Quarterly Report – Public Page

Date of Report: *5th Quarterly Report – December 20, 2024*
Contract Number: *# 693JK32310004POTA*
Prepared for: *DOT and Co-funders*
Project Title: Implement Fiber Optic Technology for Underground Gas Storage Well Monitoring
Prepared by: *Pipeline Research Council International, Inc.*
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For quarterly period ending: *December 31, 2024*

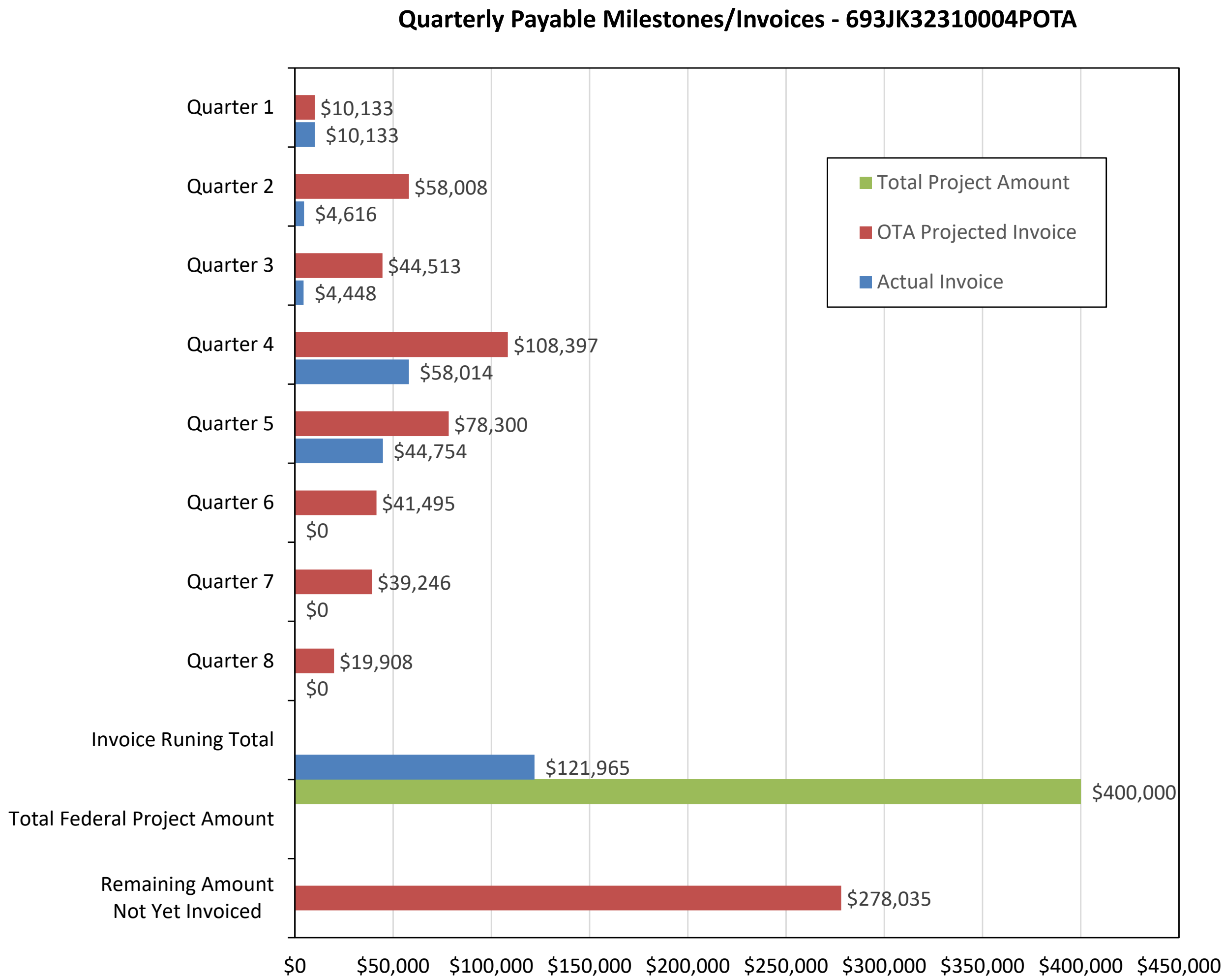
1: Items Completed During this Quarterly Period:

Item #	*Task #*	*Activity/Deliverable*	*Title*	*Federal Cost*	*Cost Share*
5	*2*	*Complete engineering design for DSS & DAS laboratory tests*	*Results to be included in the quarterly report*	*$40,065.00*	*$40,065.00*
12	*4*	*5th quarterly status report & project management*	*Submit 5th quarterly report*	*$4,689.00*	*$4,689.00*

2: Items Not Completed During this Quarterly Period:

Item #	*Task #*	*Activity/Deliverable*	*Title*	*Federal Cost*	*Cost Share*
7	*2*	*Setup and commission DSS laboratory test apparatus*	*Test setup description to be included in the quarterly report*	*$80,600.00*	*$80,600.00*
8	*2*	*Conduct DSS laboratory tests*	*Test execution summary to be included in the quarterly report*	*$23,175.00*	*$23,175.00*
10	*2*	*Setup and commission DAS laboratory test apparatus*	*Test setup description to be included in the quarterly report*	*$42,385.00*	*$42,385.00*
11	*2*	*Conduct DAS laboratory tests*	*Test execution summary to be included in the quarterly report*	*$31,226.00*	*$31,226.00*

3: Project Financial Tracking During this Quarterly Period:



4: Project Technical Status:

[Item #5] [Task #2] [Complete engineering design for DSS & DAS laboratory tests] [Results to be included in the quarterly report]

Engineering design for the DSS and DAS laboratory tests has been completed. Design drawings of all test setup components were prepared, and procurement has commenced. Detailed test plan and test matrix were also prepared. This task is completed.

[Item #12] [Task #4] [5th quarterly status report & project management] [Submit 5th quarterly report]

A quarterly Technical Advisory Panel (TAP) meeting was held on December 11th, 2024. The final engineering design for DSS & DAS laboratory tests was reviewed in the meeting. The overall project progress and future work plan for the next quarter were discussed with the TAP. This task is completed.

5: Project Schedule:

[Item #7] [Task #2] [Setup and commission DSS laboratory test apparatus] [Test setup description to be included in the quarterly report]

This task is currently delayed, and it's expected to be completed in the next quarter.

[Item #8] [Task #2] [Conduct DSS laboratory tests] [Test execution summary to be included in the quarterly report]

This task is currently delayed, and it's expected to be completed in the next quarter.

[Item #10] [Task #2] [Setup and commission DAS laboratory test apparatus] [Test setup description to be included in the quarterly report]

This task is currently delayed, and it's expected to be completed in the next quarter.

[Item #11] [Task #2] [Conduct DAS laboratory tests] [Test execution summary to be included in the quarterly report]

This task is currently delayed, and it's expected to be completed in the next quarter.

APPENDIX A – ENGINEERING DESIGN FOR DSS AND DAS LABORATORY TESTS

Item 5, Task 2: Complete engineering design for DSS and DAS laboratory tests

A.1. INTRODUCTION

One of the main tasks in this research program is to conduct full-scale laboratory tests to assess the technical capability of fibre optic cable (FOC) technologies for well monitoring in underground gas storage wells. Since the project team has deemed there to be sufficient evidence from numerous research studies and field tests regarding distributed temperature sensing (DTS) technologies for downhole monitoring, this research program is focused on addressing existing knowledge gaps in two key areas: 1) monitoring of casing strain and wellbore deformation using distributed strain sensing (DSS); and 2) sensing of gas leaks through the casing string and cement annulus using distributed acoustic sensing (DAS) deployed within the cement annulus.

Two separate test setups have been designed for DSS and DAS testing. Each test design includes a simulated wellbore with a cemented concentric pipe-in-pipe configuration, including an inner pipe with a 10.75-in outer diameter (OD) to represent the production casing and an outer pipe with a 16-in OD to represent the wellbore. Although the simulated wellbore is representative of a typical salt cavern well, it is expected that the test outcome will also be applicable for depleted reservoir wells, which typically have smaller casing sizes.

The test matrix for both DSS and DAS testing has also been developed. The test matrix consists of various simulated downhole events, including casing deformations for DSS testing and gas leaks for DAS testing. Note that, while the overall test matrix has been developed, the test parameters may be subject to further refinement or adjustment to maximize the outcome of this research program.

A.2. DSS TEST DESIGN

A.2.1 DSS Test Setup

The DSS test will be performed in C-FER's Tubular Testing System (TTS). This test will be used to evaluate the vendors' technologies on their ability to detect the strain profile in the simulated well assembly. A rendering of the test setup is shown in Figure A.1.

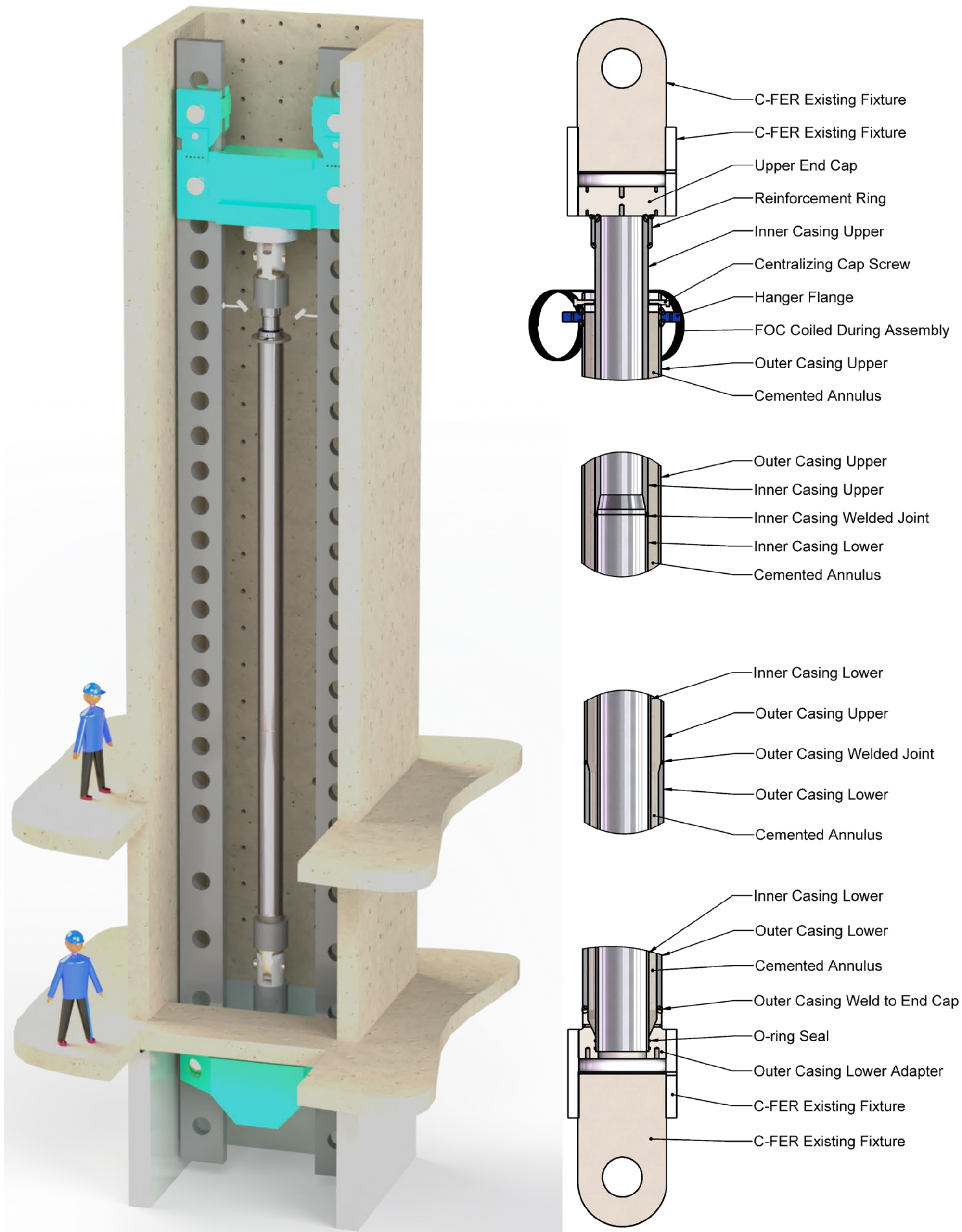


Figure A.1 Rendering of DSS Test Setup in TTS

Finite Element Analysis (FEA) has been performed to assist the DSS test setup design. In particular, the FEA results were used as a reference to choose the casing candidates and to help identify regions for reinforcement (to minimize weak regions that could fail under small load). In addition, the FEA results will also serve as a reference to determine the maximum load to be applied during testing, and to provide a reference to understand the axial strain distribution along the test assembly. Figure A.2 shows the FEA model and the predicted longitudinal strain distribution under an axial load of 1,496 kips. The corresponding relative axial displacement between the top and bottom flanges is 0.5-in.

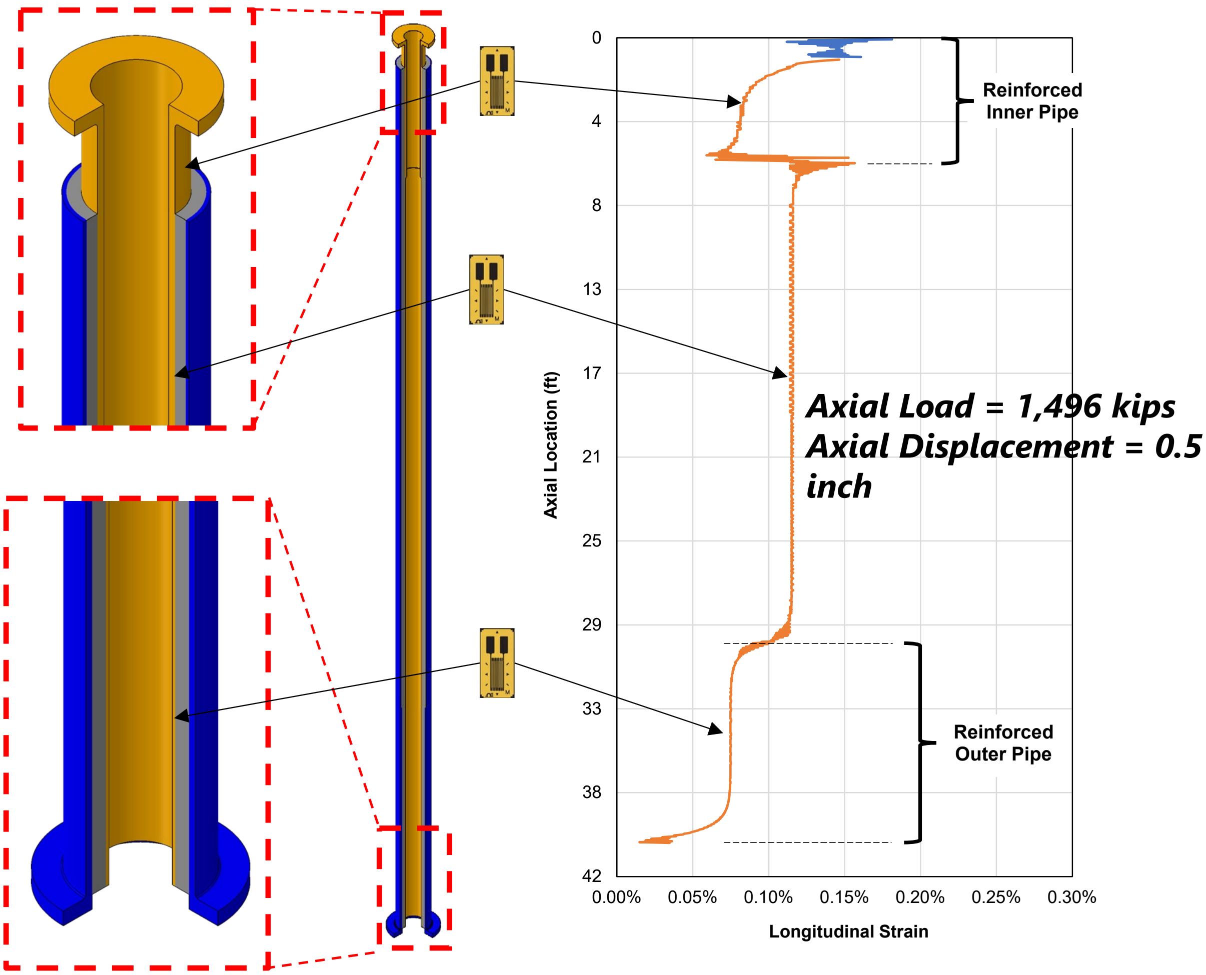


Figure A.2 FEA Model and Predicted Longitudinal Strain Distribution along the Inner Casing

Inner Casing Assembly

The inner casing assembly will be comprised of 10-in Schedule 60 pipe (Grade 359, 10.75-in OD x 0.5-in wall thickness (WT)) with a reinforced section near the top end of the assembly of 10in Schedule 160 pipe (Grade 359, 10.75-in OD x 1.125-in WT). The main purpose of the reinforced section is to increase the maximum load that the test can reach by strengthening the casing where it protrudes from the cemented anulus (the weakest point of the assembly).

Outer Casing Assembly

The outer casing assembly will be comprised of 16-in Schedule 40 pipe (Grade 359, 16-in OD x 0.5-in WT) with a reinforced section near the bottom end of the assembly of 16-in Schedule 100 pipe (Grade 359, 16-in OD x 1.031-in WT). The reinforced section will create a step-change in the anticipated strain profile of the assembly, as shown in Figure A.2. This feature will provide an opportunity to evaluate the ability of the DSS system to measure varying strain distribution along the test assembly.

End Caps

The upper end cap will be welded to the top of the reinforced section of the inner casing and will transmit tension loads from the TTS to the DSS test assembly. The lower end cap will be welded to the bottom of the reinforced section of the outer casing and will serve four main functions:

1. transmit tension loads from the TTS to the DSS test assembly;
2. centre the inner casing assembly within the outer casing assembly during cementing;
3. prevent cement leakage via a double O-ring seal; and
4. host pressurization ports to allow for integrity checks on the cement annulus before and during testing.

Cemented Annulus

Once the vendor DSS cables and strain gauges have been installed on the outer wall of the inner casing assembly, the inner casing will be lowered into the outer casing to form an annular gap. The annular gap will be filled with cement to create a bond between the inner and outer casings and to simulate cement/rock surrounding a typical well casing.

Strain Gauge Locations

Strain gauges will be attached to the outer wall of the inner casing (inside the cemented annulus) to provide a baseline measurement for the actual strain in the inner casing (ie, the simulated well casing). Strain gauge readings will provide both a comparison point for the DSS results and an improved understanding of the strains reached during testing for test monitoring and safety. Strain gauges will be included in each of the three main stress “regions” of the DSS assembly, including the reinforced inner pipe, the reinforced outer pipe, and the region in the center, as shown in Figure A.2.

Loading Fixtures

The assembly end caps have been designed to interface with existing TTS fixtures (couplers, padeyes, yokes) to allow the DSS test assembly to be mounted in the TTS load frame and to transmit tension loads from the TTS to the test assembly.

A.2.2 DSS Test Matrix

Table A.1 shows the test matrix for the DSS testing. The testing will be comprised of four different stages: integrity checks, dry run, cyclic testing, and limit load testing.

Test Step	No. of Cycles	Axial Load (kip)	Description
Integrity Check	-		Pressure test of cement seal integrity
Dry Run	-	250	Brief hold at each load step to confirm instrumentation
		500	
		750	
		1,000	
Integrity Check	-		Pressure test of cement seal integrity
Cyclic 1	50	1,000	Cycling between near 0 and 1,000 kip
Integrity Check	-		Pressure test of cement seal integrity
Cyclic 2	50	1,500	Cycling between near 0 and 1,500 kip
Integrity Check	-		Pressure test of cement seal integrity
Limit Load	-	TBD	Increase load to failure in 250 kip increments
Integrity Check	-		Pressure test of cement seal integrity

Table A.1 DSS Test Matrix

Integrity Checks

Integrity checks will be performed before the start of testing and repeated after each stage of testing to determine whether the hydraulic isolation of the cement annulus has been compromised. These will be performed by applying pressure to the bottom of the cemented annulus. A small volume of water will be poured on top of the cement annulus, as shown in Figure A.3. If bubbles form in the pool of water at the top of the annulus, it will indicate a continuous leak path through the cement.

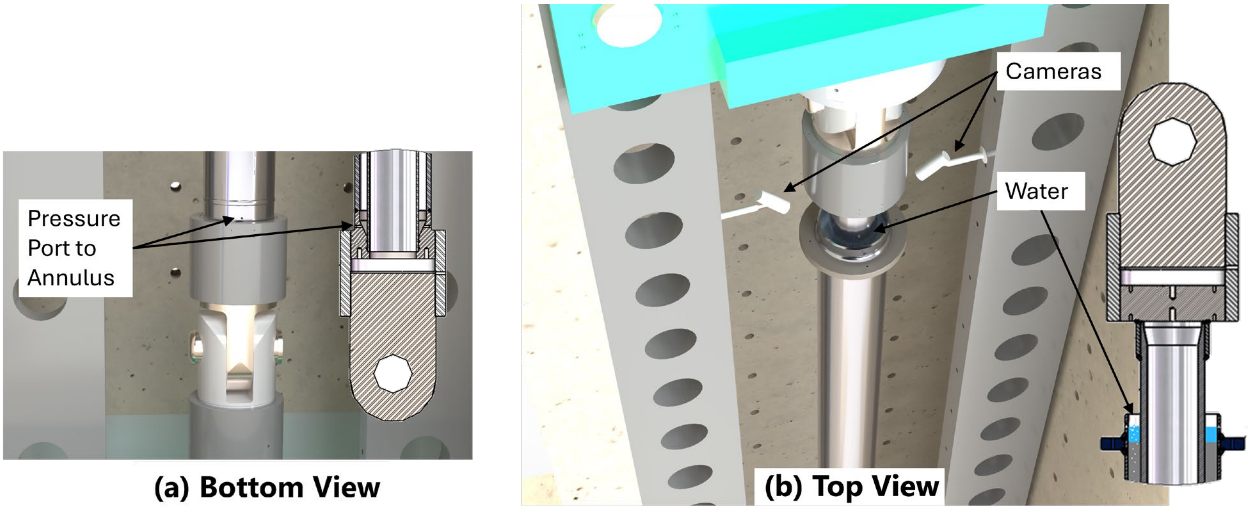


Figure A.3 DSS Cement Seal Integrity Test

Dry Run

The dry run will include a controlled increase in tensile load in steps of 250 kip to a load of 1,000 kip. At each step, there will be a short hold period to ensure that all instrumentation (including the DSS systems) is performing as expected. These will also provide a period of stable strains at each load step for comparison with the DSS vendor results.

Cyclic Testing

Cyclic testing will be performed to simulate cyclic progressive salt cavern roof subsidence under the pressure cycle operation condition of the cavern. The tensile load will be cycled between near-zero load up to 1,000 kip for 50 cycles. After performing an integrity check, an additional 50 cycles to a load of 1,500 kip will be performed to simulate more aggressive subsidence.

Limit Load Testing

The limit load testing will be used to determine at what load the fibre optic cables are compromised. This will involve increasing the tensile load in steps until a stopping criterion is met. The stopping criterion may include failure of the fibre optic cable, a target maximum load is reached, the structural integrity of the test pipes is compromised, or any other safety concerns are identified.

A.3. DAS TEST DESIGN

A.3.1 DAS Test Setup

The DAS test will be performed in C-FER's Deep Well Simulator (DWS). This test will be used to evaluate the vendors' technologies on their ability to detect various leaks in the simulated well assembly. A rendering of the test setup in the DWS is shown in Figure A.4.

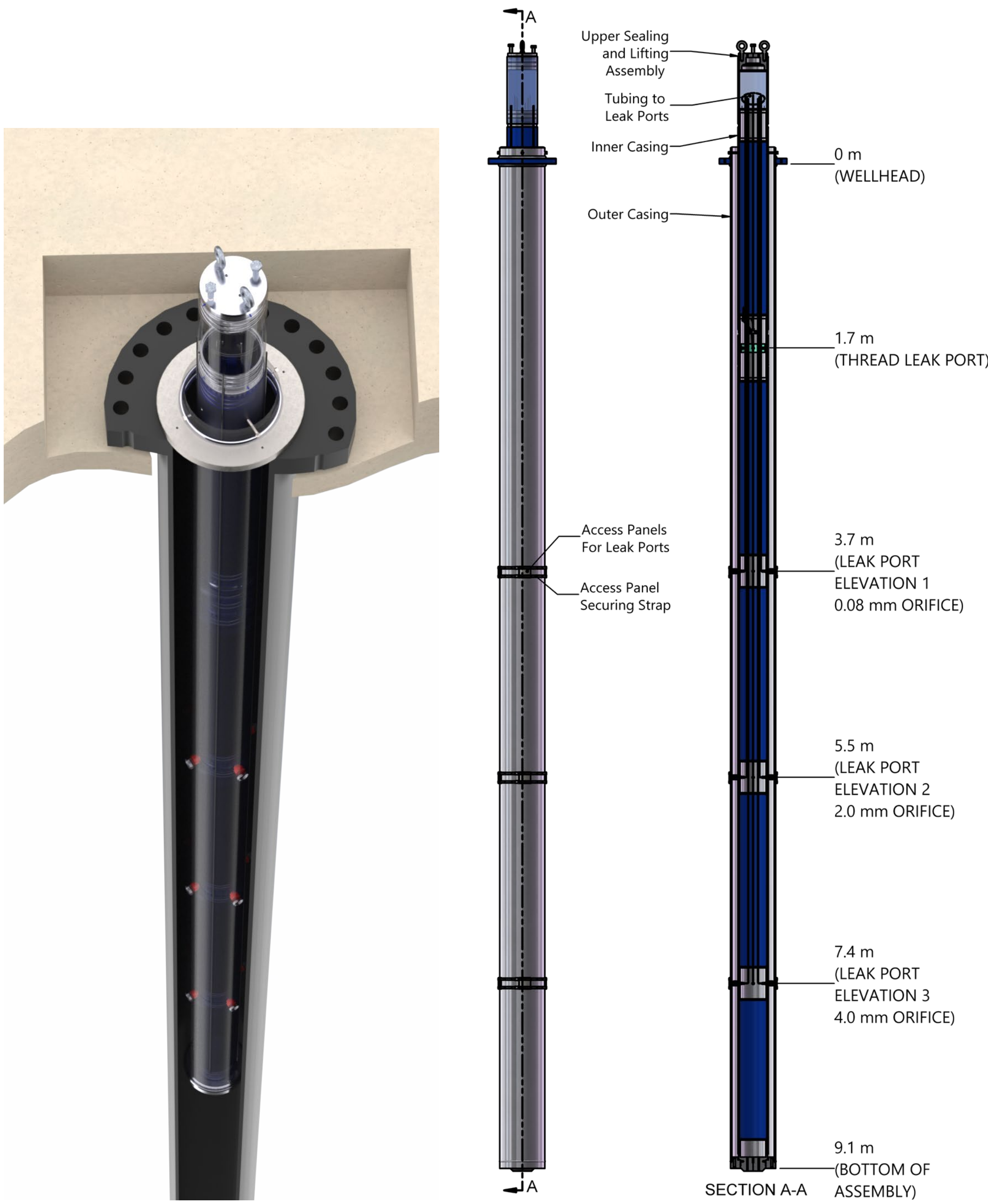


Figure A.4 Schematic of DAS Test Setup in DWS

Pressure Supply

Pressurized nitrogen gas will be used as the simulated leak source. The pressure of the gas will be controlled with a regulator and monitored with a pressure transducer throughout the testing.

This gas will be delivered through ¼-in stainless steel tubing to the designated leak ports.

Only one leak port will be tested at a time; therefore, an adjustable design has been completed to allow the pressure supply to be efficiently switched between the leak ports.

Pipe Alignment

The casing joints will be connected using threaded connections with O-ring seals. This design will allow each section of casing to be aligned with each other by adjusting the rotation to align the leak port housings, and the position will be fixed using set screws. This will ensure that all orifice leak port locations will be aligned down the entire assembly.

Micro Annulus

The micro annulus will be a gap created between the inner casing and cement prior to testing. This gap will measure only a few thousandths of an inch radially and will allow for movement of the gas from the leak ports through the cemented annulus.

To form the micro annulus, the inner casing will be pressurized during the cement curing stage. Once the cement is set, releasing the inner casing pressure would result in a radial shrinkage of the casing to create a micro annulus.

Orifice Leak Ports

The orifice leak ports have been designed to simulate pinhole leaks through the casing wall. Orifice leak ports will be stationed at three different depths, each with a different orifice size (0.8 mm, 2.0 mm, and 4.0 mm). Figure A.5 shows a rendering of the leak port design, Figure A.6 shows a schematic of the leak port installed in the inner casing, and Figure A.7 shows a cross-section of the inner casing.

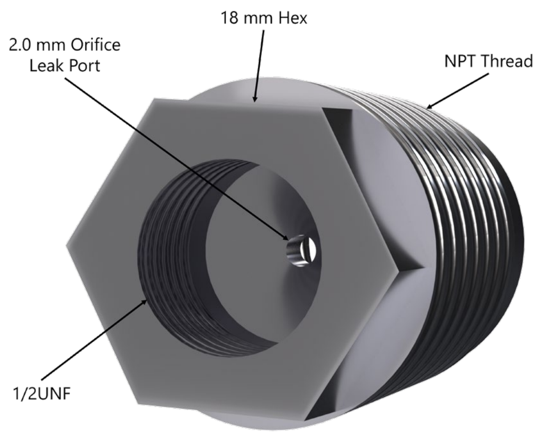


Figure A.5 Leak Port Insert

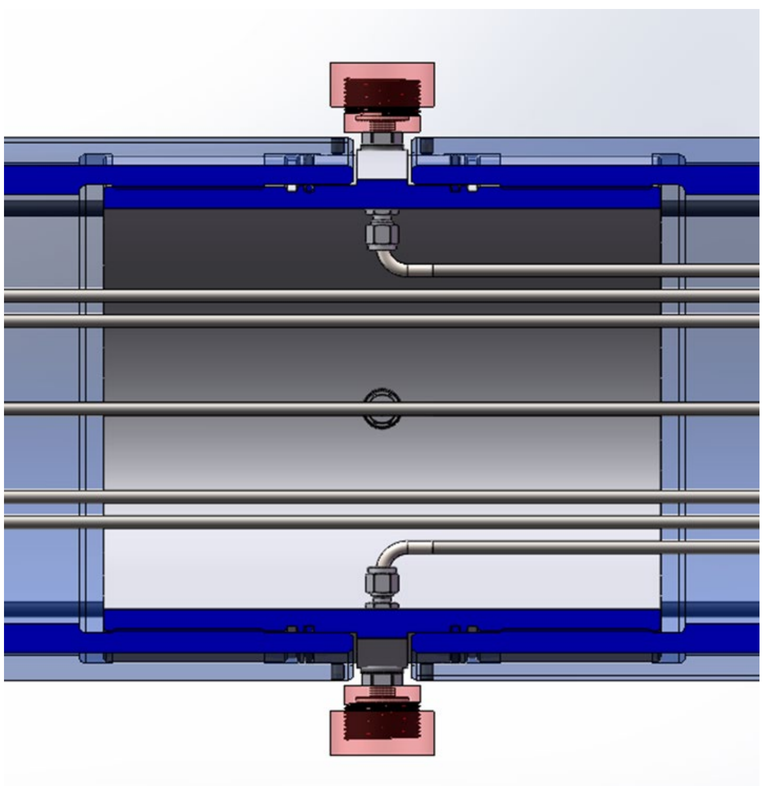


Figure A.6 Leak Port Schematic

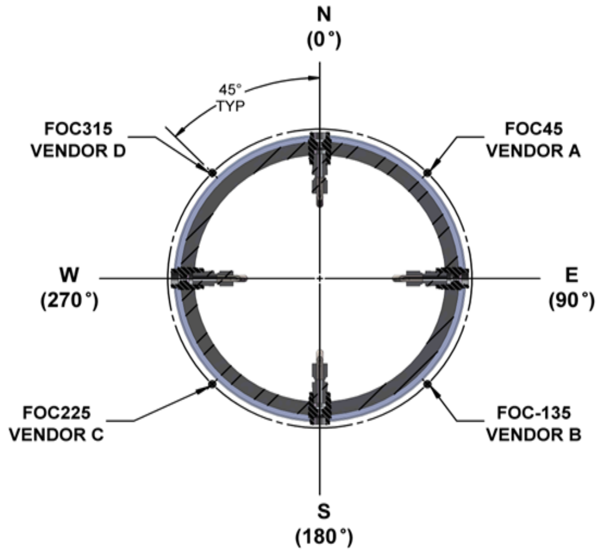


Figure A.7 Section View of Leak Port with FOC Locations

Each port will leak into a small cavity between the inner and outer casings created during the assembly process. The micro annulus created between the inner casing and the cement will allow the gas to flow through cement annulus.

To ensure that the leak ports remain open during cementing, a temporary plug will be placed in each orifice. After the cement is cured, the temporary plugs will be removed, resulting in a small cavity outside of the leak port. Figure A.8 shows a schematic of the leak port assembly including the temporary plugs. To access the leak ports from outside the outer casing, access ports are cut into the outer casing. After the temporary plugs are removed, the access port will be covered and sealed prior to testing. Figure A.9 shows an exploded view of the leak port temporary plugs, along with the cover for the access ports.

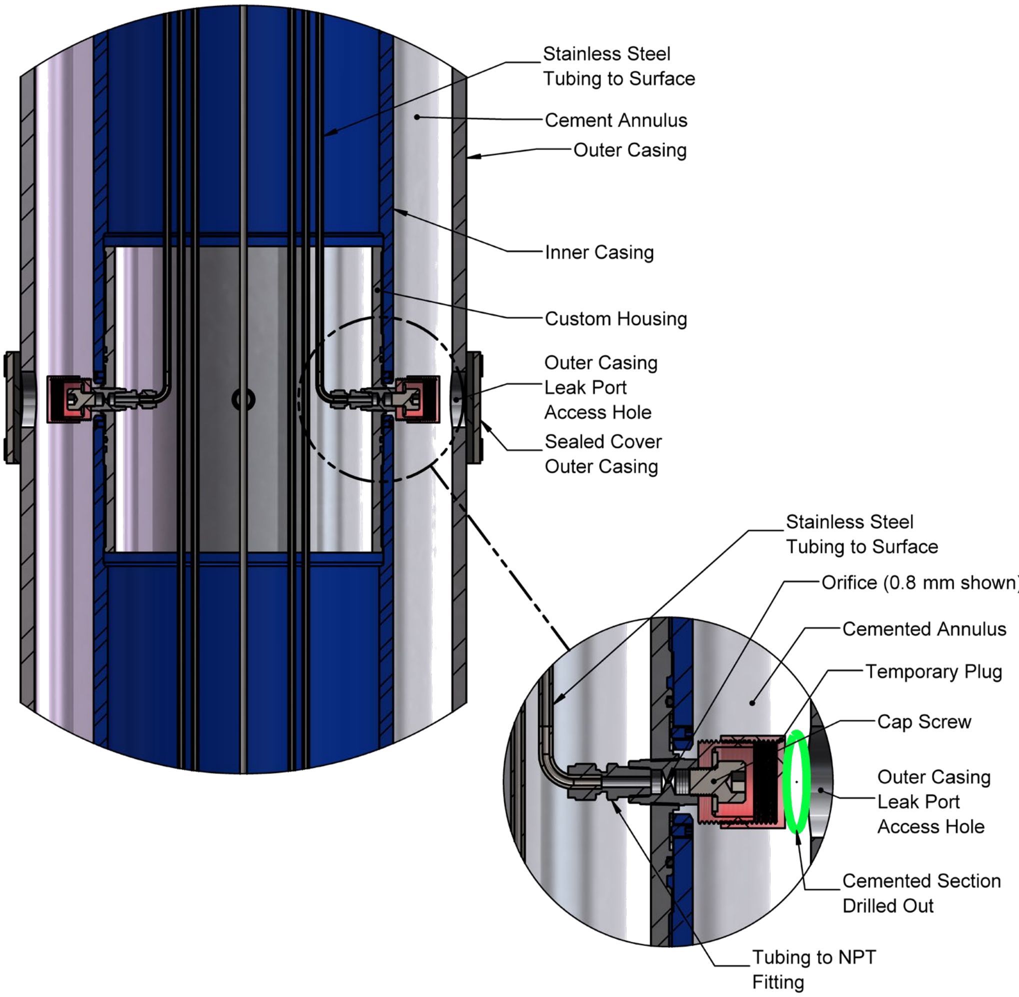


Figure A.8 Leak Port Section View

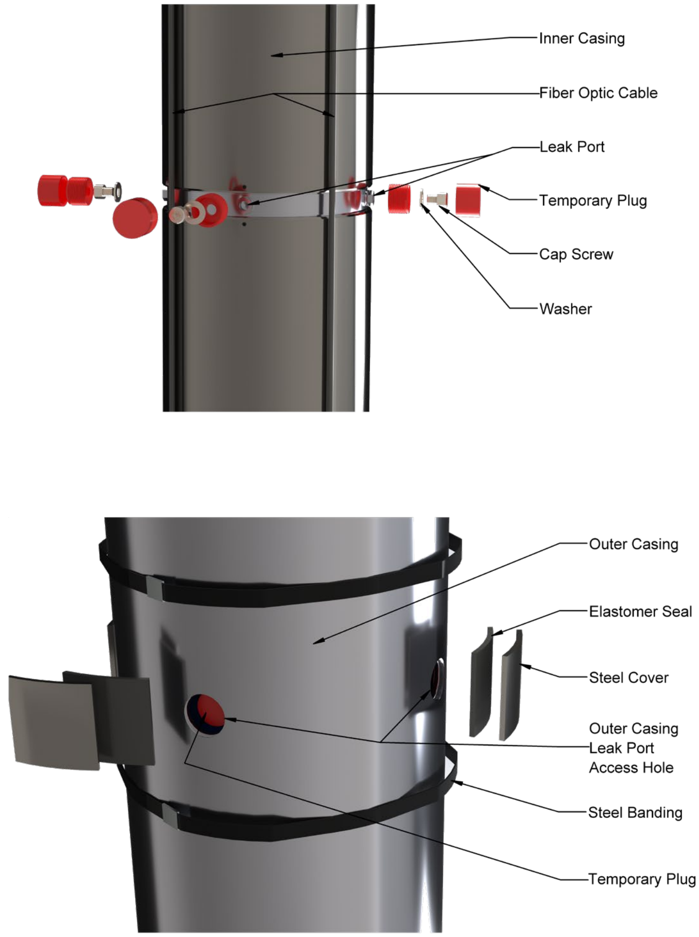


Figure A.9 Leak Port Temporary Plug and Access Port Schematic

Threaded Connection Leak Port

The threaded connection leak port will be comprised of a singular threaded connection that will be allowed to leak directly into the small cavity created by the micro annulus. This leak port will be controlled by a singular tube section at the top of the assembly, but the gas will be split into four different sections before being inserted into the leak ring. This will ensure a uniform leak is created around the entire diameter of the pipe.

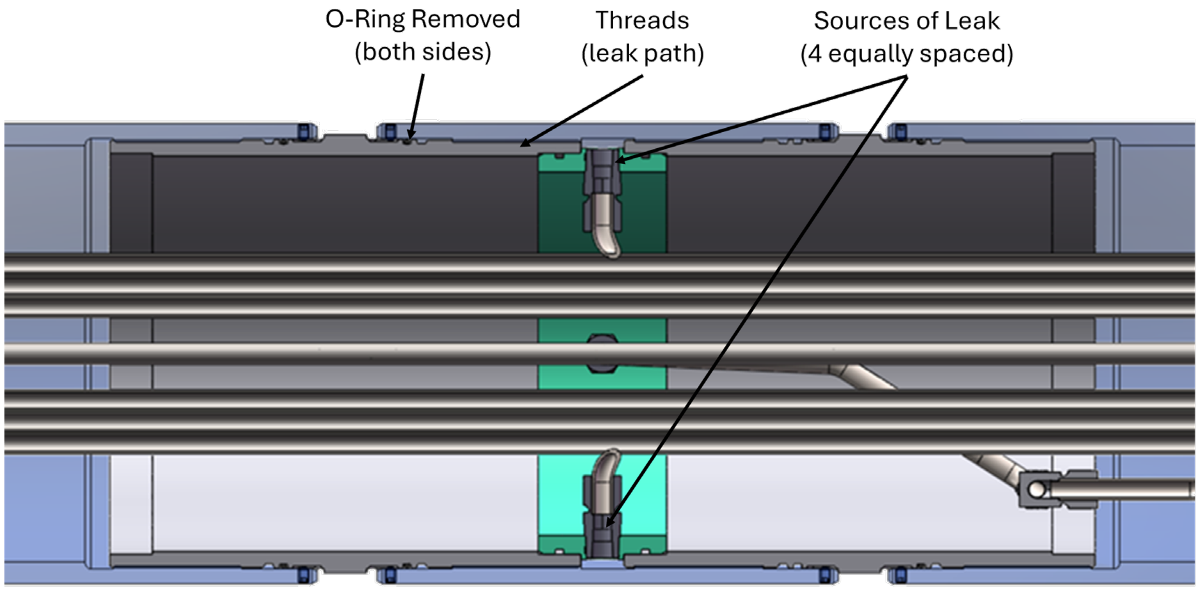


Figure A.10 Section View of Thread Leak Port

<u>Overall Assembly Alignment</u>

The inner and outer casings will be aligned using two separate features. The bottom housing will centralize the lower end of the inner casing when it is fitted into the outer casing. The top of the inner casing will be located using fully threaded bolts and centralizing ports.

A.3.2 DAS Test Matrix

Table A.2 shows the test matrix for the DAS testing, which is comprised of several variables. There will be three different orifice diameters (0.8 mm, 2.0 mm, and 4.0 mm), along with the thread leak, for a total of four different leak geometries. Testing will be performed at four different pressures to achieve a range of release flow rates. Additionally, for each of the orifice sizes, there will be four release orientations. With a total of up to four FOC locations positioned midway between release ports, this will result in two angular offsets between the release orientation and the FOC location. The test matrix also provides two similar releases for each set of parameters, which provides some redundancy in the event of a leak port becoming clogged. As with the DSS testing, as the testing progresses, the DAS vendors will be consulted to verify that their systems are responding to the testing and to determine if adjustments to the test parameters may be needed to obtain the most value from the testing.

					Angular Offsets From Release to FOC			
Event Number	Orifice Diameter (mm)	Release Pressure (psi)	Orientation (degrees)	Orientation (NESW)	FOC45 Angle from Release	FOC135 Angle from Release2	FOC225 Angle from Release3	FOC315 Angle from Release4
1	Thread	50	All	All	#N/A	#N/A	#N/A	#N/A
2	Thread	50	All	All	#N/A	#N/A	#N/A	#N/A
3	Thread	250	All	All	#N/A	#N/A	#N/A	#N/A
4	Thread	250	All	All	#N/A	#N/A	#N/A	#N/A
5	Thread	500	All	All	#N/A	#N/A	#N/A	#N/A
6	Thread	500	All	All	#N/A	#N/A	#N/A	#N/A
7	Thread	1,000	All	All	#N/A	#N/A	#N/A	#N/A
8	Thread	1,000	All	All	#N/A	#N/A	#N/A	#N/A
9	0.80	50	0	N	45	135	135	45
10	0.80	50	90	E	45	45	135	135
11	0.80	50	180	S	135	45	45	135
12	0.80	50	270	W	135	135	45	45
13	0.80	250	0	N	45	135	135	45
14	0.80	250	90	E	45	45	135	135
15	0.80	250	180	S	135	45	45	135
16	0.80	250	270	W	135	135	45	45
17	0.80	500	0	N	45	135	135	45
18	0.80	500	90	E	45	45	135	135
19	0.80	500	180	S	135	45	45	135
20	0.80	500	270	W	135	135	45	45
21	0.80	1,000	0	N	45	135	135	45
22	0.80	1,000	90	E	45	45	135	135
23	0.80	1,000	180	S	135	45	45	135
24	0.80	1,000	270	W	135	135	45	45
25	2.00	50	0	N	45	135	135	45
26	2.00	50	90	E	45	45	135	135
27	2.00	50	180	S	135	45	45	135
28	2.00	50	270	W	135	135	45	45
29	2.00	250	0	N	45	135	135	45
30	2.00	250	90	E	45	45	135	135
31	2.00	250	180	S	135	45	45	135
32	2.00	250	270	W	135	135	45	45
33	2.00	500	0	N	45	135	135	45
34	2.00	500	90	E	45	45	135	135
35	2.00	500	180	S	135	45	45	135
36	2.00	500	270	W	135	135	45	45
37	2.00	1,000	0	N	45	135	135	45
38	2.00	1,000	90	E	45	45	135	135
39	2.00	1,000	180	S	135	45	45	135
40	2.00	1,000	270	W	135	135	45	45
41	4.00	50	0	N	45	135	135	45
42	4.00	50	90	E	45	45	135	135
43	4.00	50	180	S	135	45	45	135
44	4.00	50	270	W	135	135	45	45
45	4.00	250	0	N	45	135	135	45
46	4.00	250	90	E	45	45	135	135
47	4.00	250	180	S	135	45	45	135
48	4.00	250	270	W	135	135	45	45
49	4.00	500	0	N	45	135	135	45
50	4.00	500	90	E	45	45	135	135
51	4.00	500	180	S	135	45	45	135
52	4.00	500	270	W	135	135	45	45
53	4.00	1,000	0	N	45	135	135	45
54	4.00	1,000	90	E	45	45	135	135
55	4.00	1,000	180	S	135	45	45	135
56	4.00	1,000	270	W	135	135	45	45

Table A.2 DAS Test Matrix