ✓ Thermistor check- measured resistance: 12.8 KOhms
- ☑ Measured necessary packer lengths
  - ✓ Tip to front of packer (sample interval length): 28.5"
  - ✓ Tip to last union on back of packer: 52"
  - ✓ Tip to back of first stick of conveyance pipe: 10' (120")
- ☑ Conveyance pipe.
  - ✓ Centralizers flared and secured
  - ✓ 1st stick perforated
  - ✓ Down going sticks perforated (4 holes/stick)
- ☑ Spacer rings used on conveyance pipes (not 1st or last)
- ☑ Stainless tubing sanded
- ☑ Tremie pipe sanded
  - ✓ Tremie pipe attached 2 ft above vent holes
- ☑ Package touched TD (audible thump at end)
  - ✓ TD measured before install: 58' 5¾"
  - ✓ Measured package length (tip to collar): 58.5' (58' 6")
- ☑ Borehole collar
  - ✓ Bolts tightened
  - ✓ Gaskets installed
  - ✓ Face plate secured
  - ✓ Grout port and vent port labeled
  - ✓ Grout connections ready (1" cam-lock)

Signature indicating borehole ready for grouting

Brad Fritz [signature] Date 9-19-22



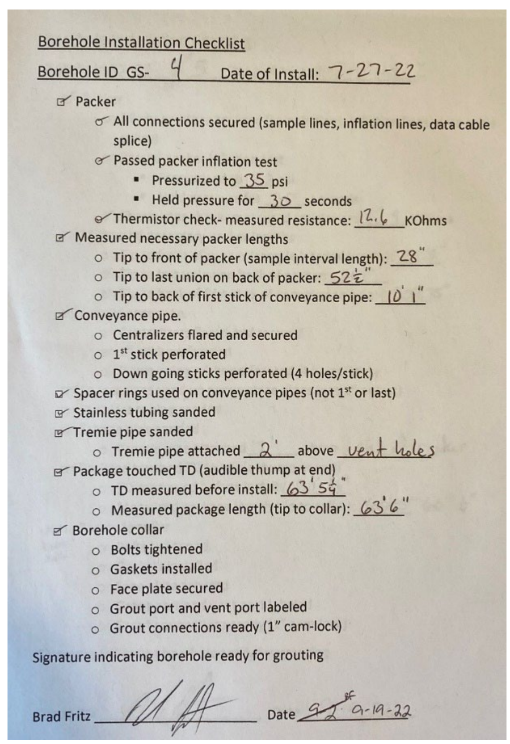
Borehole Installation Checklist

Borehole ID GS- 3 Date of Install: 7-27-22

- ☑ Packer
  - ✓ All connections secured (sample lines, inflation lines, data cable splice)
  - ✓ Passed packer inflation test
    - Pressurized to 37 psi
    - Held pressure for 15 seconds
  - ✓ Thermistor check- measured resistance: 12.3 KOhms
- ☑ Measured necessary packer lengths
  - ✓ Tip to front of packer (sample interval length): 28"
  - ✓ Tip to last union on back of packer: 12' 3"
  - ✓ Tip to back of first stick of conveyance pipe: 17' 5" (209")
- ☑ Conveyance pipe.
  - ✓ Centralizers flared and secured
  - ✓ 1st stick perforated
  - ✓ Down going sticks perforated (4 holes/stick)
- ☑ Spacer rings used on conveyance pipes (not 1st or last)
- ☑ Stainless tubing sanded
- ☑ Tremie pipe sanded
  - Tremie pipe attached 2.5 above end of packer
- ☑ Package touched TD (audible thump at end)
  - TD measured before install: 60' 10½"
  - Measured package length (tip to collar): 61'
- NA down hole ☐ Borehole collar
  - Bolts tightened
  - Gaskets installed
  - Face plate secured
  - Grout port and vent port labeled
  - Grout connections ready (1" cam-lock)

Signature indicating borehole ready for grouting

Brad Fritz [signature] Date 9-19-22



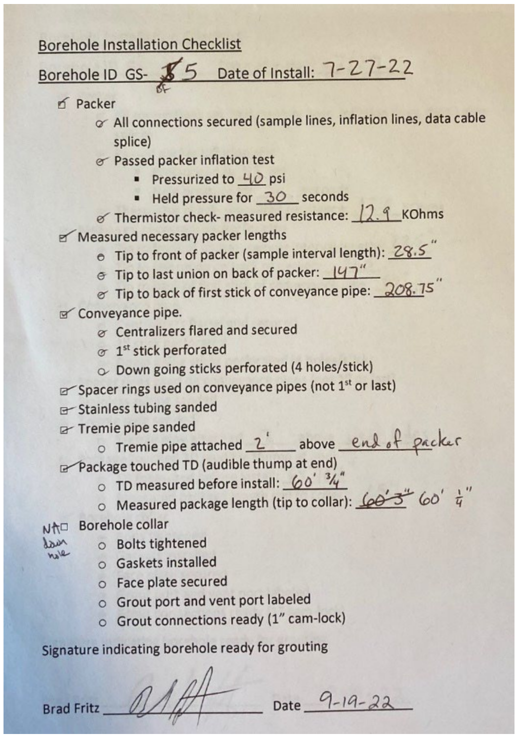
Borehole Installation Checklist

Borehole ID GS- 4 Date of Install: 7-27-22

- ☑ Packer
  - ✓ All connections secured (sample lines, inflation lines, data cable splice)
  - ✓ Passed packer inflation test
    - Pressurized to 35 psi
    - Held pressure for 30 seconds
  - ✓ Thermistor check- measured resistance: 12.6 KOhms
- ☑ Measured necessary packer lengths
  - Tip to front of packer (sample interval length): 28"
  - Tip to last union on back of packer: 52½"
  - Tip to back of first stick of conveyance pipe: 10' 1"
- ☑ Conveyance pipe.
  - Centralizers flared and secured
  - 1st stick perforated
  - Down going sticks perforated (4 holes/stick)
- ☑ Spacer rings used on conveyance pipes (not 1st or last)
- ☑ Stainless tubing sanded
- ☑ Tremie pipe sanded
  - Tremie pipe attached 2' above vent holes
- ☑ Package touched TD (audible thump at end)
  - TD measured before install: 63' 5¼"
  - Measured package length (tip to collar): 63' 6"
- ☑ Borehole collar
  - Bolts tightened
  - Gaskets installed
  - Face plate secured
  - Grout port and vent port labeled
  - Grout connections ready (1" cam-lock)

Signature indicating borehole ready for grouting

Brad Fritz [signature] Date ~~9-2~~ 9-19-22



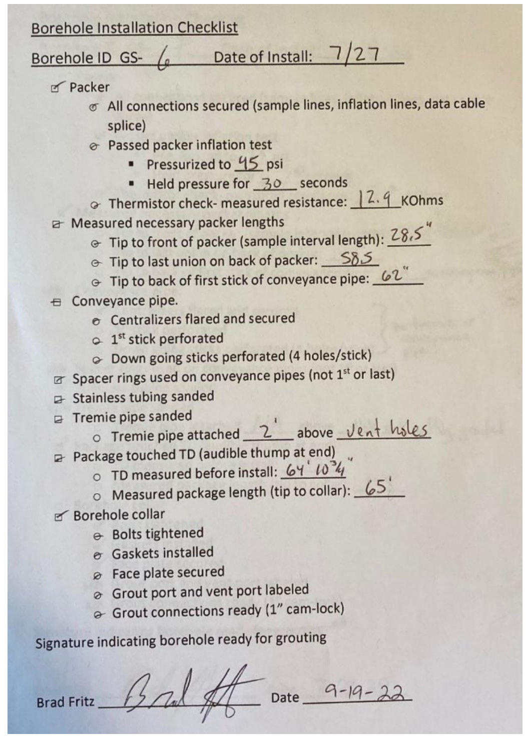
Borehole Installation Checklist

Borehole ID GS- ~~8~~ 5 Date of Install: 7-27-22

- ☑ Packer
  - ☑ All connections secured (sample lines, inflation lines, data cable splice)
  - ☑ Passed packer inflation test
    - Pressurized to 40 psi
    - Held pressure for 30 seconds
  - ☑ Thermistor check- measured resistance: 12.9 KOhms
- ☑ Measured necessary packer lengths
  - ☑ Tip to front of packer (sample interval length): 28.5"
  - ☑ Tip to last union on back of packer: 147"
  - ☑ Tip to back of first stick of conveyance pipe: 208.75"
- ☑ Conveyance pipe.
  - ☑ Centralizers flared and secured
  - ☑ 1st stick perforated
  - ☑ Down going sticks perforated (4 holes/stick)
- ☑ Spacer rings used on conveyance pipes (not 1st or last)
- ☑ Stainless tubing sanded
- ☑ Tremie pipe sanded
  - Tremie pipe attached 2' above end of packer
- ☑ Package touched TD (audible thump at end)
  - TD measured before install: 60' 3/4"
  - Measured package length (tip to collar): ~~60' 3"~~ 60' 1/4"
- NA ☐ Borehole collar (down hole)
  - Bolts tightened
  - Gaskets installed
  - Face plate secured
  - Grout port and vent port labeled
  - Grout connections ready (1" cam-lock)

Signature indicating borehole ready for grouting

Brad Fritz [signature] Date 9-19-22



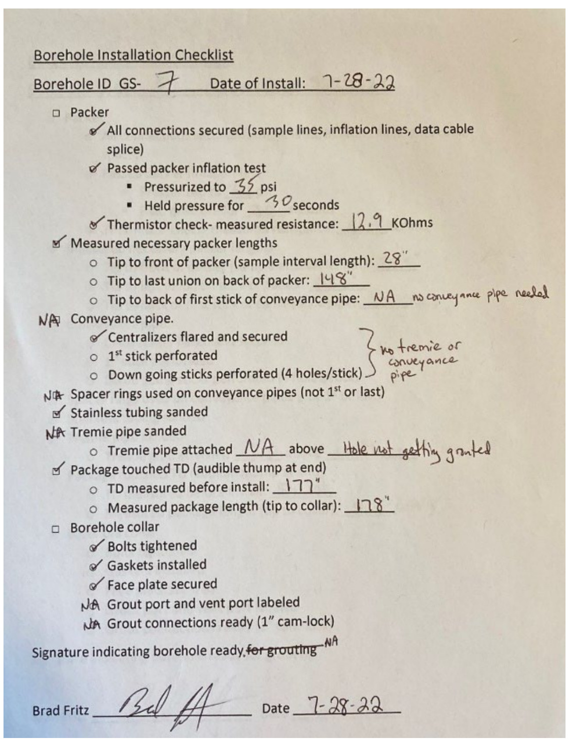
Borehole Installation Checklist

Borehole ID GS- 6 Date of Install: 7/27

- ☑ Packer
  - ☑ All connections secured (sample lines, inflation lines, data cable splice)
  - ☑ Passed packer inflation test
    - Pressurized to 45 psi
    - Held pressure for 30 seconds
  - ☑ Thermistor check- measured resistance: 12.4 KOhms
- ☑ Measured necessary packer lengths
  - ☑ Tip to front of packer (sample interval length): 28.5"
  - ☑ Tip to last union on back of packer: 58.5
  - ☑ Tip to back of first stick of conveyance pipe: 62"
- ☑ Conveyance pipe.
  - ☑ Centralizers flared and secured
  - ☑ 1st stick perforated
  - ☑ Down going sticks perforated (4 holes/stick)
- ☑ Spacer rings used on conveyance pipes (not 1st or last)
- ☑ Stainless tubing sanded
- ☑ Tremie pipe sanded
  - Tremie pipe attached 2' above vent holes
- ☑ Package touched TD (audible thump at end)
  - TD measured before install: 64' 10 3/4"
  - Measured package length (tip to collar): 65'
- ☑ Borehole collar
  - ☑ Bolts tightened
  - ☑ Gaskets installed
  - ☑ Face plate secured
  - ☑ Grout port and vent port labeled
  - ☑ Grout connections ready (1" cam-lock)

Signature indicating borehole ready for grouting

Brad Fritz [signature] Date 9-19-22



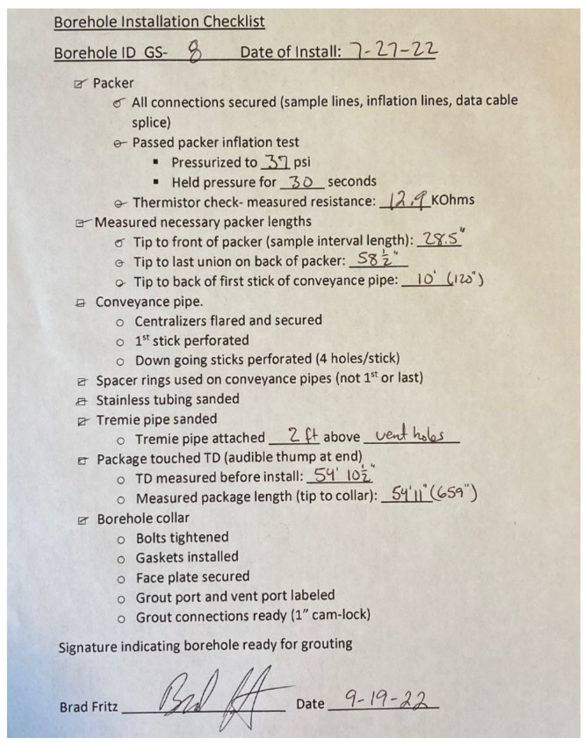
Borehole Installation Checklist

Borehole ID GS- 7 Date of Install: 7-28-22

- ☐ Packer
  - ☑ All connections secured (sample lines, inflation lines, data cable splice)
  - ☑ Passed packer inflation test
    - Pressurized to 35 psi
    - Held pressure for 30 seconds
  - ☑ Thermistor check- measured resistance: 12.9 KOhms
- ☑ Measured necessary packer lengths
  - Tip to front of packer (sample interval length): 28"
  - Tip to last union on back of packer: 148"
  - Tip to back of first stick of conveyance pipe: NA no conveyance pipe needed
- NA Conveyance pipe.
  - ☑ Centralizers flared and secured
  - 1st stick perforated
  - Down going sticks perforated (4 holes/stick) } no tremie or conveyance pipe
- NA Spacer rings used on conveyance pipes (not 1st or last)
- ☑ Stainless tubing sanded
- NA Tremie pipe sanded
  - Tremie pipe attached NA above Hole not getting grouted
- ☑ Package touched TD (audible thump at end)
  - TD measured before install: 177"
  - Measured package length (tip to collar): 178"
- ☐ Borehole collar
  - ☑ Bolts tightened
  - ☑ Gaskets installed
  - ☑ Face plate secured
  - NA Grout port and vent port labeled
  - NA Grout connections ready (1" cam-lock)

Signature indicating borehole ready ~~for grouting~~ NA

Brad Fritz [signature] Date 7-28-22



Borehole Installation Checklist

Borehole ID GS- 8 Date of Install: 7-27-22

- ☑ Packer
  - ☑ All connections secured (sample lines, inflation lines, data cable splice)
  - ☑ Passed packer inflation test
    - Pressurized to 37 psi
    - Held pressure for 30 seconds
  - ☑ Thermistor check- measured resistance: 12.9 KOhms
- ☑ Measured necessary packer lengths
  - ☑ Tip to front of packer (sample interval length): 28.5"
  - ☑ Tip to last union on back of packer: 58 1/2"
  - ☑ Tip to back of first stick of conveyance pipe: 10' (120")
- ☑ Conveyance pipe.
  - Centralizers flared and secured
  - 1st stick perforated
  - Down going sticks perforated (4 holes/stick)
- ☑ Spacer rings used on conveyance pipes (not 1st or last)
- ☑ Stainless tubing sanded
- ☑ Tremie pipe sanded
  - Tremie pipe attached 2 ft above vent holes
- ☑ Package touched TD (audible thump at end)
  - TD measured before install: 54' 10 1/2"
  - Measured package length (tip to collar): 54' 11" (659")
- ☑ Borehole collar
  - Bolts tightened
  - Gaskets installed
  - Face plate secured
  - Grout port and vent port labeled
  - Grout connections ready (1" cam-lock)

Signature indicating borehole ready for grouting

Brad Fritz [signature] Date 9-19-22

Appendix C – Gas Block Test

The gas block on the thermistor data cable (at the splice location) was tested per instructions provided by the confinement team. This appendix documents the design and fabrication of the gas block as well as the testing.

C.1 Introduction

The gas sampling boreholes that will be installed for PE-1 include a data cable connecting the sample zone to the data acquisition system. It is required that this cable include a gas block to minimize the potential for gas transport to the tunnel through the cable. This report describes the connection included in the design of the gas borehole package, the approach used to build the gas block, and a demonstration test that the gas block functions as intended.

C.2 Method

As designed, the borehole package consists of a packer (to isolate the sampling interval) with pass-through ports. The borehole will be filled with grout between the packer and the collar (Figure C1). The gas block is added to the thermistor cable splice. The gas block is made by injecting epoxy into a heat-shrink sleeve placed around the splice, and then shrinking the sleeve (Figure C2). This approach has several benefits; the heat used to shrink the sleeve drives air bubbles out of the epoxy, and the shrinking of the tubing forces the epoxy into the small intestinal spaces around the cable and splice.

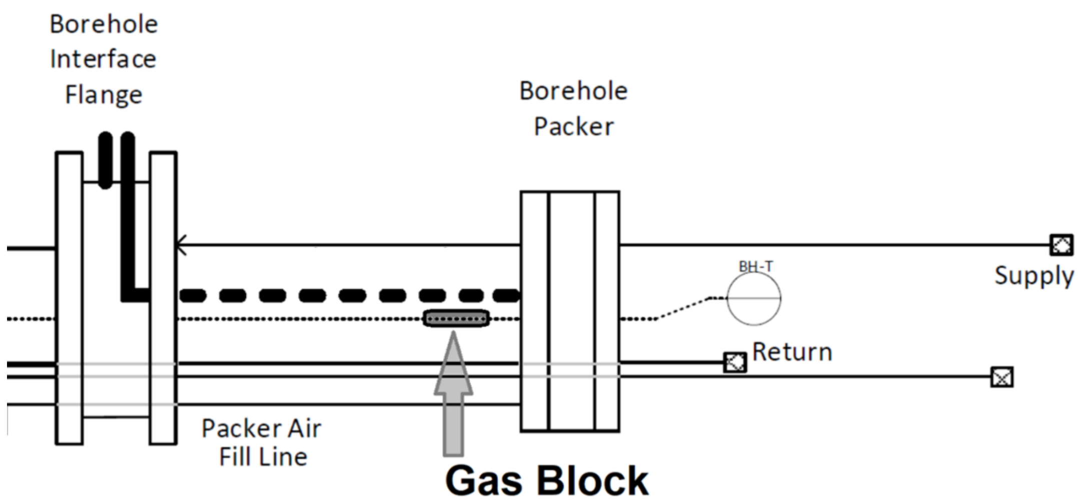


Figure C1. Borehole packer assembly design.

Figure C2. Gas block.

The gas block was tested by splicing a piece of the thermistor cable to a 10-foot long section of the same Cat-5 cable that runs from the packer, down the borehole, through the collar and into the tunnel (Figure C3). The end of the Cat-5 cable was pressurized (various pressures, up to 24 psig) for 15 minutes. The end of the thermistor cable was submerged in a soap-water solution; the presence of bubbles would then indicate air moving through the cables and gas block. The pressure was maintained on the end of the cable using an air pump and a needle valve. By adjusting the needle valve, various backpressures could be maintained. The pressure applied to the end of the cable was measured with a 0-30 psig pressure transducer. This test was repeated at three different pressures.

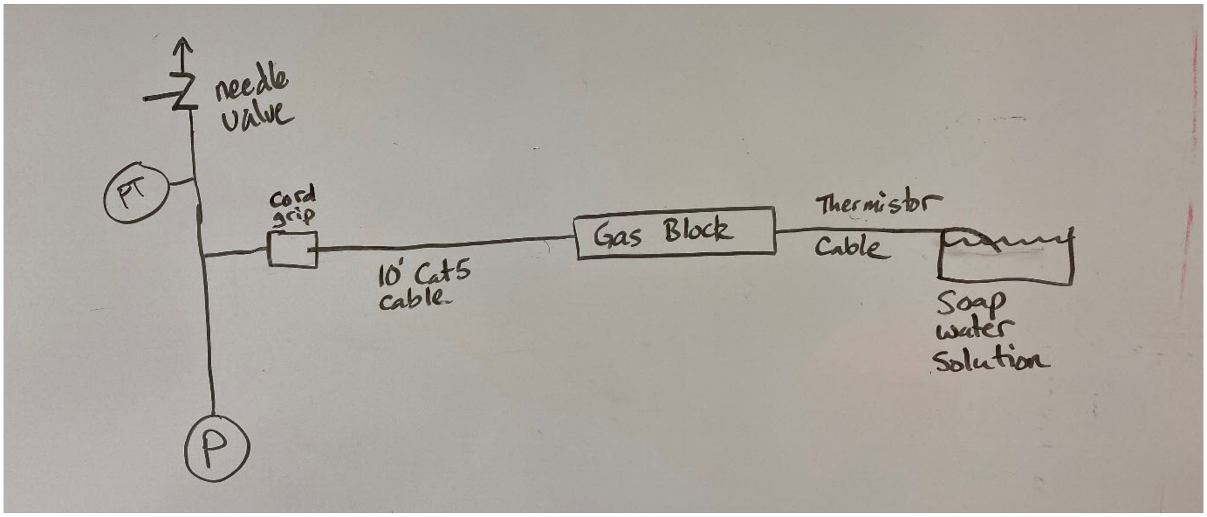


Figure C3. Test setup.

C.3 Results

The results of the gas block test indicated that the gas block design would perform as intended. Pressure was maintained at 9, 17.6 and 24 psig for at least 15 minutes for each test (Figure C4). No bubbles were observed at the end of the cable (Figure C5).

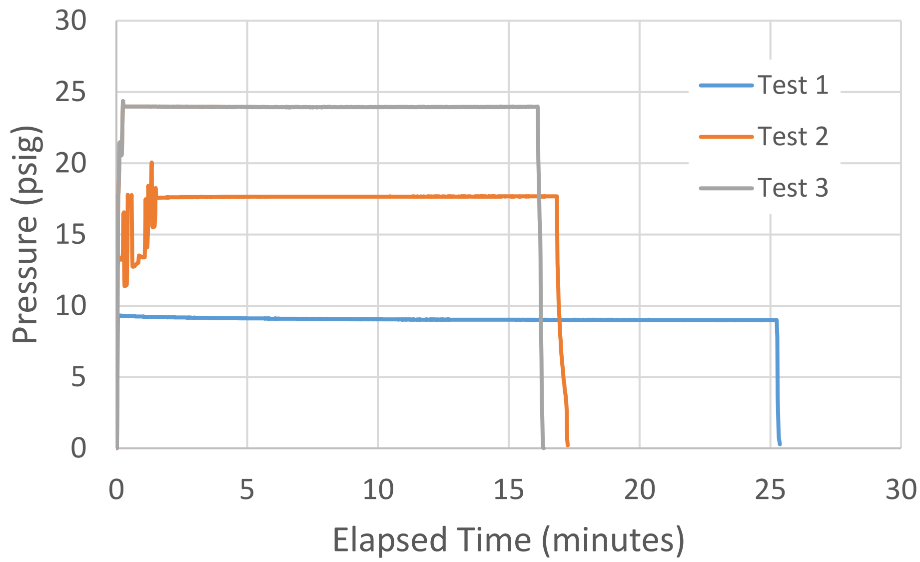


Figure C4. Pressure applied to the end of the cable for all three tests.

Figure C5. Pictures of cable end in soap-water solution. No bubbles present.

Chapter 3 – Permeability Testing of Gas Sampling Boreholes Installed for PE1-A

1.0 Introduction

In support of Experiment A of the PE-1 experiment series, 8 gas sampling boreholes were installed. These boreholes were sealed with grout, leaving only a short section of open borehole at the end for the sampling zone. The boreholes were instrumented with multiple tubes to support gas sampling and pressure monitoring of the sampling zone. A recirculation system was designed and installed, providing a means for circulating and sampling gas from the boreholes (Chapter 1). As part of the initial quality control checks performed to evaluate borehole performance and installation quality, permeability measurements were conducted for each of the 8 gas sampling boreholes. After the initial testing, additional permeability tests were conducted over the course of the experiment. This report summarizes the results of permeability testing conducted on each borehole before and after Experiment A.

2.0 Methods

There were several methods used to conduct permeability tests in the gas sampling boreholes. All tests used a constant rate injection of air into the formation until a steady-state pressure was reached. All methods were analyzed using the same analytical solution. Some of the permeability measurements were made with the packer deflated (typically because the packer failed). An intercomparison of the various test methods indicated that the various approaches generally yielded comparable results.

2.1 Short Duration Tests

For the initial permeability testing, a pump was used to inject air into the formation for a moderately short period of time (generally 3 to 5 minutes). The test apparatus consisted of a diaphragm pump (22D1180, Gast mfg.) a needle valve and flow meter (M-series, Alicat Sci., Tucson AZ). The air flow was connected to the sample port of the boreholem (Figure 30), while the return line was capped and the pressure in the formation was monitored with a 0-15 psia pressure transducer (PX409, Omega, Norwalk CT). The flow and pressure were recorded by an onboard data logger measuring at a 2 Hz rate (CR6, Campbell Sci, Logan UT). A test was started by collecting baseline formation pressure data briefly and then initiating flow. Pressure in the formation was monitored and once the pressure stabilized the test was terminated (Figure 31).

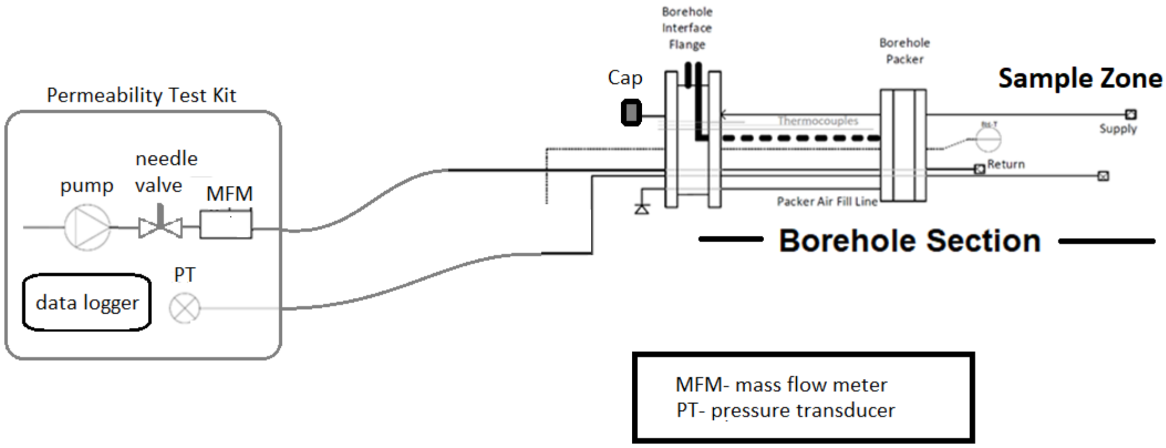


Figure 30. Hardware set-up for the short duration permeability tests.

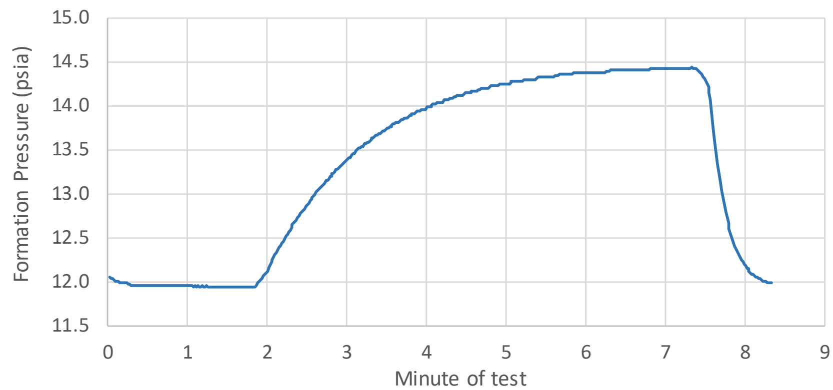


Figure 31. Example of pressure response measured in GS-5 during short duration permeability test.

2.2 Closed Loop

The design of the gas sampling system allowed for low volume closed loop permeability tests to be conducted. This was accomplished by stopping circulation (setting the flow rate to zero) while the recirculation pump was left on. In this manner air was pulled from the formation and stored under pressure in the secondary water trap (Figure 32). After allowing the formation pressure to equilibrate, the isolation valves were used to allow flow from the enclosure to the borehole, but not allow air flow out of the borehole. The stored air was then used to drive flow back into the formation, resulting in a measurable pressure response in the formation (Figure 33). For most of the boreholes this approach yielded reasonable results that agreed with the short and long duration test methods.

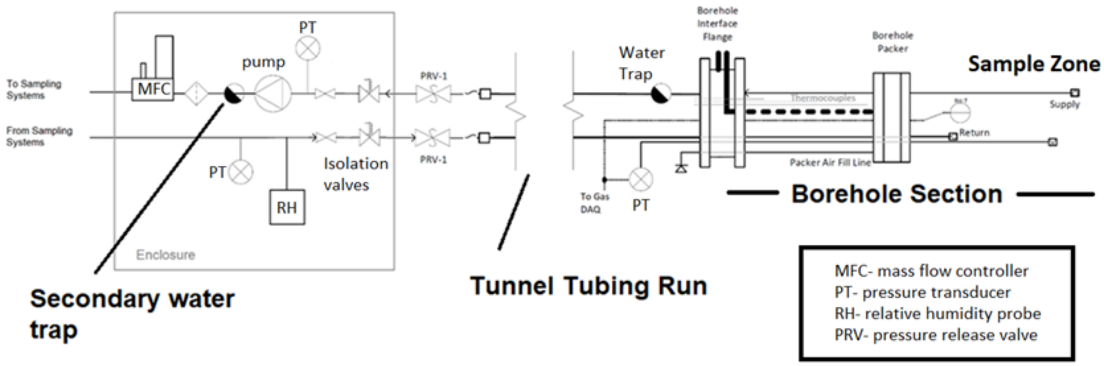


Figure 32. Diagram of system plumbing as used for closed loop tests.

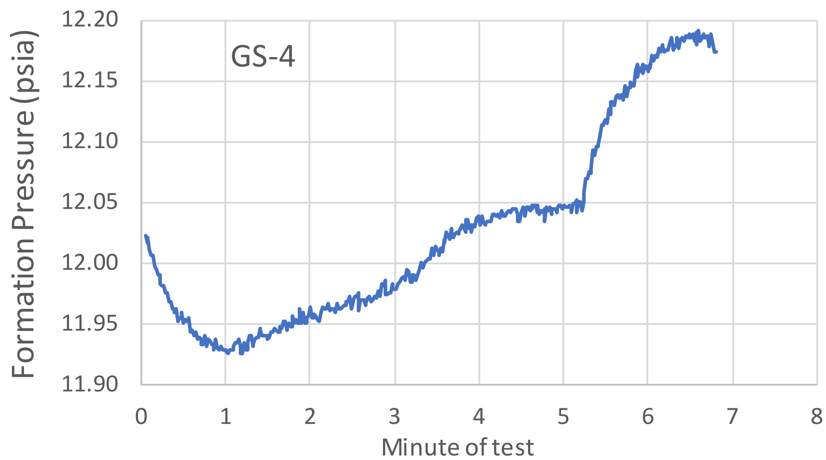


Figure 33. Example of pressure response measured in GS-4 during closed loop permeability test.

2.3 Long Duration

Following Experiment A, the borehole sampling lines were required to be purged to remove potentially toxic gases from the sampling lines. To accomplish this, the borehole sample lines were disconnected and capped on the borehole side (Figure 34). The sampling system was then run for at least 60 minutes. This configuration allowed air from the tunnel to be circulated through the sampling system and injected into the borehole, resulting in a long duration pump test (Figure 35).

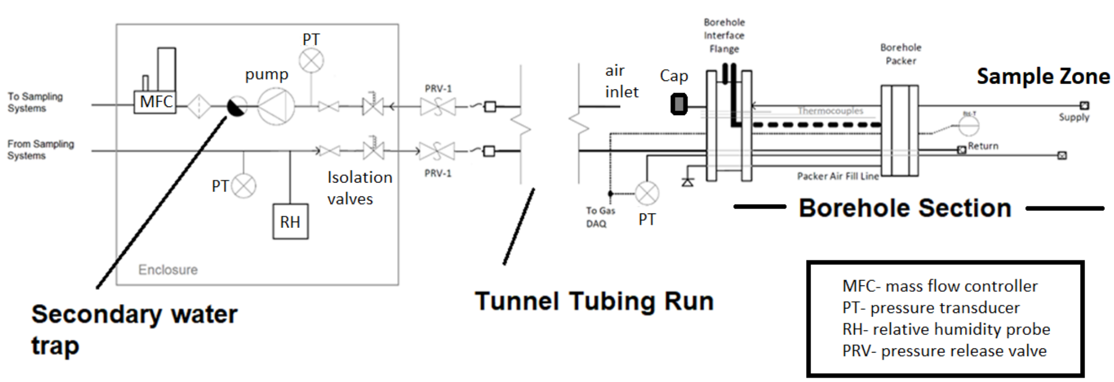


Figure 34. System plumbing during the long duration permeability tests.

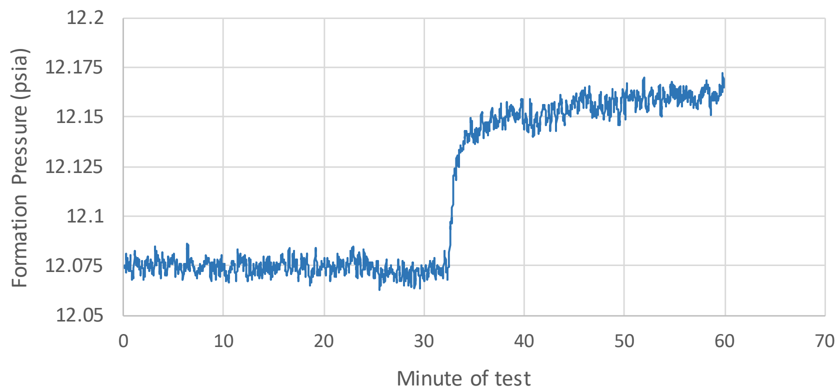


Figure 35. Example of pressure response measured in GS-2 during long duration permeability test.

2.4 High Flow

To complement the single borehole permeability test methods described above, two high flow injection tests were conducted in an attempt to observe a response at adjacent boreholes. This test used a pair of pancake style air compressors to deliver air at rates in excess of 150 L/min (Figure 36). Flow rate was measured using a variable area style inline flow meter; while the stated accuracy was 5%, the effective resolution was on the order of 20 L/min, or 10 to 15 % of the flow rates used for this test. The pressure response in adjacent boreholes is not discussed here. However, the tests were analyzed as single borehole permeability tests in the same manner as the other methods.

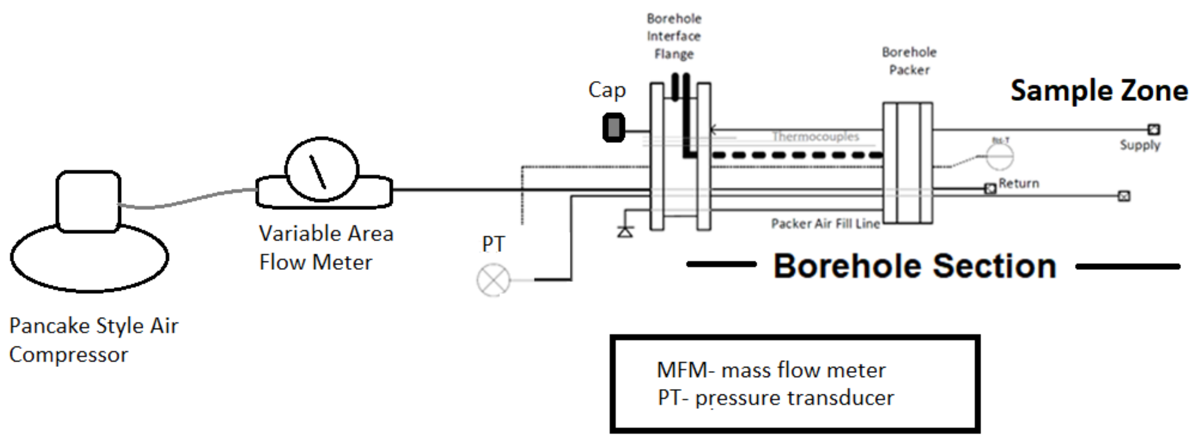


Figure 36. Equipment used to conduct high flow permeability tests.

2.5 Analysis

Permeability was calculated according to the analytical method described in Zeigler (1976) “Determination of Rock Mass Permeability”. This method requires knowledge of the injection interval (sampling zone), the initial formation pressure, the flow rate and the resulting pressure in the injection interval. For all permeability tests pressure and flow were recorded. The sampling interval dimensions were known from construction details (28 in long and 4.8 in diameter). The packer was 24 inches long and, when inflated, served to isolate the sampling interval from the remainder of the borehole. When uninflated, the packer length was added to the injection interval length. As described in the borehole completion report (Chapter 2), boreholes with the sampling interval lower than the collar were constructed with a dual-packer design. For these tests, if conducted with the packer deflated, the injection interval was assumed to be 11.75 ft long.

3.0 Results

Some limited summary and analysis of the results are provided here in the body of the report. However, the measurements and the associated results from all permeability tests are included in Appendix A. The intent of this report is not to conduct detailed analysis of transport properties of phenomena, but simply to provide the measurements for future use.

3.1 Summary

Over the 15 months that post-grouting permeability tests were conducted in the gas sampling boreholes, 91 permeability tests were conducted. Tests conducted prior to grouting are not reported here, but are discussed in the borehole completion report (Chapter 2). While summary statistics (Table 11) might indicate that the results were not particularly repeatable for any single borehole, there were a number of factors that led to variability between different sets of tests. For example, it appeared that the measured permeability around GS-1 and GS-2 changed after the explosion (Figure 37), resulting in a high relative standard deviation when the entire set permeability measurements is considered.

Table 11. Summary of all post-grouting permeability tests conducted on Gas Sampling boreholes for experiment PE1A. Note that this table should not be used to assign permeabilities to the respective boreholes.

Borehole	Average Perm. (Darcy)	Std. Deviation (Darcy)	Relative Std. Deviation	Number of measurements
GS-1	0.317	0.176	0.55	14
GS-2	0.666	0.409	0.61	14
GS-3	0.0579	0.00689	0.12	13
GS-4	0.413	0.0668	0.16	17
GS-5	0.0175	0.0107	0.61	6
GS-6	0.848	0.130	0.15	14
GS-7	0.095	NA	NA	1
GS-8	1.45	0.373	0.26	12

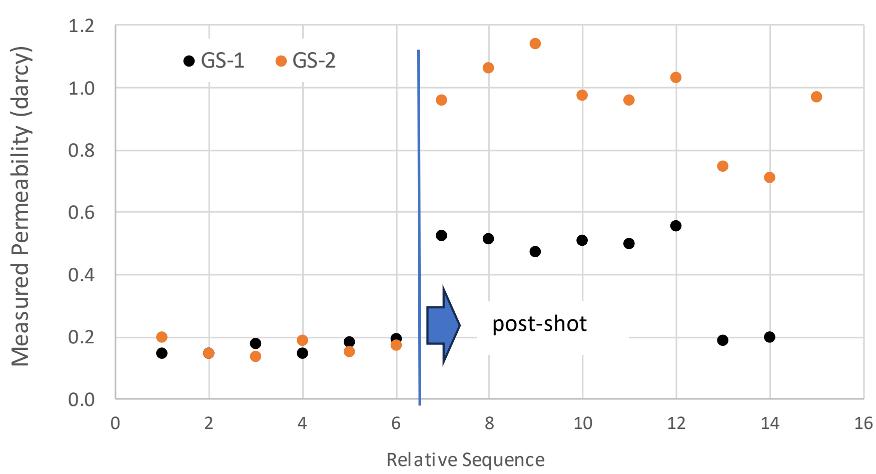


Figure 37. Measured permeabilities of boreholes GS-1 and GS-2. Note hollow circles denote measurements made prior to grouting of borehole.

3.2 Comparison of Methods

Intercomparison of the results with different methods is important for evaluating the representativeness of the measured permeabilities. In particular, the closed-loop method used a small volume of air, meaning the volume of formation interrogated by the test was also relatively small. In comparing methods, it was important to isolate resulting from other phenomena. Therefore, measurements made after the explosion were considered separately from measurements made before the explosion (Table 12). While the sample size is small for most combinations of location, method and time, the relative standard deviation is much smaller than when the results are considered in aggregate (Table 11). The low relative standard deviation for a given set of test conditions indicates that the method was repeatable. Due to the small sample size, a detailed quantitative comparison of methods was not conducted. However, for most of the boreholes, there was less than a 30% difference in the average measured permeability between any two methods with the same conditions. Some exceptions for this were GS-8 and GS-5 as well as post- explosion measurements for GS-1 and GS-2.

For GS-8, the high permeability resulted in very small pressure changes at the flow rates tested. This led to greater uncertainty in the calculated permeability, which likely led to greater variability between methods. It is assumed that the lower measured permeabilities post- explosion at GS-1 and GS-2 with the long duration method is associated with changes in the formation resulting from the explosion. Borehole GS-5 is discussed in a separate section below.

Table 12. Summary of permeability results (average, standard deviation, relative standard deviation, and number of tests) compiled by location, test method and pre- vs post-explosion.

		Permeability (Darcy)		Standard Dev. (Darcy)		Rel. Std. Dev.		count	
Borehole	Method	Pre	Post	Pre	Post	Pre	Post	Pre	Post
GS-1	Short Duration	0.146		0.00072		0.00		2	
	Closed Loop	0.174	0.512	0.019	0.028	0.11	0.05	4	6
	Long Duration		0.192		0.0068		0.04		2
GS-2	Short Duration	0.14		0.007		0.05		2	
	Closed Loop	0.169	1.02	0.02	0.072	0.12	0.07	3	6
	Long Duration		0.729		0.025		0.03		2
	High Flow		0.967		NA				1
GS-3	Short Duration	0.0498		0.0052		0.10		2	
	Closed Loop	0.0597	0.0599	0.0092	0.0056	0.15	0.09	3	7
	Long Duration		0.0545		NA				1
GS-4	Short Duration	0.3250		0.0330		0.10		2	
	Closed Loop	0.403	0.434	0.052	0.066	0.13	0.15	4	8
	Long Duration		0.386		0.0077		0.02		2
	High Flow		0.517		NA				1
GS-5	Short Duration	0.0189*		NA		NA		1	
	Closed Loop	0.0249		0.0061		0.24		3	
	Long Duration		0.0108		NA				1
GS-6	Short Duration	0.844		0.07		0.08		2	
	Closed Loop	0.923	0.83	0.24	0.085	0.26	0.10	5	6
	Long Duration		0.584		NA				1
GS-7	Short Duration	0.095		NA		NA		1	
GS-8	Short Duration	2.36		NA		NA		1	
	Closed Loop	1.41	1.46	0.32	0.16	0.23	0.11	3	6
	Long Duration		1.03		0.014		0.01		2

*Single measurement with packer deflated. Measurement with packer inflated not included

3.3 Discussion on GS-5

It should be noted that Experiment A was conducted with the packer in GS-5 uninflated. This is because the initial permeability measured in GS-5 with the packer inflated (0.0006 Darcy, Appendix A Table 12) indicated that the borehole was in a tight formation. Additionally, several months after the initial tests the formation decreased in permeability; it became impossible to conduct permeability tests in the lower portion of GS-5 after this. It was assumed that the formation, and possibly part of the sampling interval was saturated as there was evidence of liquid water in the sample lines. Therefore, the decision was made to leave the packers deflated, effectively creating an 11.75 foot long sampling interval. The top of this interval was in a different, and more permeable, portion of the geologic formation. Subsequent permeability measurements reflect this.

3.4 Comparison to elevation

One interesting pattern noted in the permeability results is that the measured permeability was generally proportional to borehole elevation. For comparison, the pre- explosion permeability measured using the closed-loop method (Short Duration method for GS-7;Table 12) was compared to the elevation of the center of the gas sampling zone. Boreholes higher in the formation were generally noted to have higher measured permeability (Figure 38).

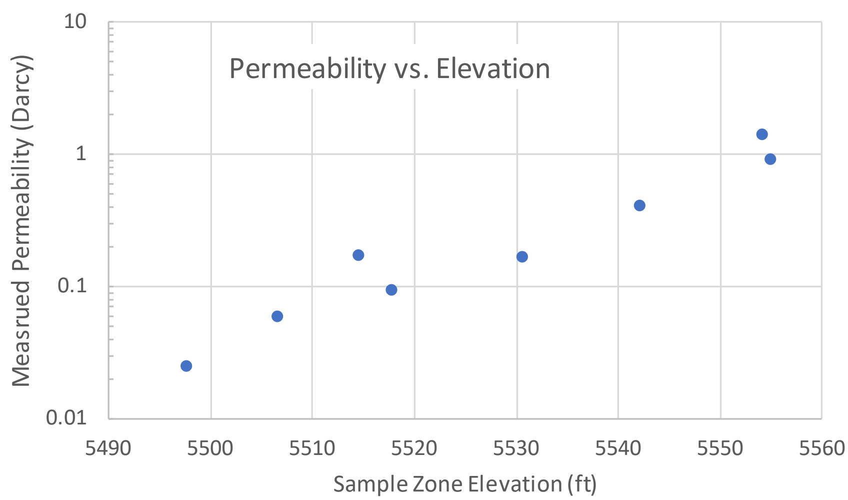


Figure 38. Measured permeability (pre- explosion, closed loop) compared to center elevation of the gas sampling zone (US survey feet).

4.0 Conclusion

This report summarizes the 91 permeability measurements made in the gas sampling boreholes both before and after the explosion from Experiment A. The individual results are provided in Appendix A. The intent of this report is not to provide scientific interpretation of the results, but rather to make the data available for use in other investigations. The basic analysis of results conducted here indicate that the data are of good quality, consistent within the methods, and should be considered adequate for use in integration with and interpretation of other project data.

5.0 References

Zeigler, T.W. 1976. DETERMINATION OF ROCK MASS PERMEABILITY

U.S. Army Corps of Engineers Technical Report S-76-2, U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

Appendix A – Supporting Values

This appendix provides the supporting values that were used in calculating permeability for all 91 measurements discussed in this report.

Short Duration Method, Pre-explosion

Borehole	GS-6		GS-6	*GS-5*[1]	GS-5	GS-4	GS-4	GS-3
Date	11/14/22		11/14/22	*11/14/22*	11/14/22	11/14/22	11/14/22	11/14/22
Packer	deflated		inflated	*inflated*	deflated	deflated	inflated	inflated
Flow (L/min)	8.71		9.35	*1.17*	3.75	8.94	9.38	1.88
Initial P (psia)	12.12		12.12	*12.12*	12.12	12.13	12.13	12.13
Final P (psia)	12.29		12.39	*35.15*	13.63	12.64	12.74	12.92
temperature	19		19	*19*	19	19	19	19
Permeability (Darcy)	0.8934		0.7941	*0.0006*	0.0189	0.30147	0.3478	0.0534

Borehole	GS-3	GS-2	GS-2	GS-1	GS-7	GS-8	GS-1
Date	11/14/22	11/14/22	11/14/22	11/14/22	11/15/22	11/15/22	11/16/22
Packer	inflated	deflated	deflated	inflated	inflated	inflated	inflated
Flow (L/min)	5.58	8.23	8.03	5.5	6.1	9.21	8.19
Initial P (psia)	12.13	12.12	12.12	12.12	12.16	12.16	12.16
Final P (psia)	14.67	13.08	13.43	12.96	13.57	12.25	13.4
temperature	19	19	19	19	19	19	19
Permeability (Darcy)	0.0461	0.1448	0.1348	0.1467	0.0948	2.36414	0.1457

Closed Loop Method, Pre-explosion

Borehole	GS-1	GS-1	GS-2	GS-3	GS-4	GS-6
Date	5/25/23	6/13/23	6/26/23	6/26/23	6/26/23	6/26/23
Packer	inflated	deflated	deflated	inflated	inflated	deflated
Flow (L/min)	1	1	1	1	0.995	3
Initial P (psia)	12.05	12.065	11.91	12.177	11.75	12.115
Final P (psia)	12.18	12.222	11.994	12.34	11.81	12.16
temperature	19	19	19	19	19	19
Permeability (Darcy)	0.1774	0.1467	0.1895	0.0494	0.3836	1.0629

Borehole	GS-4	GS-5	GS-6	GS-1	GS-2	GS-3	GS-8
Date	6/26/23	6/26/23	6/26/23	8/25/23	8/25/23	8/25/23	8/25/23
Packer	inflated	deflated	deflated	inflated	deflated	deflated	inflated
Flow (L/min)	0.998	0.1	1	1	1	1	1
Initial P (psia)	11.75	12.07	12.09	12.1285	12.133	12.09	12.0969
Final P (psia)	11.816	12.115	12.11	12.2563	12.24	12.3262	12.111
temperature	19	19	19	19	19	19	19
Permeability (Darcy)	0.3496	0.0180	0.7980	0.1805	0.1486	0.0670	1.6436

Borehole	GS-4	GS-5	GS-6	GS-5	GS-6	GS-8
Date	8/25/23	8/25/23	8/25/23	8/25/23	10/11/23	10/11/23
Packer	inflated	deflated	inflated	deflated	inflated	inflated
Flow (L/min)	1	1	1	0.2	1	1
Initial P (psia)	12.118	12.148	12.103	12.118	12.024	11.898
Final P (psia)	12.167	12.44	12.1245	12.173	12.05	11.92

[1] Result not included in summary statistics. Collected with packer inflated; packer was deflated for remainder of experiment.

Borehole	GS-4	GS-5	GS-6	GS-5	GS-6	GS-8
temperature	19	19	19	19	19	19
Permeability (Darcy)	0.4723	0.02744	1.0775	0.0294	0.8909	1.0530

Borehole	GS-3	GS-1	GS-2	GS-4	GS-6	GS-8
Date	10/11/23	10/11/23	10/11/23	10/11/23	10/13/23	10/13/23
Packer	inflated	inflated	deflated	inflated	inflated	inflated
Flow (L/min)	0.6	1	1	1	3	3
Initial P (psia)	11.93	11.96	11.796	11.742	12.042	12.035
Final P (psia)	12.15	12.08	11.89	11.799	12.13	12.08
temperature	19	19	19	19	19	19
Permeability (Darcy)	0.0627	0.1923	0.1693	0.4058	0.7876	1.5430

Closed Loop Method, Post-explosion

Borehole	GS-3	GS-1	GS-1	GS-2	GS-2
Date	10/28/23	10/28/23	10/28/23	10/28/23	10/28/23
Packer	inflated	inflated	inflated	deflated	deflated
Flow (L/min)	0.92	1	3	3	5
Initial P (psia)	11.99	12.02	12.02	12.05	12.05
Final P (psia)	12.355	12.064	12.155	12.1	12.125
temperature	19	19	19	19	19
Permeability (Darcy)	0.0576	0.5260	0.5124	0.9564	1.0616

Borehole	GS-4	GS-4	GS-6	GS-8	GS-3	GS-4	GS-6
Date	10/28/23	10/28/23	10/28/23	10/28/23	10/31/23	10/31/23	10/31/23
Packer	inflated	inflated	inflated	inflated	inflated	inflated	inflated
Flow (L/min)	1	2	3	3	0.5	2	3
Initial P (psia)	12.027	12.027	12.055	12.032	12.05	12.087	12.115
Final P (psia)	12.093	12.155	12.138	12.083	12.267	12.208	12.195
temperature	19	19	19	19	19	19	19
Permeability (Darcy)	0.3504	0.3604	0.8352	1.3611	0.0530	0.3814	0.8667

Borehole	GS-8	GS-1	GS-2	GS-3	GS-3	GS-4	GS-6
Date	10/31/23	11/3/23	11/3/23	11/3/23	11/3/23	11/3/23	11/3/23
Packer	inflated	inflated	deflated	inflated	inflated	inflated	inflated
Flow (L/min)	3	3	3	2	1	2	2
Initial P (psia)	12.074	12.081	12.133	12.008	12.02	12.096	12.108
Final P (psia)	12.115	12.228	12.175	12.665	12.43	12.203	12.167
temperature	19	19	19	19	19	19	19
Permeability (Darcy)	1.6938	0.4704	1.1390	0.0687	0.0556	0.4315	0.7841

Borehole	GS-8	GS-1	GS-2	GS-3	GS-4	GS-6	GS-8
Date	11/3/23	11/5/23	11/5/23	11/5/23	11/5/23	11/5/23	11/5/23
Packer	inflated	inflated	deflated	inflated	inflated	inflated	inflated
Flow (L/min)	2	3	3	1	3	3	3
Initial P (psia)	12.077	12.066	12.096	11.996	12.076	12.089	12.07
Final P (psia)	12.106	12.202	12.145	12.399	12.215	12.182	12.126
temperature	19	19	19	19	19	19	19
Permeability (Darcy)	1.5972	0.5086	0.9760	0.0566	0.4976	0.7451	1.2393

Borehole	GS-1	GS-2	GS-3	GS-4	GS-6	GS-8	GS-4
Date	12/8/23	12/8/23	12/8/23	12/8/23	12/8/23	12/8/23	12/8/23
Packer	deflated	deflated	inflated	inflated	inflated	inflated	inflated
Flow (L/min)	3	3	1	3	3	3	1
Initial P (psia)	12.044	12.075	11.977	12.049	12.072	12.038	12.049
Final P (psia)	12.14	12.125	12.333	12.185	12.143	12.086	12.102
temperature	19	19	19	19	19	19	19
Permeability (Darcy)	0.4972	0.9564	0.0642	0.5086	0.9769	1.4464	0.4365

Borehole	GS-1	GS-2	GS-3	GS-4	GS-6	GS-8
Date	12/17/23	12/17/23	12/17/23	12/17/23	12/17/23	12/17/23
Packer	deflated	deflated	deflated	inflated	inflated	inflated
Flow (L/min)	3	2	1	2	3	3
Initial P (psia)	12.113	12.128	12.138	12.098	12.11	12.069
Final P (psia)	12.199	12.159	12.386	12.189	12.2	12.117
temperature	19	19	19	19	19	19
Permeability (Darcy)	0.5552	1.0292	0.0638	0.5077	0.7701	1.4464

Long Duration Method, Post-explosion

Borehole	GS-2			GS-2	GS-1	GS-1	GS-3	GS-4	GS-4
Date	12/18/23			12/18/23	12/18/23	12/18/23	12/18/23	12/18/23	12/18/23
Packer	deflated			deflated	deflated	deflated	deflated	inflated	inflated
Flow (L/min)	4			6.09	4	6.65	4	4	5.969
Initial P (psia)	12.0747			12.074	12.023	12.023	12.009	12.0489	12.0489
Final P (psia)	12.16			12.21	12.359	12.55	13.13	12.29	12.3971
temperature	19			19	19	19	19	19	19
Permeability (Darcy)	0.7464			0.7113	0.1875	0.1972	0.0545	0.3809	0.3918

Borehole	GS-5	GS-6	GS-8	GS-8
Date	12/18/23	12/18/23	12/18/23	12/18/23
Packer	deflated	deflated	deflated	deflated
Flow (L/min)	4	4	4	6.49
Initial P (psia)	11.7123	12.101	12.0585	12.0585
Final P (psia)	14.225	12.21	12.12	12.16
temperature	19	19	19	19
Permeability (Darcy)	0.0108	0.5835	1.0363	1.0171

High Flow Methods, Post-explosion

Borehole	GS-2	GS-4
Date	12/19/23	12/19/23
Packer	deflated	deflated
Flow (L/min)	170	226
Initial P (psia)	12.04	12.02
Final P (psia)	14.58	17.67
temperature	19	19
Permeability (Darcy)	0.9671	0.5173

Chapter 4 – Calculation of Lag Time in Gas Signal Arrival

1.0 Introduction

In support of Experiment A of the PE-1 experiment series, eight gas sampling boreholes were drilled at varying distances from the working point. The boreholes were completed and instrumented with multiple tubes to support gas sampling and pressure monitoring of the sampling zone. A system was designed and installed to allow for recirculating and sampling of gas from the boreholes. This circulation system also pulled gas from tunnel environment monitoring locations within the 06-Bypass drift. Installation details are captured in an as-built document (Chapter 1) and a borehole completion report (Chapter 2). Several real-time monitoring systems and grab sample collection systems were connected to the circulation system. When analyzing results from the real-time systems or grab samples, it is important to understand the lag time between gas arrivals in the formation and the observed arrivals on the instruments. There is a delay as gas moves from the formation into the borehole and then through the tubing and water traps to the recirculation system and ultimately to the measurement systems. Adding additional complications to this delay is the fact that pressure in the formation varied over time and the flow rate of the system was adjusted to compensate for the increased pressure. This report discusses the various system components and the factors that contribute to lag time. An equation for calculating lag time for any set of conditions is presented and a table of calculated lag times for each borehole and measurement system provides an estimated range of lag times.

2.0 Discussion

To calculate the lag time between arrival in the formation and instrument response, several pieces of information are necessary. The primary information required is system volume and pressure and flow rate. Each are discussed here in the methods section; this information is combined in the results. Additionally, some tracer testing conducted prior to experiment A are described and used to provide additional support to the lag time calculations.

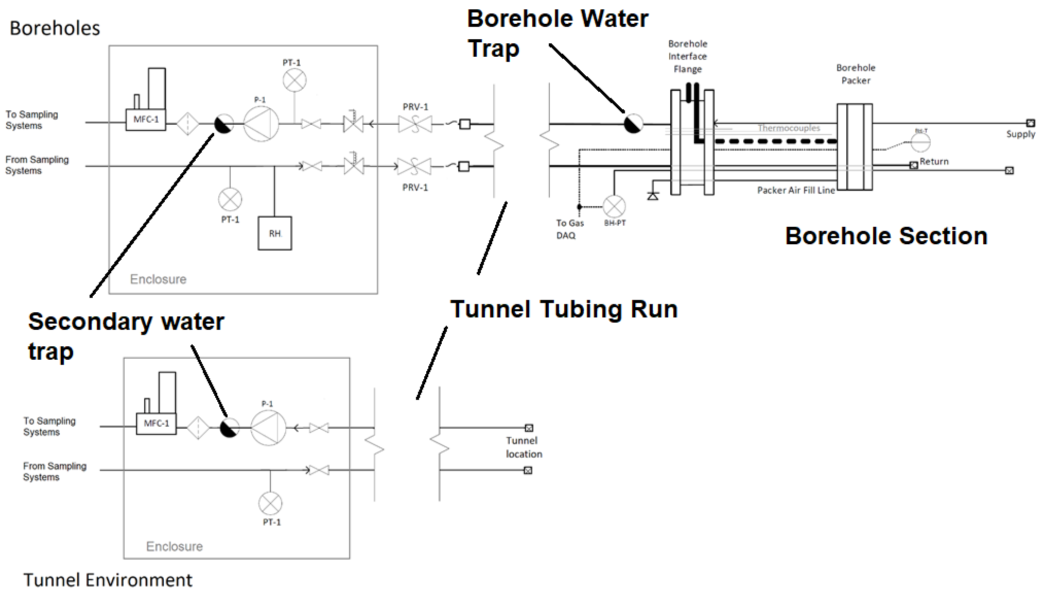


Figure 39. Gas recirculation plumbing schematic.

2.1 System Volume

The gas recirculation system consists of several sections. The borehole section, the water traps, the tunnel tubing run, the gas cabinet and the 650 tubing run. While the as-built document considered these sections for a generic borehole, here the volume for each borehole and associated tubing runs are accounted for individually.

The borehole sampling zones are 28 inches long with a 4.78 in diameter, equating to an 8.2 L sampling zone volume for seven of the eight boreholes. One borehole (GS-5) was completed with a dual packer string but the packers were not inflated during the experiment. This resulted in an internal sampling zone volume of 27 L for GS-5. Similarly, the packer for GS-2 failed after grouting and was not inflated during the experiment. However, even uninflated the packer filled most of the excess volume; for GS-2 the sampling interval volume was also assumed to be 8.2 L.

The tubing installed in the boreholes was 0.25 in OD stainless steel tubing with a 0.035 in wall thickness. This results in an internal volume of 0.3054 in3 per foot of tubing (16.4 mL/m). This same tubing was used for internal plumbing on the gas circulation cabinet and for distribution lines between systems in the 650-facility. The tubing lines connecting the boreholes and tunnel environment locations to the gas circulation cabinet were 0.375 in OD stainless steel tubing with a 0.049 in wall thickness, resulting in an internal volume of 0.723 in3 per foot of tubing (38.9 mL/m). This tubing connected the borehole collar to the water traps and the water traps to gas circulation cabinet. The tubing lengths are provided for each borehole based on as-built measurements (Table 14).

Each borehole included a water trap mounted at the borehole collar. The internal volume of the water trap was 9.4 L. Additionally, each sampling location included a small water trap located inside the gas circulation cabinet. These water traps were 2 L, although they were slowly filling with water over the course of the experiment. Since the water traps were emptied the day before the experiment, and the most critical arrivals occurred within 24 hours of the experiment, the internal volume of the small water traps is assumed to be 2 L for the calculations included in this report.

The xenon detectors are in series in the recirculation loop, providing an additional volume for gas to travel through before reaching the HE byproducts, tunnel environment or grab sampling systems. Each xenon detector contains an internal volume of 7.5 L.

The HE byproducts and tunnel environment systems are in parallel with the recirculation loop. This results in a potential additional lag time for these instruments independent of the recirculation system. The HE byproducts analyzers use a 1 L/min flow rate and have approximately 10 feet of ¼” OD tubing, resulting in an additional delay of ~0.1 min. The tunnel environment system has very short lengths of internal tubing; any additional lag time is considered to be negligible (less than 5 seconds).

The gas cabinet circulation system is built with internal ¼” OD tubing. The cabinet width is 30 inches, and tubing runs more or less straight across, but with some dead volume associated with fittings, unions and the RH sensor volume. Therefore, the internal tubing volume (excluding the water trap) is estimated to be 0.1 L. Similarly, the combined tubing length between instruments in the 650 facility varied between 21 and 25 feet, equating to a nominal volume of 0.1 L. While there is some small difference in the travel time between the HE Byproducts system and the grab sampling system, the difference is negligible. A 3-meter long section of ¼” OD tubing has a volume of 50 mL. For a flow rate of 4 L/min, the difference in arrival time would be on the order of 1 second; or much less than the uncertainty in arrival times resulting from the mixing within the larger volumes.

The grab sampling systems collected samples over a 5-minute collection period. While some additional lag time would occur as sample moves from the recirculation system to the grab sampler, the delay would be much less than the collection period and is not considered.

Table 13. Gas system component volumes.

Component	Volume (L)
Borehole sample zone (GS-1, -2, -3, -4, -6, -7, -8)	8.2
Borehole sample zone (GS-5)	27
Large Water Trap	9.4
Small water trap in gas circulation cabinet	2
Xenon detectors	7
Gas circulation cabinet internal tubing	0.1
650 circulation loop tubing volume	0.1

Table 14. Tubing lengths and calculated volumes for each borehole and Tunnel Environment sampling location (from Chapter 1).

Location	¼" in borehole (ft), [L]	3/8" in tunnel (ft), [L]	Total tubing volume* [L]
GS-1	60 [0.3]	917 [10.9]	11.4
GS-2	60 [0.3]	917 [10.9]	11.4
GS-3	63 [0.3]	891 [10.6]	11.1
GS-4	63 [0.3]	891 [10.6]	11.1
GS-5	63 [0.3]	855 [10.1]	10.6
GS-6	63 [0.3]	855 [10.1]	10.6
GS-7	12 [0.1]	950 [11.3]	11.8
GS-8	55 [0.3]	950 [11.3]	11.8
Tun. Env. 1	NA	850 [10.8]	11.0
Tun. Env. 2	NA	425 [5.0]	5.2
Tun. Env. 3	NA	400 [4.7]	4.9

*includes gas cabinet and 650 recirculation tubing volumes

2.2 Flow Rate

The nominal flow rate of the gas recirculation system was 4 L/min for boreholes and the tunnel environment sampling locations. However, for boreholes the flow rate was adjusted to account for increased formation pressure. This was necessary to keep the travel time between borehole and detectors below the required threshold. For example, if the pressure in the formation doubled then the flow rate (at STP) would also have to double to achieve the same transport time from borehole to the instruments.

2.3 Pressure

As described above, it is necessary to know the pressure in the formation to convert the flow rate at standard conditions (STP) to the flow rate at the system pressure. Each borehole and tunnel environment location had dedicated pressure. Data from these sensors was used to adjust the flow rate at STP to the flow rate at the actual conditions. No adjustment was made for temperature; temperatures were very close to standard conditions and the relative impact on calculated lag time was much less than 0.1 minutes.

2.4 Gas Composition

The mass flow meters used to measure flow rate in the sample circulation lines are calibrated relative to gas viscosity. For boreholes where the gas composition results in a gas viscosity significantly different than air, the reported values will be in error. For example, GS-2 had a nominal gas viscosity of 157 micropoise during the first 24-hours of the experiment. The viscosity of air (at 25 C) is about 185 microposie, meaning the reported flow rate of gas was (185/157= 1.18) 18% lower than the actual flow rate.

2.5 Tracer Tests

In an effort to verify the calculated transit times, borehole tracer injection tests were conducted for each of the boreholes. These tests injected a gas mixture containing CO, CO2, CH4, and H2 into the borehole with the circulation system running. Throughout the experiments used to calculate the lag time, recirculation pumps were set to a flow rate of 4.0 L/min. The tracer gas was injected into the borehole at a rate of 1.0 L/min for a duration of 10 to 12 minutes.

The tracer concentration response had a dynamic behavior, indicating gas mixing within the gas boreholes and water traps. Detailed examination of the concentration profiles shows features such as concentration maxima, minima, and changes in inflection points of the concentration profiles. These features can be used as markers to calculate the time taken by gases to travel between the gas borehole and the instrumentation. While there is a slight difference between the travel time from the borehole to the instruments and the return time to the borehole, this difference is not significant relative to the average travel time. For simplicity, we will assume that the travel time is the same in both directions.

To calculate the lag time, each tracer concentration profile was divided into 7 segments (Figure 40-Example of tracer arrivals and the segmentation approach used to calculate lag times). The first segment corresponds to the increase in tracer concentrations observed during the injection period. Segments 2 through 6 represent the time it takes for the injected tracer gases to complete two travel loops. The maximum concentration observed at the junction between segments 2 and 3, as well as the concentration minima between segments 5 and 6, were used to estimate the travel time.

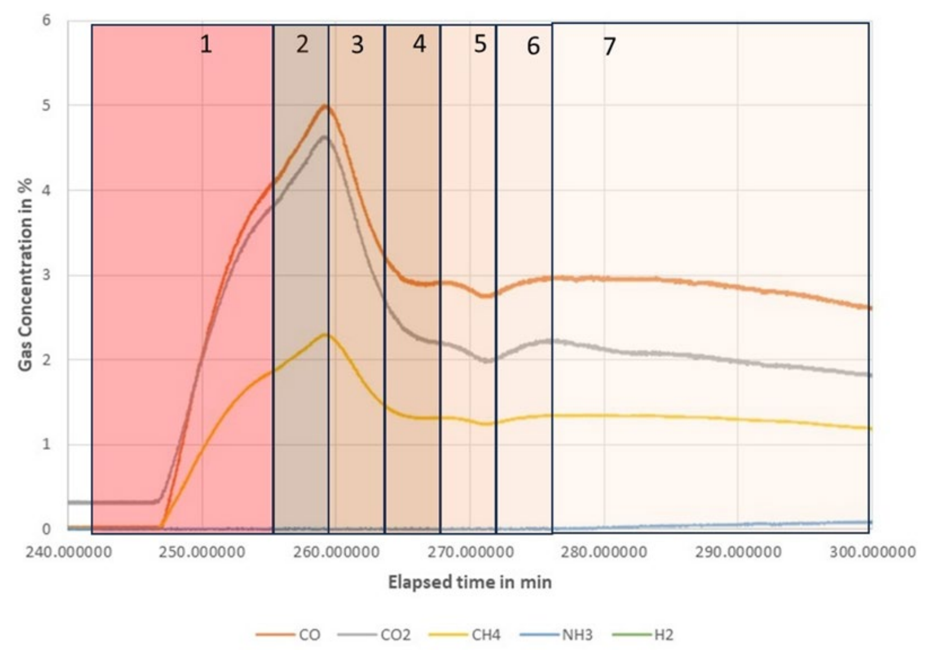


Figure 40. Example of tracer arrivals and the segmentation approach used to calculate lag times.

3.0 Results

The lag time (T_l) for gas moving between the formation (or the tunnel environment) to a detector was calculated according to Eq. 1 below. The lag time is the ratio of the system volume divided by the actual flow rate. The actual flow rate is the flow rate measured at STP adjusted to account for the system pressure. As an example, if the system pressure is 2 atmospheres, there is twice as much mass in the line as at 1 atm; therefore, it will take twice as long to remove all the mass from the line, making the actual flow rate ½ of the flow rate at STP.

Determination of the system volume is not straightforward. In particular, the way dead volumes (e.g. water traps) are addressed is somewhat complicated. Imagine a single gas molecule moving down the tubing; once that molecule reaches the water trap (or other dead volume) it could spend some moderate amount of time within the volume before being pushed out, or it could immediately leave the volume without any significant hold-up time. While the hold-up time for any one gas molecule would occur according to some probability distribution, here we simply treat the system volumes with a scale factor (f_v). For the calculated arrival times, three scale factors were considered; a fast arrival with the volume being treated as 1/10th of the true volume (f_v =0.1), a slow arrival where the volume is equal to the true volume (f_v =1) and a moderate arrival where the volume is assumed to be equal to half of the true volume (f_v =0.5). Different analyses might employe different scale factors; if the initial indication of detectable concentrations is desired, then assuming a small scale factor would be appropriate in calculating the lag time. On the other hand, if the time to achieve peak concentration is being investigated then a scale factor of 1 would be more appropriate. The equation for calculating lag time in the gas circulation system is:

$$T_l = \frac{[V_t + f_v(V_b + V_{T1} + V_{T2} + V_X)]}{R_S \frac{P_S}{P_f}} \quad \text{Eq. 1}$$

Where
V_t- total combined tubing volume
f_v- scale factor for the empty volumes (0 - 1)
V_b- volume of borehole
V_{T1}- volume of the large water trap near the collar
V_{T2}- volume of the small water trap in the circulation cabinet
V_x- volume of the xenon detector
R_s- recirculation rate at STP
P_s- standard pressure (1 atm)
P_f- pressure of the formation

While Equation 1 above provides the means for a user to calculate an arrival time using flow and pressure data from any specific point in time, a range of lag times were calculated for each borehole and tunnel environment sampling location (Table 16). These lag times were calculated for various time windows corresponding to changes in the flow rate set-point or formation pressure (Figure 41) and at three different volume scale factors. Additionally, the lag time to the xenon detector was calculated separately from the lag time associated with the HE Byproducts and grab sampler system (since gas had to move through the xenon system to get to the HE Byproducts system). Overall, the average calculated lag time between any borehole and either detector for all three scale factors was 5.4 minutes, with a standard deviation of 2.67 minutes. The maximum calculated lag time was 14.4 minutes and the minimum was 1.6 minutes, for a total range of just 12.8 minutes. Note that these calculated lag times do not account for any changes in the gas composition. It was determined that the relative impact of gas composition was much less than the uncertainty associated with the treatment of the water traps. For example, the borehole flowrate most impacted by the gas composition was GS-2 (Table 15). For GS-2, an 18% difference in the measured vs actual flow rate would result in a change in the estimated lag time (*f*=1) of 1.7 minutes. Compared to a greater than 7-minute difference in the estimated lag time using the fast and slow scale factors.

Table 15. Maximum estimated impact to the measured flow rate resulting from gas composition.

GS1	GS2	GS3	GS4	GS5	GS6	GS7	GS8
10%	18%	3%	15%	1%	15%	1%	5%

Depending on the desired fidelity of the analysis, a fixed lag time could be applied to all results, a borehole and time-window specific lag time could be selected from the table, or a point-in-time specific lag time could be calculated with corrections for the gas composition at the time of arrival. For the tunnel environment locations, since there were no changes in flow rate or pressure, minimal changes in composition, and no large water trap, the primary variation in the estimated lag time is associated with the treatment of the xenon detector.

It should be noted that the results presented here assume that the gas circulating system is operating before arrival in the formation. For GS-1 and GS-2, this is likely not the case. The formation was pressurized before the systems isolation valves were opened and circulation began. It is likely that the borehole sample volume, the water trap and at least some of the tubing run was filled with formation gas before circulation began. For very early arrivals subtraction of a lag time should be considered carefully.

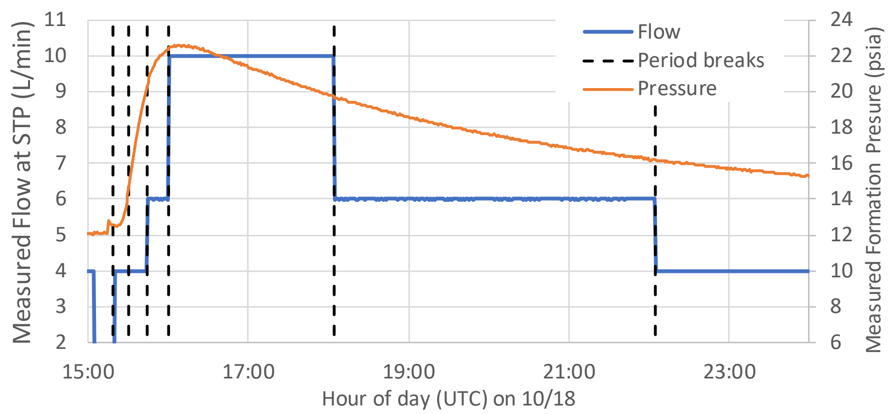


Figure 41. Example of breaks in calculated lag time periods for GS-1.

Table 16. Calculated lag times for boreholes and tunnel environment locations. Experiment ended on 11/14/23.

Interval Start	Interval End	Flow (L/min)	Press. (psia)	Lag Time (min): Xenon			Lag Time (min): HE		
				Fast	Med	Slow	Fast	Med	Slow
GS1									
10/18 15:15	10/18 15:19	0	12	0	0	0	0	0	0
10/18 15:19	10/18 15:30	4	13.5	3.1	4.9	7.1	3.2	5.7	8.8
10/18 15:30	10/18 15:44	4	17	3.9	6.1	9.0	4.1	7.2	11.1
10/18 15:44	10/18 16:00	6	20	3.0	4.8	7.0	3.2	5.7	8.7
10/18 16:00	10/18 18:04	10	22	2.0	3.2	4.6	2.1	3.7	5.8
10/18 18:04	10/18 19:30	6	19	2.9	4.6	6.7	3.0	5.4	8.3
10/18 19:30	10/18 22:05	6	17	2.6	4.1	6.0	2.7	4.8	7.4
10/18 22:05	10/19 5:00	4	15	3.4	5.4	7.9	3.6	6.4	9.8
10/19 5:00	10/20 0:00	4	13	3.0	4.7	6.9	3.1	5.5	8.5
10/20 0:00	11/14/23	4	12	2.7	4.3	6.3	2.9	5.1	7.9
GS2									

10/18 15:15	10/18 15:27	0	12	0	0	0	0	0	0
10/18 15:27	10/18 15:38	11	47	3.9	6.2	9.0	4.1	7.3	11.2
10/18 15:38	10/18 15:53	9	39	3.9	6.2	9.1	4.2	7.4	11.3
10/18 15:53	10/18 16:20	10	30	2.7	4.3	6.3	2.9	5.1	7.9
10/18 16:20	10/18 17:30	10	22	2.0	3.2	4.6	2.1	3.7	5.8
10/18 17:30	10/18 18:05	9.5	20	1.9	3.0	4.4	2.0	3.6	5.5
10/18 18:05	10/18 22:05	6	17	2.6	4.1	6.0	2.7	4.8	7.4
10/18 22:05	10/195:00	4	14	3.2	5.0	7.4	3.4	5.9	9.2
10/19 5:00	11/14/23	4	12	2.7	4.3	6.3	2.9	5.1	7.9
GS3									
10/18 15:15	10/18 15:19	0	12	0	0	0	0	0	0
10/18 15:19	10/18 16:13	4	12.5	2.8	4.4	6.5	2.9	5.2	8.1
10/18 16:13	10/18 16:44	5	15	2.7	4.3	6.3	2.8	5.0	7.8
10/18 16:44	10/18 17:18	6	17	2.5	4.0	5.9	2.7	4.8	7.4
10/18 17:18	10/18 18:03	10	18	1.6	2.6	3.8	1.7	3.0	4.7
10/18 18:03	10/18 22:03	6	18	2.7	4.3	6.3	2.8	5.0	7.8
10/18 22:03	10/18 22:47	4	16.5	3.7	5.9	8.6	3.9	6.9	10.7
10/18 22:47	10/19 3:28	6	15	2.2	3.6	5.2	2.3	4.2	6.5
10/19 3:28	10/19 15:25	6	14	2.1	3.3	4.9	2.2	3.9	6.1
10/19 15:25	11/14/23	4	12	2.7	4.3	6.3	2.8	5.0	7.8
GS4									
10/18 15:15	10/18 15:22	0	12	0	0	0	0	0	0
10/18 15:22	10/18 15:45	10	31	2.8	4.4	6.5	2.9	5.2	8.1
10/18 15:45	10/18 16:10	10	27.5	2.4	3.9	5.7	2.6	4.6	7.1
10/18 16:10	10/18 17:00	10	23	2.0	3.3	4.8	2.2	3.9	6.0
10/18 17:00	10/18 18:05	10	19	1.7	2.7	4.0	1.8	3.2	4.9
10/18 18:05	10/18 22:05	6	16	2.4	3.8	5.6	2.5	4.5	6.9
10/18 22:05	10/19 15:00	4	13.5	3.0	4.8	7.0	3.2	5.7	8.8
10/19 15:00	11/14/23	4	12	2.7	4.3	6.3	2.8	5.0	7.8
GS5									
10/18 15:15	10/18 15:18	0	12	0	0	0	0	0	0
10/18 15:18	10/18 17:00	4	12	2.9	6.1	10.0	3.1	6.8	11.5
10/18 17:00	10/18 21:34	4	13.5	3.3	6.8	11.3	3.5	7.7	13.0
10/18 21:34	10/18 22:14	6	14.7	2.4	5.0	8.2	2.5	5.6	9.4
10/18 22:14	10/19 5:00	4	14	3.4	7.1	11.7	3.6	8.0	13.5
10/19 5:00	10/19 15:00	4	13	3.2	6.6	10.8	3.4	7.4	12.5
10/19 15:00	11/14/23	4	12	2.9	6.1	10.0	3.1	6.8	11.5
GS6									
10/18 15:15	10/18 15:18	0	12	0	0	0	0	0	0
10/18 15:18	10/18 15:40	4	15	3.7	7.6	12.5	3.9	8.6	14.4
10/18 15:40	10/18 15:45	5	17	3.3	6.9	11.3	3.5	7.8	13.1
10/18 15:45	10/18 16:00	6	17.25	2.8	5.8	9.6	3.0	6.6	11.1
10/18 16:00	10/18 16:15	9.5	17.5	1.8	3.7	6.1	1.9	4.2	7.1
10/18 16:15	10/18 17:00	6	16.5	2.7	5.6	9.2	2.8	6.3	10.6
10/18 17:00	10/18 19:06	6	15.75	2.6	5.3	8.8	2.7	6.0	10.1
10/18 19:06	10/18 22:02	5	14.25	2.8	5.8	9.5	2.9	6.5	11.0
10/18 22:02	10/19 3:00	4	13	3.2	6.6	10.8	3.4	7.4	12.5
10/19 3:00	11/14/23	4	12	2.9	6.1	10.0	3.1	6.8	11.5
GS7									
10/18 15:15	10/18 15:18	0	12	0	0	0	0	0	0
10/18 15:18	11/14/23	4	12	2.8	4.4	6.4	3.0	5.2	7.9
GS8									
10/18 15:15	10/18 15:18	0	12	0	0	0	0	0	0
10/18 15:18	10/18 15:52	4	12.5	2.9	4.6	6.7	3.1	5.4	8.3

10/18 15:52	10/18 16:43	4	13.5	3.2	5.0	7.2	3.3	5.8	8.9
10/18 16:43	10/18 22:05	5	13.9	2.6	4.1	5.9	2.7	4.8	7.4
10/18 22:05	10/19 15:05	4	13	3.0	4.8	6.9	3.2	5.6	8.6
10/19 15:05	11/14/23	4	12	2.8	4.4	6.4	3.0	5.2	7.9
Tunnel Environment									
TE1- Entire experiment		4	12	2.3	2.4	2.7	2.4	3.2	4.2
TE2- Entire experiment		4	12	1.1	1.3	1.5	1.3	2.0	3.0
TE3- Entire experiment		4	12	1.0	1.2	1.4	1.2	2.0	2.9

The results of the tracer test support the calculated lag times. The average lag time measured with the tracer test for each borehole was between the fast and average arrival times calculated at the tested conditions (Table 17). Overall, the scale factor that fit the tracer test data best was around 0.35. This factor should be considered if specific arrival time calculations are performed.

Table 17. Comparison of lag times (min) measured with the tracer test and calculated using Eq. 1.

Borehole	Tracer test	Calculated (f=0.1)	Calculated (f=0.5)	Calculated (f=1)
GS-1	4.16	2.9	5.1	7.9
GS-2	4.50	2.9	5.1	7.9
GS-3	4.02	2.8	5.0	7.8
GS-4	3.66	2.8	5.0	7.8
GS-5	3.54	3.1	6.8	11.5
GS-6	5.22	3.1	6.8	11.5
GS-7	4.11	3.0	5.2	7.9
GS-8	4.54	3.0	5.2	7.9

4.0 Conclusion

The information presented here provide a means for calculating the lag in arrival times measured by real-time and grab sampling systems for experiment PE-1A. The tracer data provides corroboration of the calculations and indicates a moderate scale factor to be most appropriate. While the data is presented with a 0.1 minute resolution, it is assumed that the accuracy in the calculated lag times is no better than +/- 1 minute.

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