# Cryogenic Orbital Test Bed 3 (CRYOTE3)!

## Overview and Status"


| NASA MSFC" | NASA KSC" | NASA AFRC" | ULA" | a.i. solutions" | Yetispace" |
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October 29, 2015!

# CRYOTE3 Overview!

*CRYOTE3 is a grassroots CFM test effort with contributing government and industry partners focused on developing and testing hardware to produce needed data for model validation and implementation into flight systems. !*

- Tank: Centaur-derived, provided by ULA!
  - ULA built tank at Decatur using a modified Centaur process.!
  - Support adaptors and lifting fixture also supplied.!
- Integration: KSC LSP funded effort!
  - Yetispace is designing and fabricating tank support structure, fluid control, instrumentation, and thermal protection.!
  - SAA with ULA covering hardware and interactions.!
- Testing: MSFC and KSC!
  - Initial testing in atmosphere using LN2 as test fluid will take place near TS300 at MSFC in Fall/Winter 2015. !
  - Follow-on testing in atmosphere using LH2 test fluid at MSFC is also funded.!
  - Possible future activities include testing in vacuum at the MSFC TS300 20' Vacuum Chamber.!

# Previous Experience

- ER24 / Yetispace have completed multiple collaborative, grassroots test programs over the last five years, providing experience and background necessary for success in the CRYOTE3 work.!
  - *CRYOTE1!*
    - *Initiated by ULA, the CRYOTE1 test was conducted by ER24 / Yetispace at MSFC in the PRDL ESTF vacuum chamber.  The test article was assembled at IES in California and insulated at KSC.  Once completed, CRYOTE1 was shipped to MSFC and testing was completed in 2012. !*
  - *VATA!*
    - *Originally part of the CPST Technology Maturation program, VATA was intended to structurally evaluate an integrated BAC shield and MLI system applied to a cryo tank.  VATA has since been used for extensive insulation evaluations with LN2 test fluid.!*
  - *Tank-to-Tank Transfer!*
    - *The VATA and CRYOTE1 tanks are currently installed in the ESTF vacuum chamber for tank-to-tank transfer testing with VATA serving as storage tank and CRYOTE1 serving as receiver tank.  Numerous configurations and processes have been tested to date to better understand no-vent fill operations between cryogenic tanks in vacuum.  !*

# CRYOTE3 Test Objectives

- **GTO 0  Tank and Purge-Bag Purge"**
  - Remove all air and water in and around the CRYOTE3 tank prior to testing!
- **GTO 1  Vented Fill"**
  - Chill and fill CRYOTE3 tank!
  - Provide data that could be used to validate transient loading models!
- **GTO 2  Storage"**
  - Determine heating rate to tank by recording boiloff rate via load cells!
  - Determine thermal stratification inside CRYOTE3 tank via temperature rakes!
- **GTO 3  Bubble Volume"**
  - Pressurize and vent the tank to subcool/saturate LN2 and determine associated bubble volumes and emergence time after lock-up!
  - Determine bubble volume and time for bubbles to develop and emerge!
- **GTO 4  Stratification During Rapid Drain"**
  - Measure mass flow rate of gaseous nitrogen and helium required to achieve pressurization target!
  - Measure LN2 stratification profile (thickness, gradient) in tank and outflow when draining to depletion!
  - Drain tank to depletion while maintaining ullage pressure!
- **GTO 5  Fiber-Optics Sensing System (FOSS) Operation"**
  - Validate FOSS application in actual tank system (steady state and transient)!
    - Temperature mapping of liquid, ullage, tank wall, and insulation!
    - Strain mapping of tank and support structure!
    - Liquid level sensing!

# CRYOTE3 LN2 and LH2 Test Matrices

- Three LN2 tests are planned to take place at the MSFC East Test Area. Each test will use a different method of pressurization during draining:
  1. Gaseous Nitrogen (GN2) delivered through the diffuser on the tank forward end.
  2. Gaseous Helium (GHe) delivered through the diffuser on the tank forward end.
  3. GHe delivered through the bubbler on the tank aft end.
- Two LH2 tests are planned to take place at the MSFC East Test Area. Each test will use a different method of pressurization during draining:
  1. Gaseous Hydrogen (GH2) delivered through the diffuser on the tank forward end.
  2. Gaseous Helium (GHe) delivered through the diffuser on the tank forward end.
- Each test will incorporate the following phases:
  – Fill purge bag surrounding tank
  – Tank chill and fill
  – Steady-state boil-off measurement
  – Bubble volume evaluation
  – Pressurization and rapid drain in two phases:
    - Drain to 50%, measure stratification during drain
    - Recondition tank contents to atmospheric pressure
    - Drain to 0%, measure stratification during drain

# MSFC LN2 Test Matrix: Testing at Atmospheric Conditions

| | Purge | Chill/Fill | Steady-State Boil-Off | Bubble Volume | Press / Drain to 50% | Vent | Press / Drain to 0% |
|---|---|---|---|---|---|---|---|
| **TEST 1:** GN2 Press Through Forward End Diffuser | **Flow Rate:** *5 scfm cross-country GN2 delivered to tank and purge bag*<br><br>**Purge Prior to Chill/Fill:** *12 hours* | **Pressure:** *vent to atmosphere*<br><br>**Fill Rate:** *72 gpm* | **Pressure:** *vent to atmosphere*<br><br>***Top-off:*** *top-off LN2 level to full before proceeding to Bubble Volume* | **Press. Sequence:**<br>*-vent to atmosphere*<br>*-rapid GN2 press. to 5 psig*<br>*-tank self press. to 15 psig*<br>*-vent to atmosphere* | **Pressure:** *≤30 psig with GN2 through diffuser*<br><br>**Drain Rate:** *target 200 gpm (TBR)* | **Press. Sequence:**<br>*-vent to atmosphere*<br>*-allow tank contents to recondition* | **Pressure:** *≤30 psig with GN2 through diffuser*<br><br>**Drain Rate:** *target 200 gpm (TBR)* |
| **TEST 2:** GHe Press Through Forward End Diffuser | **Flow Rate:** *5 scfm cross-country GN2 delivered to tank and purge bag*<br><br>**Purge Prior to Chill/Fill:** *12 hours* | **Pressure:** *vent to atmosphere*<br><br>**Fill Rate:** *72 gpm* | **Pressure:** *vent to atmosphere*<br><br>***Top-off:*** *top-off LN2 level to full before proceeding to Bubble Volume* | **Press. Sequence:**<br>*-vent to atmosphere*<br>*-rapid GHe press. to 5 psig*<br>*-tank self press. to 15 psig*<br>*-vent to atmosphere* | **Pressure:** *≤30 psig with GHe through diffuser*<br><br>**Drain Rate:** *target 200 gpm (TBR)* | **Press. Sequence:**<br>*-vent to atmosphere*<br>*-allow tank contents to recondition* | **Pressure:** *≤30 psig with GHe through diffuser*<br><br>**Drain Rate:** *target 200 gpm (TBR)* |
| **TEST 3:** GHe Press Through Aft End Bubbler | **Flow Rate:** *5 scfm cross-country GN2 delivered to tank and purge bag*<br><br>**Purge Prior to Chill/Fill:** *12 hours* | **Pressure:** *vent to atmosphere*<br><br>**Fill Rate:** *72 gpm* | **Pressure:** *vent to atmosphere*<br><br>***Top-off:*** *top-off LN2 level to full before proceeding to Bubble Volume* | **Press. Sequence:**<br>*-vent to atmosphere*<br>*-rapid GHe press. to 5 psig*<br>*-tank self press. to 15 psig*<br>*-vent to atmosphere* | **Pressure:** *≤30 psig with GHe through aft bubbler*<br><br>**Drain Rate:** *target 200 gpm (TBR)* | **Press. Sequence:**<br>*-vent to atmosphere*<br>*-allow tank contents to recondition* | **Pressure:** *≤30 psig with GHe through aft bubbler*<br><br>**Drain Rate:** *target 200 gpm (TBR)* |
| | *12 hours* | *2 hours* | *1 hour* | *1 hour* | *6 minutes* | *10 minutes* | *6 minutes* |

# MSFC LN2 Test Matrix: Test 1*

*Pressurization with GN2 through forward end diffuser.*

| | Purge | Chill / Fill | Steady-State Boil-Off | Bubble Volume | Press / Drain to 50% | Vent | Press / Drain to 0% |
|---|---|---|---|---|---|---|---|
| **Objective** | Fill tank and purge bag with GN2 to avoid condensation and frost on the tank after LN2 fill. | Fill tank to 95% with LN2. | Measure heat load to CRYOTE3 system. | Evaluate bubble volume in ground-hold environment. | Pressurize tank with GN2 through diffuser and drain liquid to 50%; measure fluid strat. during drain. | Vent tank to atmosphere and recondition tank contents for desired condition prior to final drain. | Pressurize tank with GN2 through diffuser and drain liquid to 0%; measure fluid strat. during drain. |
| **Key Details** | Flow Rate: 5 scfm to tank and purge bag<br><br>Purge Prior to Chill/ Fill: 12 hours | Pressure: vent to atmosphere<br><br>Fill Rate: 72 gpm | Pressure: vent to atmosphere | Press. Sequence:<br>-vent to atmosphere<br>-rapid GN2 press. to 5 psig<br>-tank self press. to 15 psig<br>-vent to atmosphere | Pressure: 30 psig with GN2 through diffuser<br><br>Drain Rate: facility max (~200 gpm) | Press. Sequence:<br>-vent to atmosphere<br>-allow tank contents to recondition | Pressure: 30 psig with GN2 through diffuser<br><br>Drain Rate: facility max (~200 gpm) |
| **Key Measurements** | Flow rates: purge bag inlet flowmeter and tank vent flowmeter<br>Purge bag temp: thermocouples at inlet, outlet, interior<br>Humidity level in purge bag: humidity sensor at purge bag exit | Liquid level: diode rake and FOSS<br>Percent full: load cells<br>Pressure: ullage pressure transducer<br>Fill rate: fill line flowmeter<br>Temperature of liquid, ullage and vented gas: diode rake, FOSS, vent SD | Boil-off rate: calculated using load cell, ullage vent temp, ullage pressure data<br>Fluid stratification: diode rake and FOSS<br>Purge bag temp: thermocouples at inlet, outlet, interior | Liquid level height and appearance: borescope, with footage before, during and after shutting vent valve<br>Liquid level: diode rake and FOSS<br>Percent full: load cells | Liquid level, fluid stratification: diode rake and FOSS<br>Percent full: load cells<br>Pressurization: press line pressure transducer, SD, FM<br>Drain rate: drain line flowmeter, temperature, and pressure | Boil-off rate: calculated using load cell, ullage temp, and ullage pressure data<br>Fluid stratification: diode rake and FOSS<br>Purge bag temp: thermocouples at inlet, outlet, interior | Liquid level, fluid stratification: diode rake and FOSS<br>Percent full: load cells<br>Pressurization: press line pressure transducer, SD, FM<br>Drain rate: drain line flowmeter, temperature, and pressure |
| **Data Rate** | every 10 minutes | 25 Hz | 25 Hz | 25 Hz | 25 Hz | 25 Hz | 25 Hz |
| | *12 hours* | *2 hours* | *1 hour* | *2 hours* | *15 minutes* | *10 minutes* | *15 minutes* |

*Checkout test?

# MSFC LN2 Test Matrix:  Test 2

*Pressurization with helium through forward end diffuser.*

| | Purge | Chill / Fill | Steady-State Boil-Off | Bubble Volume | Press / Drain to 50% | Vent | Press / Drain to 0% |
|---|---|---|---|---|---|---|---|
| **Objective** | Fill tank and purge bag with GN2 to avoid condensation and frost on the tank after LN2 fill. | Fill tank to 95% with LN2. | Measure heat load to CRYOTE3 system. | Evaluate bubble volume in ground-hold environment. | Pressurize tank with GHe through diffuser and drain liquid to 50%; measure fluid strat. during drain. | Vent tank to atmosphere and recondition tank contents for desired condition prior to final drain. | Pressurize tank with GHe through diffuser and drain liquid to 0%; measure fluid strat. during drain. |
| **Key Details** | Flow Rate:  5 scfm to tank and purge bag<br><br>Purge Prior to Chill/ Fill:  12 hours | Pressure:  vent to atmosphere<br><br>Fill Rate:  72 gpm | Pressure:  vent to atmosphere | Press. Sequence:<br>-vent to atmosphere<br>-rapid GN2 press. to 5 psig<br>-tank self press. to 15 psig<br>-vent to atmosphere | Pressure:  30 psig with GHe through diffuser<br><br>Drain Rate:  facility max (~200 gpm) | Press. Sequence:<br>-vent to atmosphere<br>-allow tank contents to recondition | Pressure:  30 psig with GHe through diffuser<br><br>Drain Rate:  facility max (~200 gpm) |
| **Key Measurements** | Flow rates:  purge bag inlet flowmeter and tank vent flowmeter<br>Purge bag temp: thermocouples at inlet, outlet, interior<br>Humidity level in purge bag: humidity sensor at purge bag exit | Liquid level: diode rake and FOSS<br>Percent full: load cells<br>Pressure: ullage pressure transducer<br>Fill rate:  fill line flowmeter<br>Temperature of liquid, ullage and vented gas:  diode rake, FOSS, vent SD | - Boil-off rate: calculated using load cell, ullage vent temp, ullage pressure data<br>- Fluid stratification: diode rake and FOSS<br>- Purge bag temp: thermocouples at inlet, outlet, interior | - Liquid level height and appearance: borescope, with footage before, during and after shutting vent valve<br>- Liquid level: diode rake and FOSS<br>- Percent full: load cells | - Liquid level, fluid stratification: diode rake and FOSS<br>- Percent full: load cells<br>- Pressurization: press line pressure transducer, SD, FM<br>- Drain rate: drain line flowmeter, temperature, and pressure | - Boil-off rate: calculated using load cell, ullage temp, and ullage pressure data<br>- Fluid stratification: diode rake and FOSS<br>- Purge bag temp: thermocouples at inlet, outlet, interior | - Liquid level, fluid stratification: diode rake and FOSS<br>- Percent full: load cells<br>- Pressurization: press line pressure transducer, SD, FM<br>- Drain rate: drain line flowmeter, temperature, and pressure |
| **Data Rate** | every 10 minutes | 25 Hz | 25 Hz | 25 Hz | 25 Hz | 25 Hz | 25 Hz |
| | *12 hours* | *2 hours* | *1 hour* | *2 hours* | *15 minutes* | *10 minutes* | *15 minutes* |

# MSFC LN2 Test Matrix: Test 3

*Pressurization with helium through aft end bubbler.*

| | Purge | Chill / Fill | Steady-State Boil-Off | Bubble Volume | Press / Drain to 50% | Vent | Press / Drain to 0% |
|---|---|---|---|---|---|---|---|
| **Objective** | Fill tank and purge bag with GN2 to avoid condensation and frost on the tank after LN2 fill. | Fill tank to 95% with LN2. | Measure heat load to CRYOTE3 system. | Evaluate bubble volume in ground-hold environment. | Pressurize tank with GHe though bubbler and drain liquid to 50%; measure fluid strat. during drain. | Vent tank to atmosphere and recondition tank contents for desired condition prior to final drain. | Pressurize tank with GHe though bubbler and drain liquid to 0%; measure fluid strat. during drain. |
| **Key Details** | Flow Rate: 5 scfm to tank and purge bag<br><br>Purge Prior to Chill/ Fill: 12 hours | Pressure: vent to atmosphere<br><br>Fill Rate: 72 gpm | Pressure: vent to atmosphere | Press. Sequence:<br>-vent to atmosphere<br>-rapid GN2 press. to 5 psig<br>-tank self press. to 15 psig<br>-vent to atmosphere | Pressure: 30 psig with GHe through bubbler<br><br>Drain Rate: facility max (~200 gpm) | Press. Sequence:<br>-vent to atmosphere<br>-allow tank contents to recondition | Pressure: 30 psig with GHe through bubbler<br><br>Drain Rate: facility max (~200 gpm) |
| **Key Measurements** | Flow rates: purge bag inlet flowmeter and tank vent flowmeter<br>Purge bag temp: thermocouples at inlet, outlet, interior<br>Humidity level in purge bag: humidity sensor at purge bag exit | Liquid level: diode rake and FOSS<br>Percent full: load cells<br>Pressure: ullage pressure transducer<br>Fill rate: fill line flowmeter<br>Temperature of liquid, ullage and vented gas: diode rake, FOSS, vent SD | Boil-off rate: calculated using load cell, ullage vent temp, ullage pressure data<br>Fluid stratification: diode rake and FOSS<br>Purge bag temp: thermocouples at inlet, outlet, interior | Liquid level height and appearance: borescope, with footage before, during and after shutting vent valve<br>Liquid level: diode rake and FOSS<br>Percent full: load cells | Liquid level, fluid stratification: diode rake and FOSS<br>Percent full: load cells<br>Pressurization: press line pressure transducer, SD, FM<br>Drain rate: drain line flowmeter, temperature, and pressure | Boil-off rate: calculated using load cell, ullage temp, and ullage pressure data<br>Fluid stratification: diode rake and FOSS<br>Purge bag temp: thermocouples at inlet, outlet, interior | Liquid level, fluid stratification: diode rake and FOSS<br>Percent full: load cells<br>Pressurization: press line pressure transducer, SD, FM<br>Drain rate: drain line flowmeter, temperature, and pressure |
| **Data Rate** | every 10 minutes | 25 Hz | 25 Hz | 25 Hz | 25 Hz | 25 Hz | 25 Hz |
| | *12 hours* | *2 hours* | *1 hour* | *2 hours* | *15 minutes* | *10 minutes* | *15 minutes* |

# MSFC LH2 Test Matrix:  Testing at Atmospheric Conditions

| | Purge | Chill/Fill | Steady-State Boil-Off | Bubble Volume | Press / Drain to 50% | Vent | Press / Drain to 0% |
|---|---|---|---|---|---|---|---|
| **TEST 1:** GH2 Press Through Forward End Diffuser | **Flow Rate:** *5 scfm cross-country GN2 & GHe delivered to tank and purge bag*<br>Purge Prior to **Chill/Fill:** *10 hrs GN2 then 2 hrs with GHe* | **Pressure:** *vent to atmosphere*<br><br>**Fill Rate:** *72 gpm or highest safe facility fill rate.* | **Pressure:** *vent to atmosphere (all venting is through burn stack)*<br><br>***Top-off:*** *Top-off LH2 level to full before proceeding to Bubble Volume* | **Press. Sequence:**<br>*-vent to atmosphere*<br>*-rapid GH2 press. to 5 psig*<br>*-tank self press. to 15 psig*<br>*-vent to atmosphere* | **Pressure:** *≤30 psig with GH2 through diffuser*<br><br>**Drain Rate:**<br>*Target ~250 gpm (TBR)* | **Press. Sequence:**<br>*-vent to atmosphere*<br>*-allow tank contents to recondition* | **Pressure:** *≤30 psig with GH2 through diffuser*<br><br>**Drain Rate:**<br>*Target ~250 gpm (TBR)* |
| **TEST 2:** GHe Press Through Forward End Diffuser | **Flow Rate:** *5 scfm cross-country GN2 & GHe delivered to tank and purge bag*<br>Purge Prior to **Chill/Fill:** *10 hrs GN2 then 2 hrs with GHe* | **Pressure:** *vent to atmosphere*<br><br>**Fill Rate:** *72 gpm or highest safe facility fill rate.* | **Pressure:** *vent to atmosphere (all venting is through burn stack)*<br><br>***Top-off:*** *Top-off LH2 level to full before proceeding to Bubble Volume* | **Press. Sequence:**<br>*-vent to atmosphere*<br>*-rapid GHe press. to 5 psig*<br>*-tank self press. to 15 psig*<br>*-vent to atmosphere* | **Pressure:** *≤30 psig with GHe through diffuser*<br><br>**Drain Rate:**<br>*Target ~250 gpm (TBR)* | **Press. Sequence:**<br>*-vent to atmosphere*<br>*-allow tank contents to recondition* | **Pressure:** *≤30 psig with GHe through diffuser*<br><br>**Drain Rate:**<br>*Target ~250 gpm (TBR)* |
| | *12 hours* | *2 hours* | *1 hour* | *1 hour* | *2 minutes* | *10 minutes* | *2 minutes* |

# MSFC LH2 Test Matrix: Test 1

*Pressurization with GH2 through forward end diffuser.*

| | Purge | Chill / Fill | Steady-State Boil-Off | Bubble Volume | Press / Drain to 50% | Vent | Press / Drain to 0% |
|---|---|---|---|---|---|---|---|
| **Objective** | Fill tank and purge bag with GHe to avoid condensation and frost on the tank after LH2 fill. | Fill tank to 95% with LH2. | Measure heat load to CRYOTE3 system. | Evaluate bubble volume in ground-hold environment. | Pressurize tank with GH2 through diffuser and drain liquid to 50%; measure fluid strat. during drain. | Vent tank to atmosphere and recondition tank contents for desired condition prior to final drain. | Pressurize tank with GH2 through diffuser and drain liquid to 0%; measure fluid strat. during drain. |
| **Key Details** | Flow Rate: 5 scfm to tank and purge bag<br><br>Purge Prior to Chill/ Fill: 12 hours | Pressure: vent to atmosphere<br><br>Fill Rate: 72 gpm | Pressure: vent to atmosphere | Press. Sequence:<br>-vent to atmosphere<br>-rapid GH2 press. to 5 psig<br>-tank self press. to 15 psig<br>-vent to atmosphere | Pressure: 30 psig with GH2 through diffuser<br><br>Drain Rate: facility max (~250 gpm) | Press. Sequence:<br>-vent to atmosphere<br>-allow tank contents to recondition | Pressure: 30 psig with GH2 through diffuser<br><br>Drain Rate: facility max (~250 gpm) |
| **Key Measurements** | <u>Flow rates</u>: purge bag inlet flowmeter and tank vent flowmeter<br><u>Purge bag temp</u>: thermocouples at inlet, outlet, interior<br><u>Humidity level in purge bag</u>: humidity sensor at purge bag exit | <u>Liquid level</u>: diode rake and FOSS<br><u>Percent full</u>: load cells<br><u>Pressure</u>: ullage pressure transducer<br><u>Fill rate</u>: fill line flowmeter<br><u>Temperature of liquid, ullage and vented gas</u>: diode rake, FOSS, vent SD | <u>Boil-off rate:</u> calculated using load cell, ullage vent temp, ullage pressure data<br><u>Fluid stratification</u>: diode rake and FOSS<br><u>Purge bag temp</u>: thermocouples at inlet, outlet, interior | <u>Liquid level height and appearance</u>: borescope, with footage before, during and after shutting vent valve<br><u>Liquid level</u>: diode rake and FOSS<br><u>Percent full</u>: load cells | <u>Liquid level, fluid stratification</u>: diode rake and FOSS<br><u>Percent full</u>: load cells<br><u>Pressurization</u>: press line pressure transducer, SD, FM<br><u>Drain rate</u>: drain line flowmeter, temperature, and pressure | <u>Boil-off rate:</u> calculated using load cell, ullage temp, and ullage pressure data<br><u>Fluid stratification:</u> diode rake and FOSS<br><u>Purge bag temp</u>: thermocouples at inlet, outlet, interior | <u>Liquid level, fluid stratification</u>: diode rake and FOSS<br><u>Percent full</u>: load cells<br><u>Pressurization</u>: press line pressure transducer, SD, FM<br><u>Drain rate</u>: drain line flowmeter, temperature, and pressure |
| **Data Rate** | every 10 minutes | 25 Hz | 25 Hz | 25 Hz | 25 Hz | 25 Hz | 25 Hz |
| | *12 hours* | *2 hours* | *1 hour* | *2 hours* | *15 minutes* | *10 minutes* | *15 minutes* |

# MSFC LH2 Test Matrix: Test 2

*Pressurization with helium through forward end diffuser.*

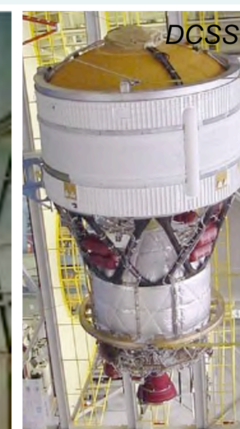
| | Purge | Chill / Fill | Steady-State Boil-Off | Bubble Volume | Press / Drain to 50% | Vent | Press / Drain to 0% |
|---|---|---|---|---|---|---|---|
| **Objective** | Fill tank and purge bag with GHe to avoid condensation and frost on the tank after LH2 fill. | Fill tank to 95% with LH2. | Measure heat load to CRYOTE3 system. | Evaluate bubble volume in ground-hold environment. | Pressurize tank with GHe through diffuser and drain liquid to 50%; measure fluid strat. during drain. | Vent tank to atmosphere and recondition tank contents for desired condition prior to final drain. | Pressurize tank with GHe through diffuser and drain liquid to 0%; measure fluid strat. during drain. |
| **Key Details** | Flow Rate: 5 scfm to tank and purge bag<br><br>Purge Prior to Chill/ Fill: 12 hours | Pressure: vent to atmosphere<br><br>Fill Rate: 72 gpm | Pressure: vent to atmosphere | Press. Sequence:<br>-vent to atmosphere<br>-rapid GH2 press. to 5 psig<br>-tank self press. to 15 psig<br>-vent to atmosphere | Pressure: 30 psig with GHe through diffuser<br><br>Drain Rate: facility max (~250 gpm) | Press. Sequence:<br>-vent to atmosphere<br>-allow tank contents to recondition | Pressure: 30 psig with GHe through diffuser<br><br>Drain Rate: facility max (~250 gpm) |
| **Key Measurements** | Flow rates: purge bag inlet flowmeter and tank vent flowmeter<br>Purge bag temp: thermocouples at inlet, outlet, interior<br>Humidity level in purge bag: humidity sensor at purge bag exit | Liquid level: diode rake and FOSS<br>Percent full: load cells<br>Pressure: ullage pressure transducer<br>Fill rate: fill line flowmeter<br>Temperature of liquid, ullage and vented gas: diode rake, FOSS, vent SD | - Boil-off rate: calculated using load cell, ullage vent temp, ullage pressure data<br>- Fluid stratification: diode rake and FOSS<br>- Purge bag temp: thermocouples at inlet, outlet, interior | - Liquid level height and appearance: borescope, with footage before, during and after shutting vent valve<br>- Liquid level: diode rake and FOSS<br>- Percent full: load cells | - Liquid level, fluid stratification: diode rake and FOSS<br>- Percent full: load cells<br>- Pressurization: press line pressure transducer, SD, FM<br>- Drain rate: drain line flowmeter, temperature, and pressure | - Boil-off rate: calculated using load cell, ullage temp, and ullage pressure data<br>- Fluid stratification: diode rake and FOSS<br>- Purge bag temp: thermocouples at inlet, outlet, interior | - Liquid level, fluid stratification: diode rake and FOSS<br>- Percent full: load cells<br>- Pressurization: press line pressure transducer, SD, FM<br>- Drain rate: drain line flowmeter, temperature, and pressure |
| **Data Rate** | every 10 minutes | 25 Hz | 25 Hz | 25 Hz | 25 Hz | 25 Hz | 25 Hz |
| | *12 hours* | *2 hours* | *1 hour* | *2 hours* | *15 minutes* | *10 minutes* | *15 minutes* |

# CRYOTE3 Tank Overview!

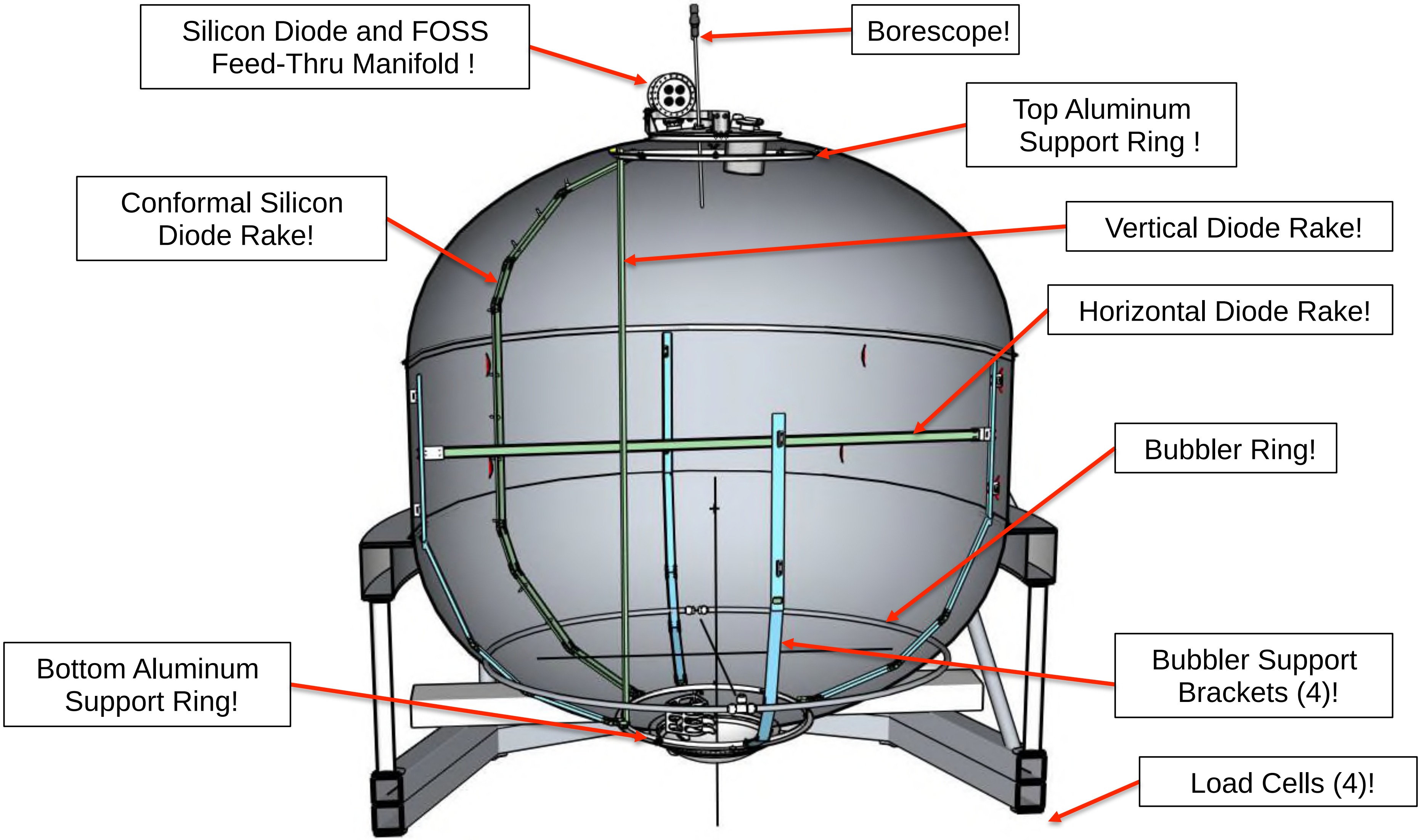
| Parameter" | Value" |
|---|---|
| Material! | stainless steel! |
| Diameter! | 10 ft (3.05 m)! |
| Length! | 10 ft (3.05 m)! |
| Wall Thickness! | 0.019-0.024 in (0.048-0.061 cm)! |
| Dome Geometry! | 1.38:1 elliptical! |
| Surface Area! | 329 $ft^2$ (30.52 $m^2$)! |
| Volume! | 579 $ft^3$ or 4331 gal (16.4 $m^3$)! |
| SA/V Ratio! | 0.51 $ft^{-1}$ (1.66 $m^{-1}$)! |
| Empty Mass! | 300 lbm (136 kg)! |
| Full Mass - Nitrogen! | 32504 lbm (14743 kg)! |
| Full Mass - Oxygen! | 45986 lbm (20859 kg)! |
| Full Mass - Hydrogen! | 3,123 lbm (1,416 kg)! |
| Pressure Rating! | 60.7 psia (419 kpa)! |
| Structural Interface! | cylinder rings! |
| Largest Penetration! | 2 ft (at top/bottom)! |
| Support Equipment! | stub adaptors! |
| Manufacturer! | ULA! |

# Tank Energy to Volume Ratios

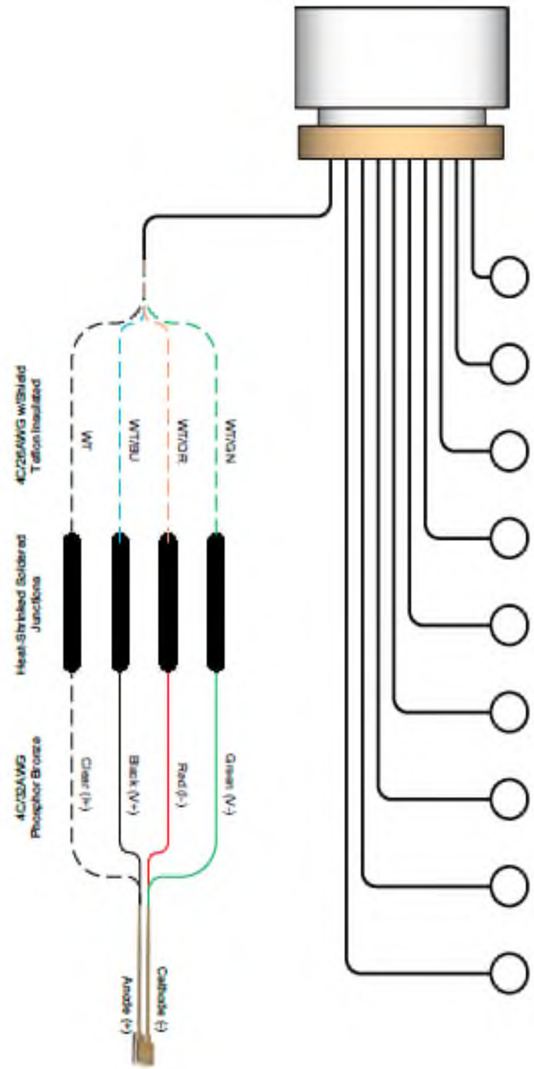
| Test Bed | Material | Liquid | Diameter | Length | Wall Thickness | Volume ($m^3$) | Empty Mass (kg) | Chill Energy (MJ) | Energy per Volume ($MJ/m^3$) |
|---|---|---|---|---|---|---|---|---|---|
| **MHTB** | Aluminum | LN2 | 10’ | 10’ | ½” | 18.1 | 1263 | 218 | 12 |
| **CTB2** | Stainless Steel | LN2 | 6’ | 6’ 6” | 3/8” | 4.0 | 1410 | 118 | 30 |
| **VATA** | Stainless Steel | LN2 | 4’ | 5’ 4” | 3/16” | 1.4 | 285 | 23.8 | 17 |
| **CRYOTE1** | Titanium w/steel lid | LN2 | 2’ 5.7” | 2’ 5.7” | 1/20” | 0.23 | 13.6 | 1.25 | 5.4 |
| **CRYOTE3** | Stainless Steel | LN2<br>LH2 | 10’ | 10’ | 0.020” | 16.4 | 136 | 11.3<br>14.3 | 0.62<br>0.87 |
| **Centaur LH2** | Stainless Steel | LH2 | 10’ | 21’ 10.8” | 0.020” | 48.7 | 395 | 41.5 | 0.85 |
| **Centaur LO2** | Stainless Steel | LO2 | 10’ | 2’ 9” | 0.030” | 16.3 | 345 | 27.4 | 1.7 |
| **5M DCSS LH2** | Aluminum | LH2 | 16’ 6” | 14’ 11.6” | Isogrid | 63.5 | 779 | 192.9 | 3.0 |
| **5M DCSS LO2** | Aluminum | LO2 | 10’ 5” | 11’ 8.9” | Isogrid | 21.5 | 430 | 80.4 | 3.7 |

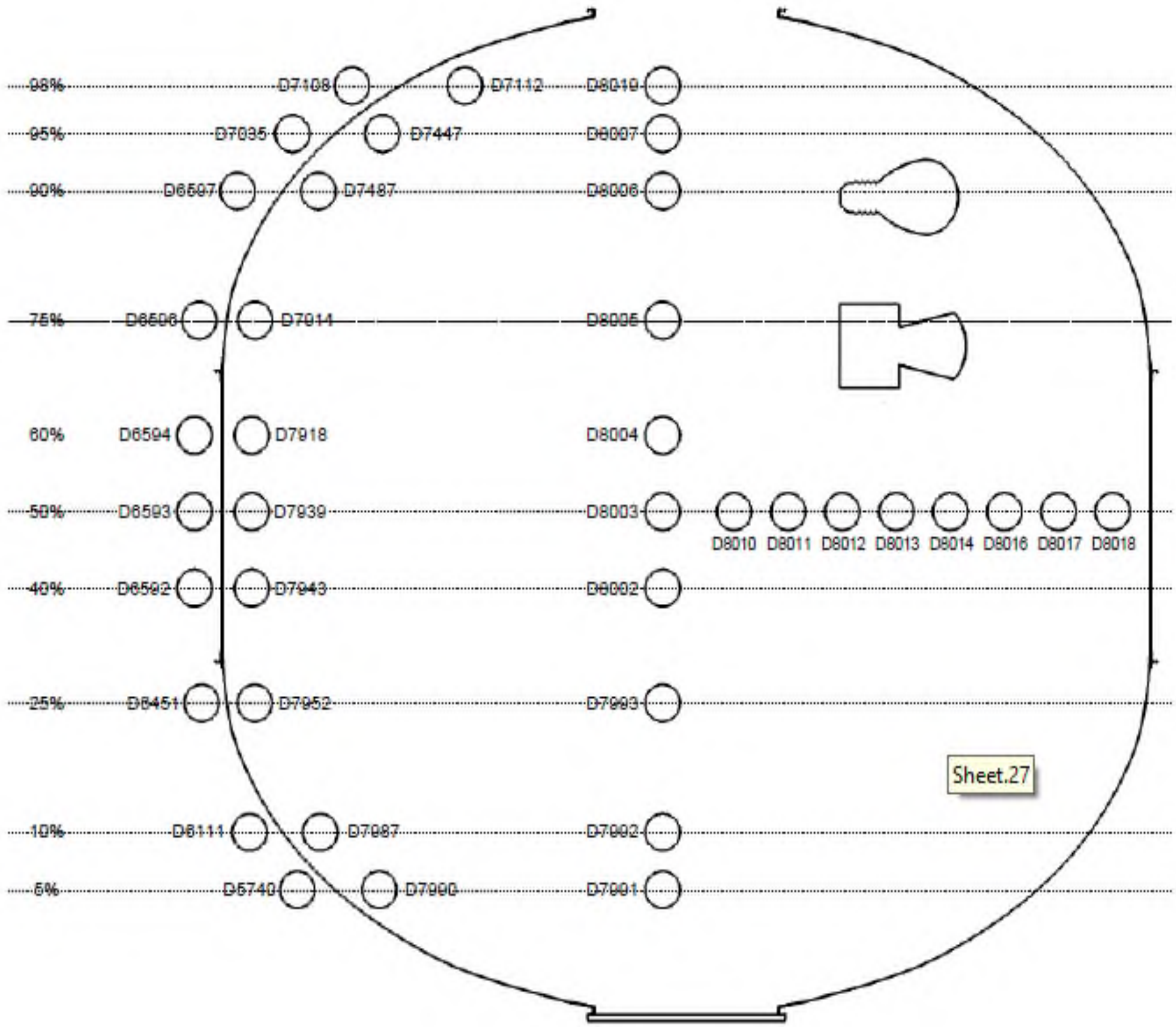


# Test Article Overview



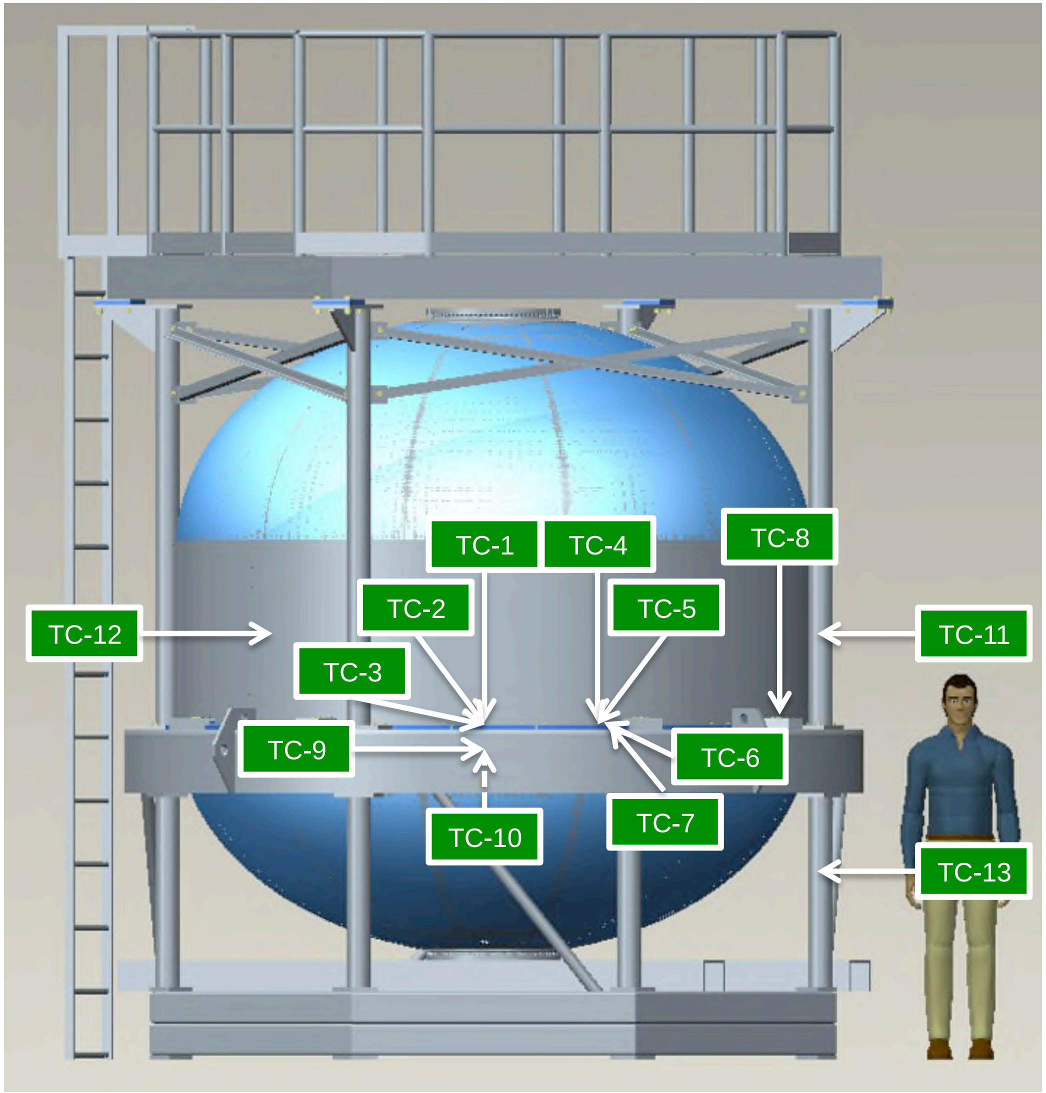
# Instrumentation Overview:  Silicon Diodes



# Instrumentation Overview: Thermocouples

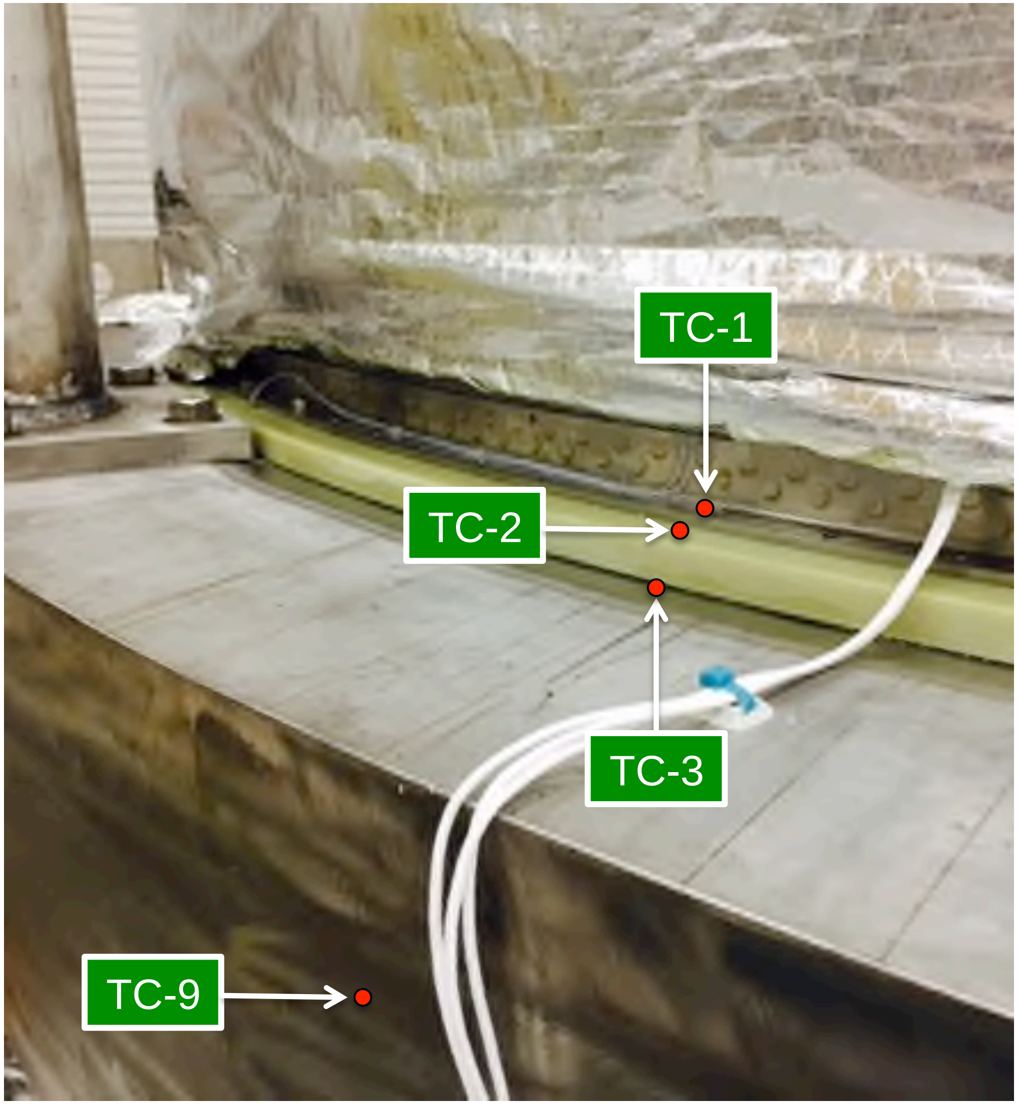
| Number | Location |
|---|---|
| TC-1 | Tank Ring (clocked at insulator center) |
| TC-2 | G10 Insulator Top (clocked at insulator center) |
| TC-3 | Between Insulator and Metal (clocked at insulator center) |
| TC-4 | Tank Ring (clocked at insulator edge) |
| TC-5 | TG10 Insulator Top (clocked at insulator edge) |
| TC-6 | Between Insulator and Metal (clocked at insulator edge) |
| TC-7 | TG10 Insulator Side (clocked at insulator edge) |
| TC-8 | Top Surface of Clamping Block |
| TC-9 | Outside Surface of Interface Ring |
| TC-10 | Inside Surface of Interface Ring |
| TC-11 | Overhead Platform Vertical Support |
| TC-12 | Outer Insulation Layer |
| TC-13 | Support Structure Vertical Support |




**We can place up to 15 TCs on and around the tank/structure.*

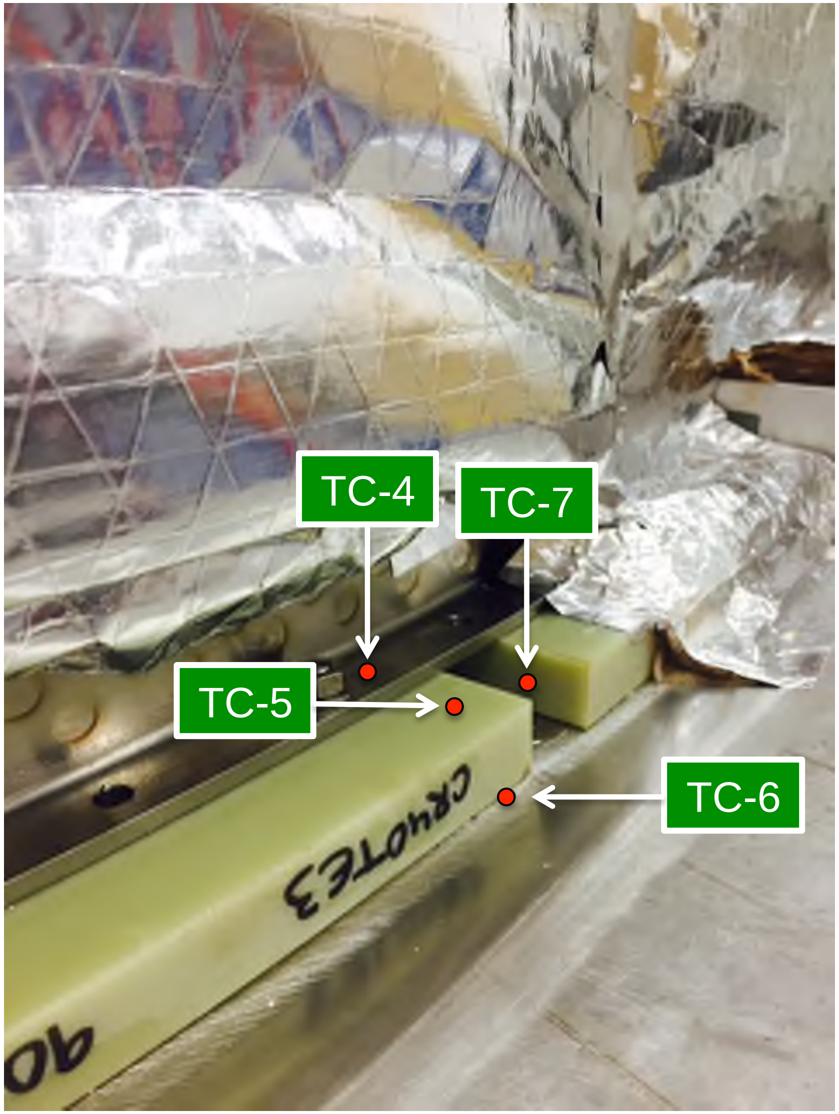
# Instrumentation Overview: # Thermocouples Clocked at Insulator Center

| Number | Location |
|---|---|
| TC-1 | Tank Ring (clocked at insulator center) |
| TC-2 | G10 Insulator Top (clocked at insulator center) |
| TC-3 | Between Insulator and Metal (clocked at insulator center) |
| TC-4 | Tank Ring (clocked at insulator edge) |
| TC-5 | TG10 Insulator Top (clocked at insulator edge) |
| TC-6 | Between Insulator and Metal (clocked at insulator edge) |
| TC-7 | TG10 Insulator Side (clocked at insulator edge) |
| TC-8 | Top Surface of Clamping Block |
| TC-9 | Outside Surface of Interface Ring |
| TC-10 | Inside Surface of Interface Ring |
| TC-11 | Overhead Platform Vertical Support |
| TC-12 | Outer Insulation Layer |
| TC-13 | Support Structure Vertical Support |



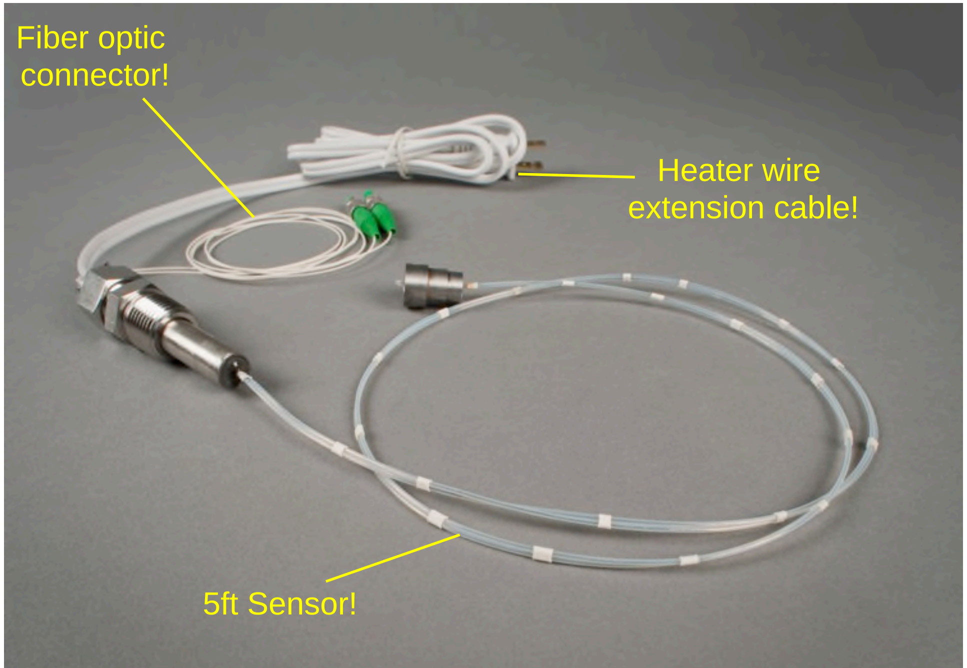
# Instrumentation Overview: # Thermocouples Clocked at Insulator Edge

| Number | Location |
|---|---|
| TC-1 | Tank Ring (clocked at insulator center) |
| TC-2 | G10 Insulator Top (clocked at insulator center) |
| TC-3 | Between Insulator and Metal (clocked at insulator center) |
| TC-4 | Tank Ring (clocked at insulator edge) |
| TC-5 | TG10 Insulator Top (clocked at insulator edge) |
| TC-6 | Between Insulator and Metal (clocked at insulator edge) |
| TC-7 | TG10 Insulator Side (clocked at insulator edge) |
| TC-8 | Top Surface of Clamping Block |
| TC-9 | Outside Surface of Interface Ring |
| TC-10 | Inside Surface of Interface Ring |
| TC-11 | Overhead Platform Vertical Support |
| TC-12 | Outer Insulation Layer |
| TC-13 | Support Structure Vertical Support |



# Fiber Optic Sensing System (FOSS) Overview

- **The Challenge"**
  - –" The translational phase between liquid and gas of cryogenics is difficult to discriminate while making liquid level measurements.!
  - –" Using discrete cryogenic temperature diodes spaced along a rake yields coarse spatial resolution of liquid level along with high wire count.!



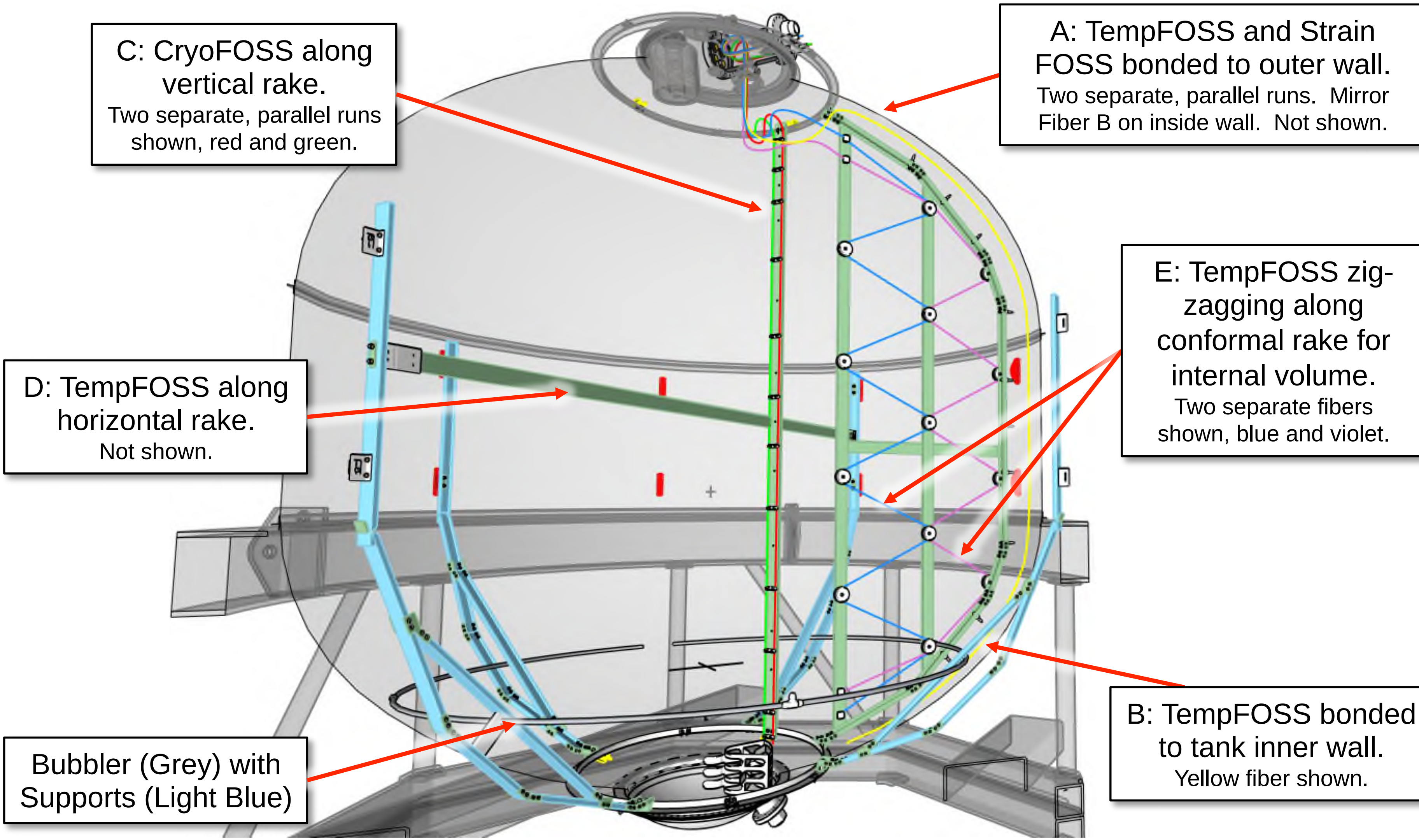

*Information courtesy of NASA Armstrong Flight Research Center (AFRC).*

- **FOSS Approach"**
  - –" Anemometry methods applied to a single fiber Bragg grating sensing cable improve transitional phase mapping.!
  - –" A single continuous grating fiber achieves excellent spatial resolution, as low as 1/16”!
  - –" Along with the single fiber optic cable a heater wire is used to accomplish the anemometry measurement.!
  - –" While the heater wire is cycled between two levels of heat, the co-located fiber is measuring the heat transfer characteristics into the surrounding environment. !
  - –" Up to 2048 discrete levels are serially multiplexed onto a single hair-like fiber.!
  - –" Up to 8 fibers can be stacked for a total of 320 sensing feet.!
  - –" A single interrogation system can be used for measuring temperature, strain, shape and liquid level, making for a complete health monitoring unit.!
  - –" Significantly lower bulkhead pass-through requirements; 1 single mode fiber and two 20 AWG wires for a single 40’ long sensor.!
  - –" Small, lightweight form factor.!

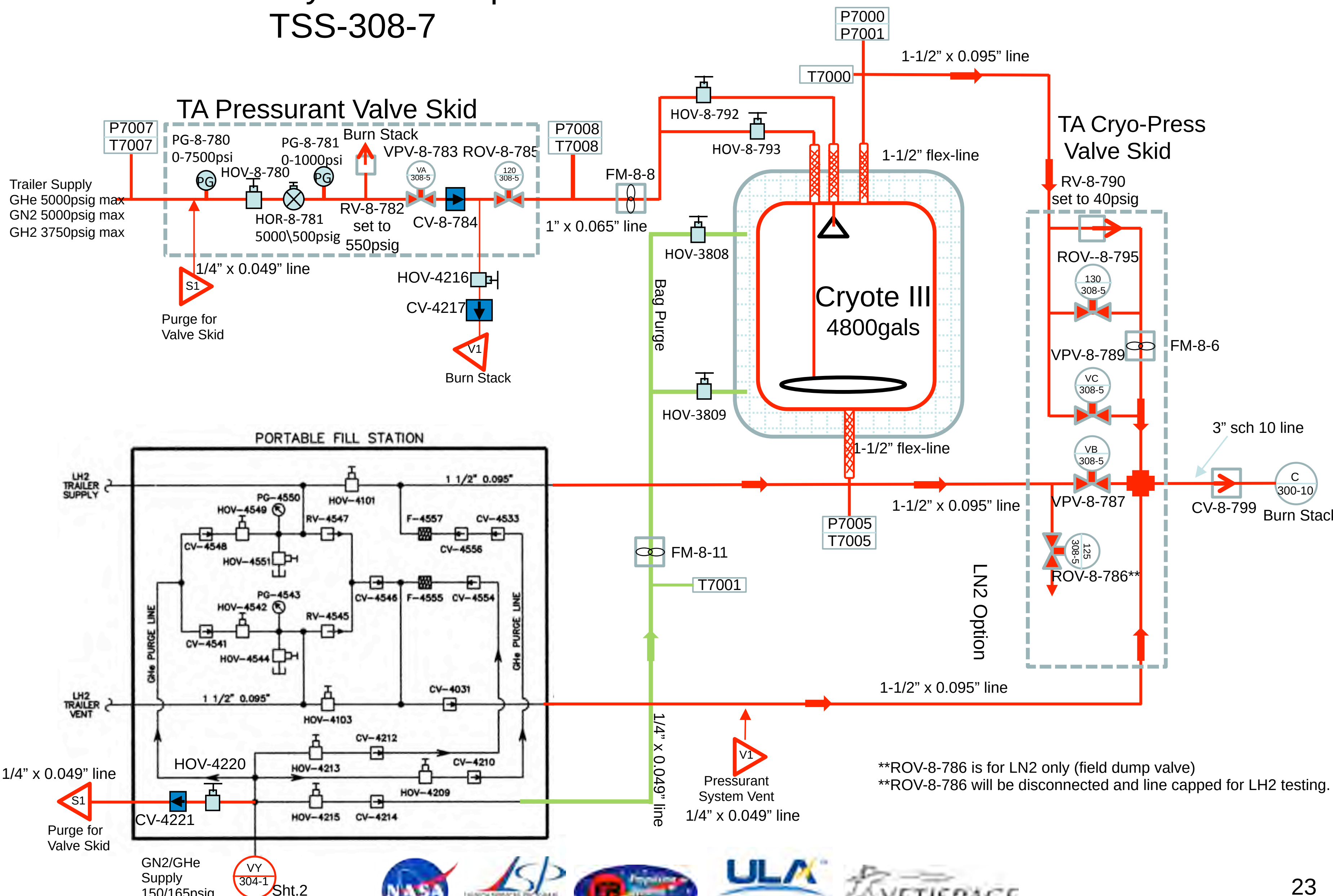
# CRYOTE3 FOSS Functionality Requirements

| | Fiber Location " | Functionality Requirements" | |
|---|---|---|---|
| Outside Tank | **A1. Tank Wall (Outside Surface)"** | Measurement Type | Absolute Temperature (Temp FOSS) |
| | *1." Compare with data from fiber mounted on inside surface of tank wall.*<br>*2." Compare with wall-mounted SDs.*<br>*3." Measure ullage stratification.* | Spatial Density | 0.5 inch |
| | | Resolution and Accuracy | 0.1 °R resolution, accurate to within 0.05 °R |
| | **A2. Tank Wall (Outside Surface)"** | Measurement Type | Strain |
| | *Anchor tank structural models by obtaining tank wall strain data during CRYOTE3 testing. Particularly, investigate transient conditions such as tank loading, pressurization, and strain differences between warm forward dome and cold aft dome.* | Spatial Density | 0.5 inch |
| | | Resolution and Accuracy | TBD |
| Inside Tank | **B. Tank Wall (Inside Surface)"** | Measurement Type | Absolute Temperature (Temp FOSS) |
| | *1." Compare with data from fiber mounted on outside surface of tank wall.*<br>*2." Compare with wall-mounted SDs.*<br>*3." Measure ullage stratification.* | Spatial Density | 0.5 inch |
| | | Resolution and Accuracy | 0.1 °R resolution, accurate to within 0.05 °R |
| | **C. Vertical Rake"** | Measurement Type | Wet/Dry (Cryo FOSS) |
| | 1. *Measure liquid level.*<br>*2." Measure liquid and ullage stratification during steady state and rapid drain.*<br>*3." Compare with rake SDs.* | Spatial Density | 0.5 inch |
| | | Resolution and Accuracy | 0.1 °R resolution |
| | **D. Horizontal Rake"** | Measurement Type | Absolute Temperature (Temp FOSS) |
| | *1." Measure liquid and ullage thermal gradient from tank centerline to wall.*<br>*2." Compare with rake SDs.* | Spatial Density | 0.5 inch |
| | | Resolution and Accuracy | 0.1 °R resolution, accurate to within 0.05 °R |
| | **E. Tank Internal Volume"** | Measurement Type | Absolute Temperature (Temp FOSS) |
| | *Measure liquid and ullage thermal gradient in the plane between the tank wall and the tank centerline and stratification from tank top to bottom.* | Spatial Density | 0.5 inch |
| | | Resolution and Accuracy | 0.1 °R resolution, accurate to within 0.05 °R |

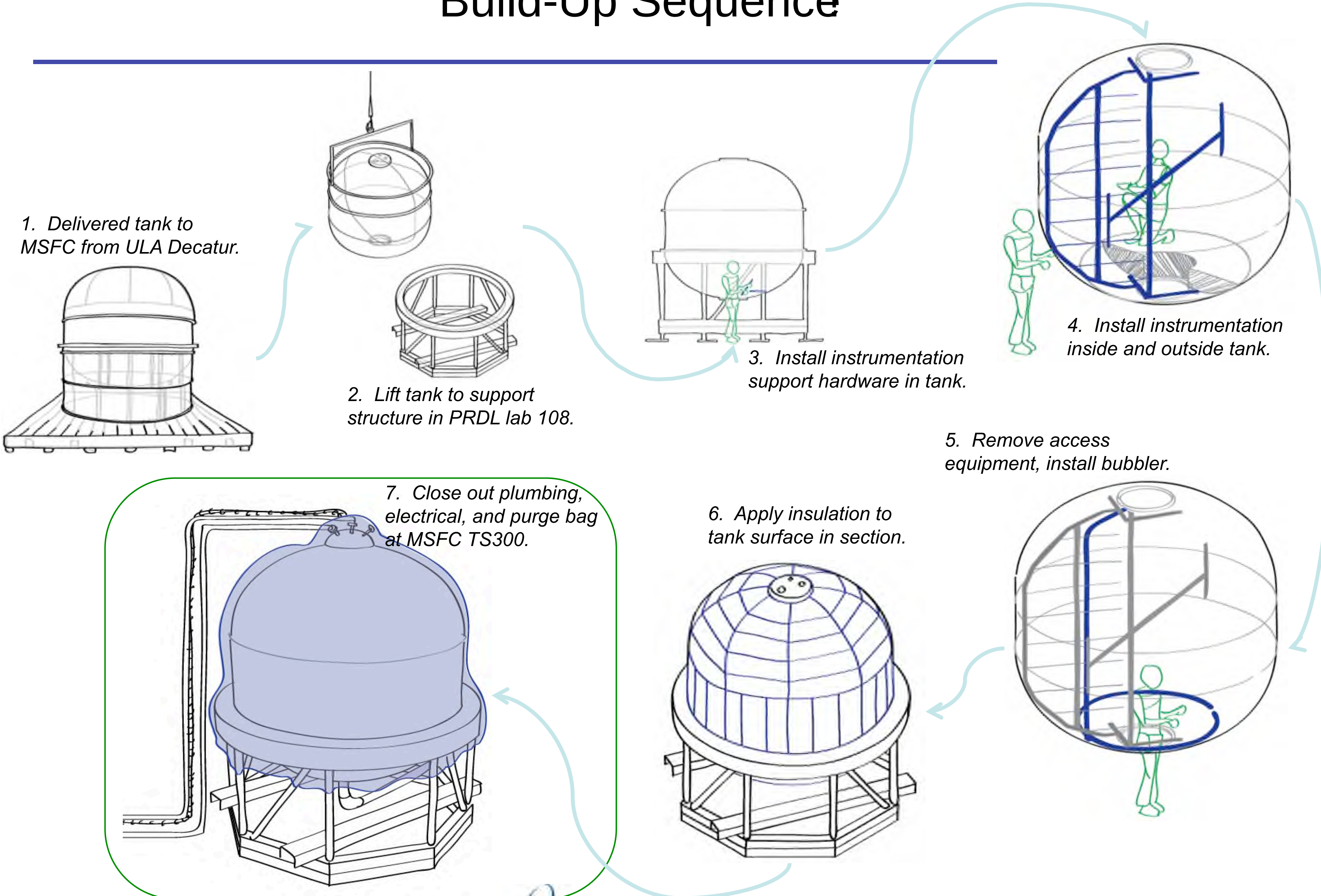
# FOSS Implementation on CRYOTE3

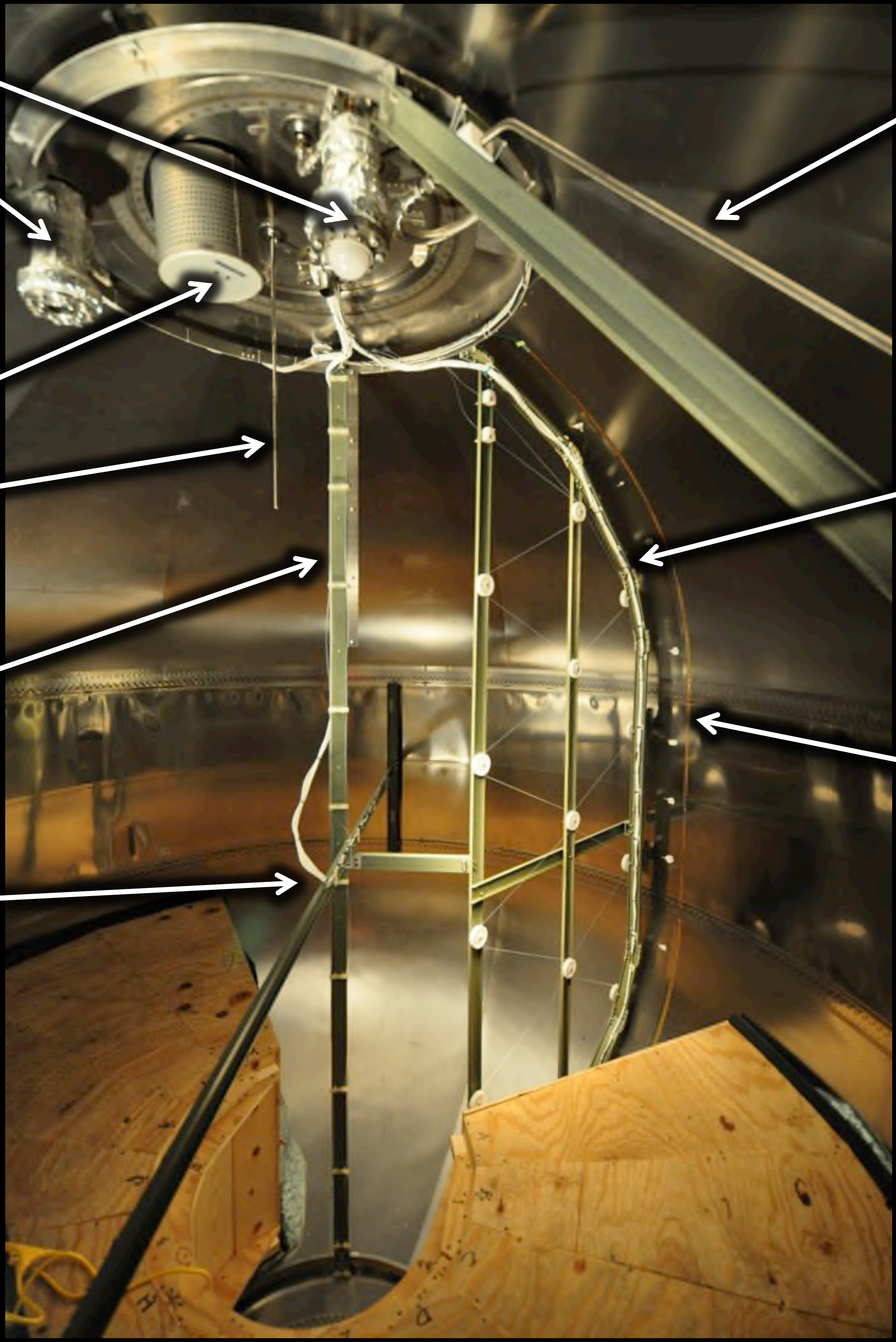


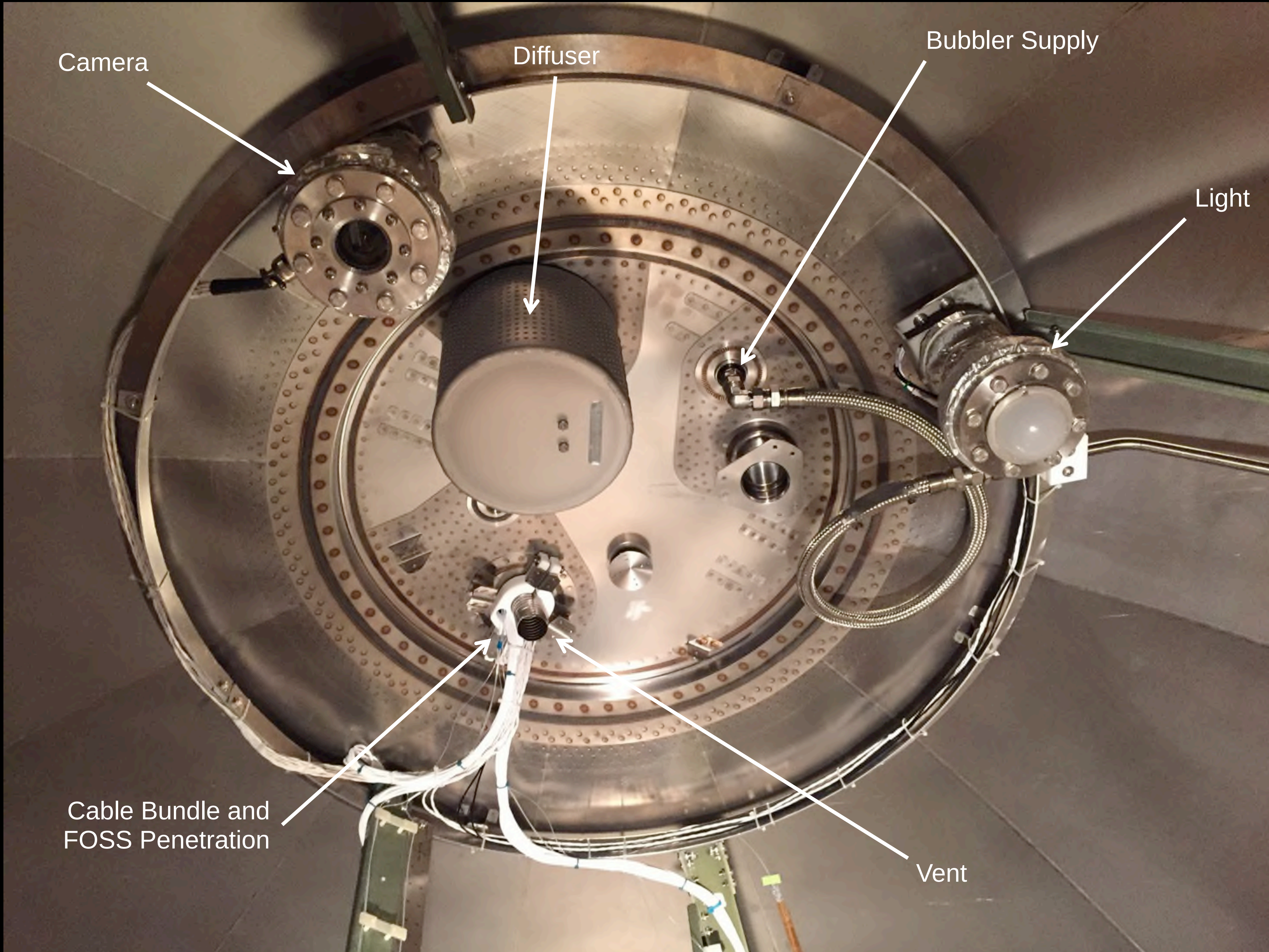
# Cryote III Setup REV 1
# TSS-308-7

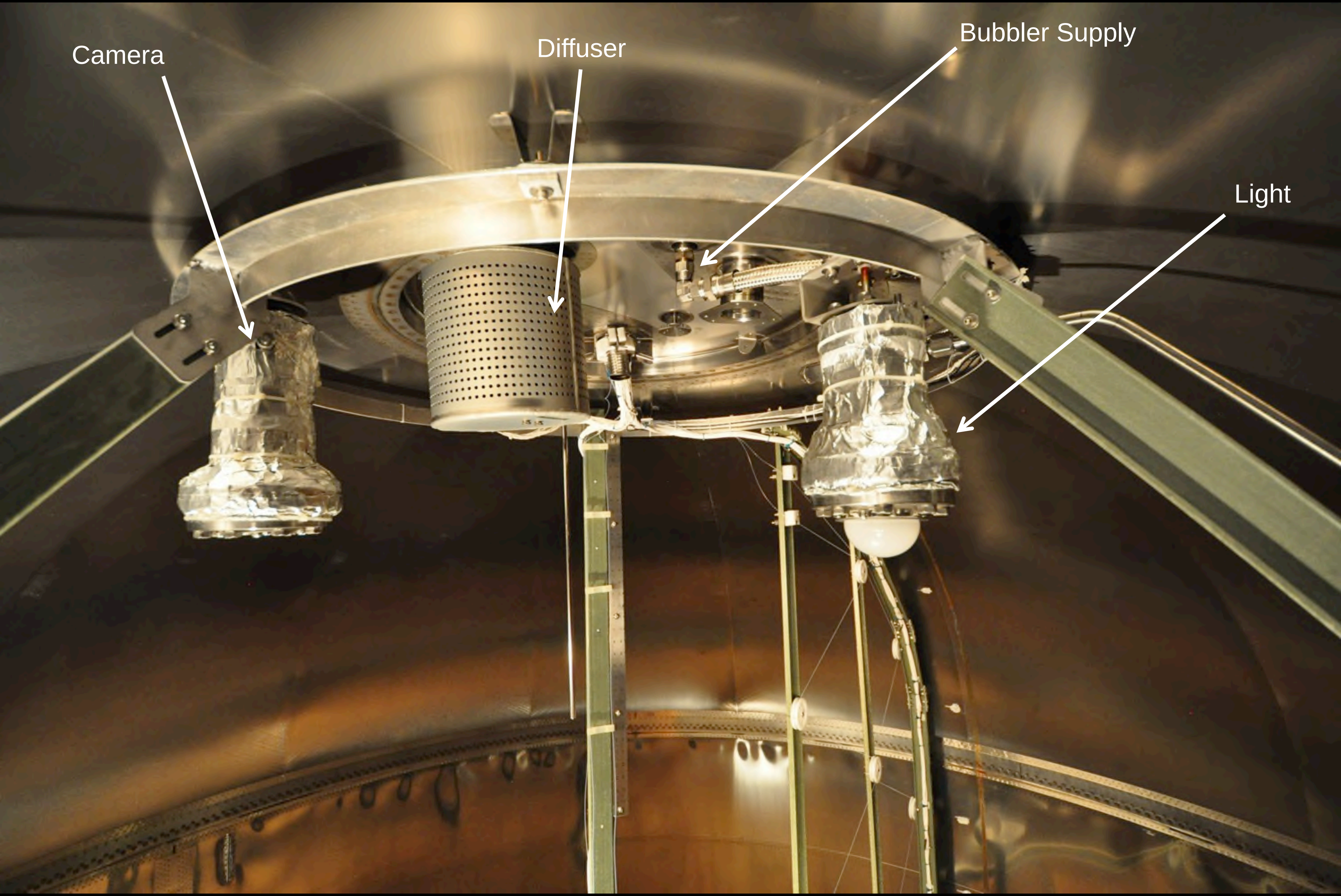


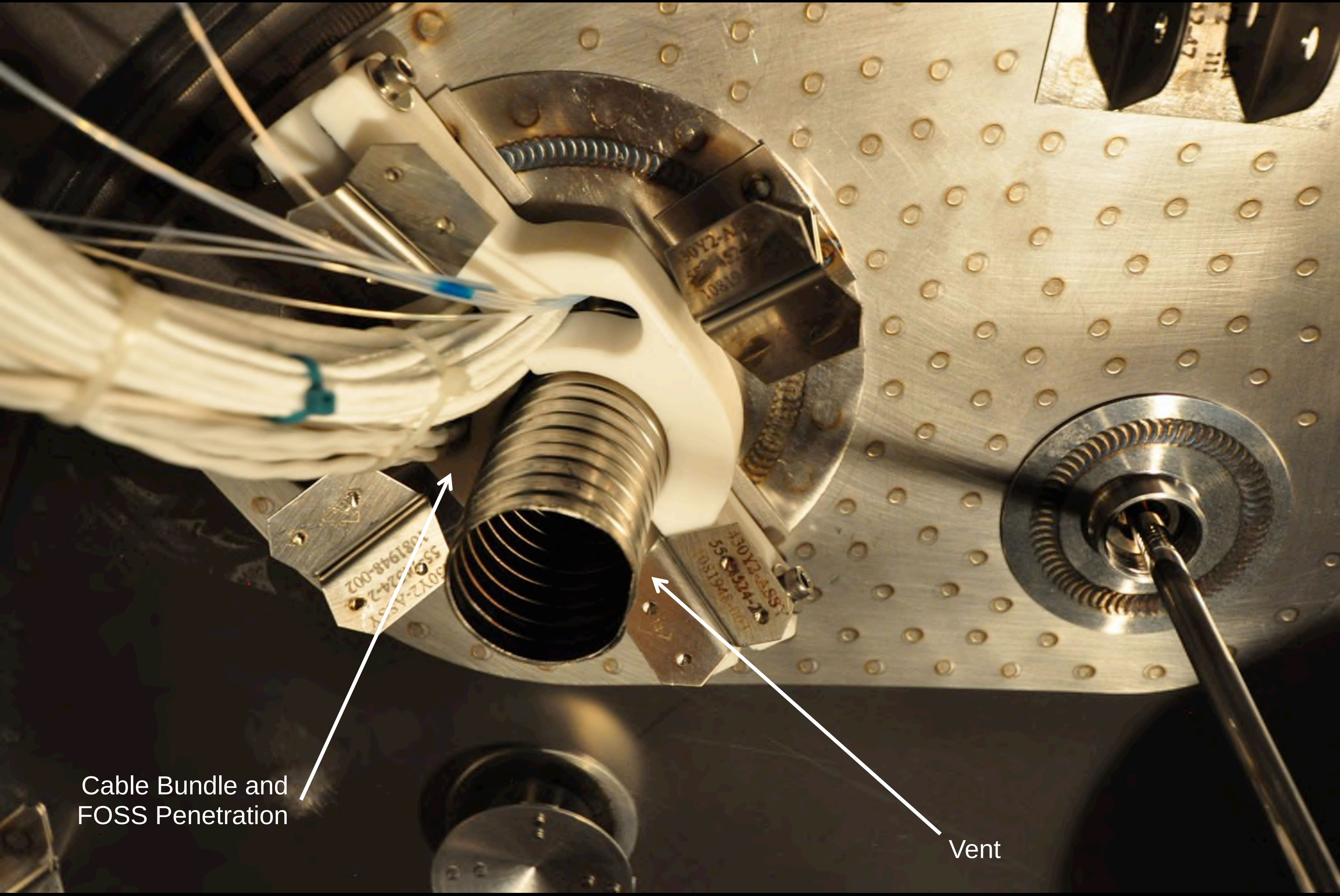
# Build-Up Sequence




Light
Camera
Bubbler Plumbing
Diffuser
Borescope
Zig-Zag FOSS Rake
Vertical SD and FOSS Rake
Internal Tank Wall Mounted SDs and FOSS
Horizontal SD and FOSS Rake

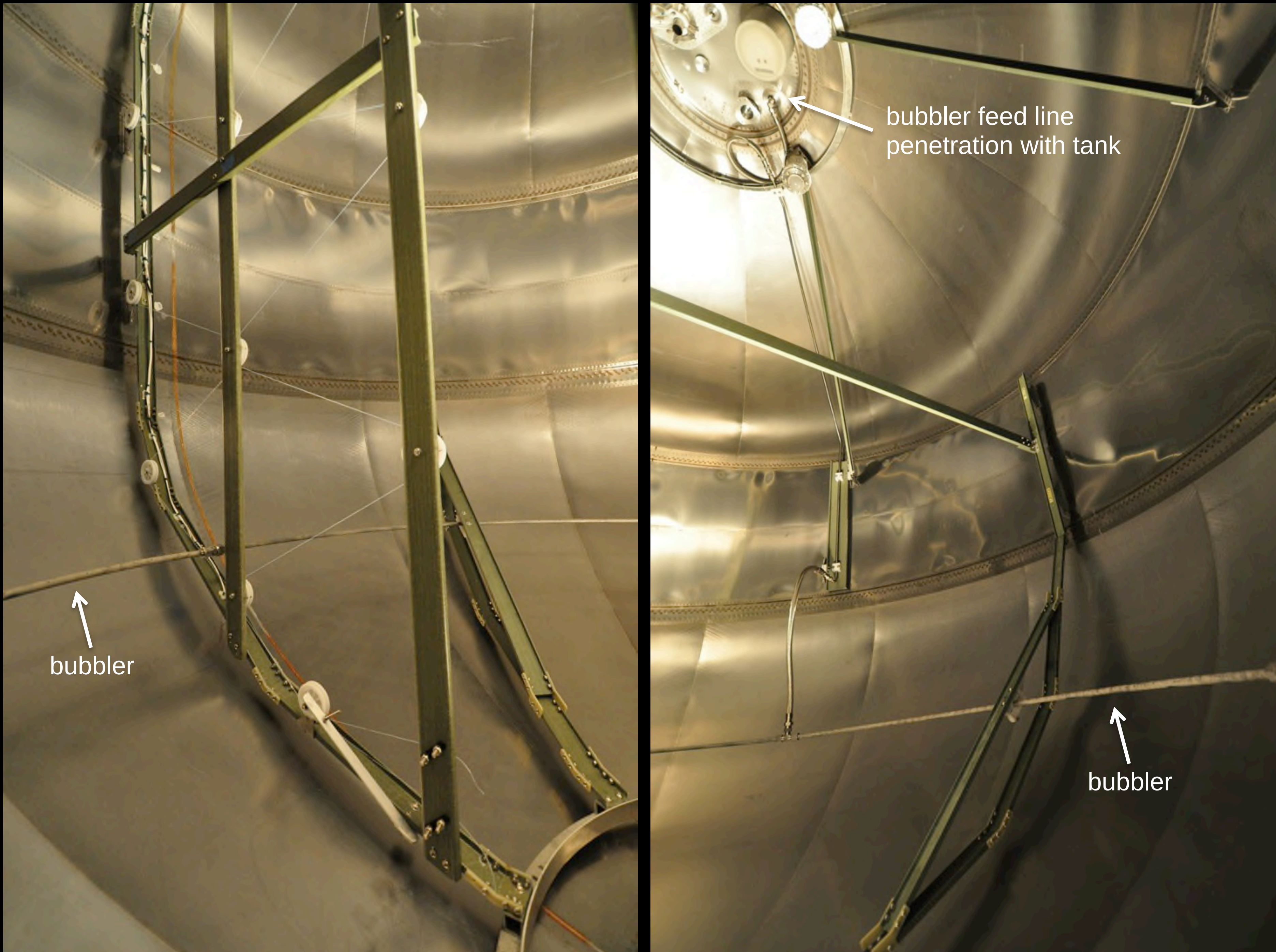

Camera
Diffuser
Bubbler Supply
Light
Cable Bundle and
FOSS Penetration
Vent

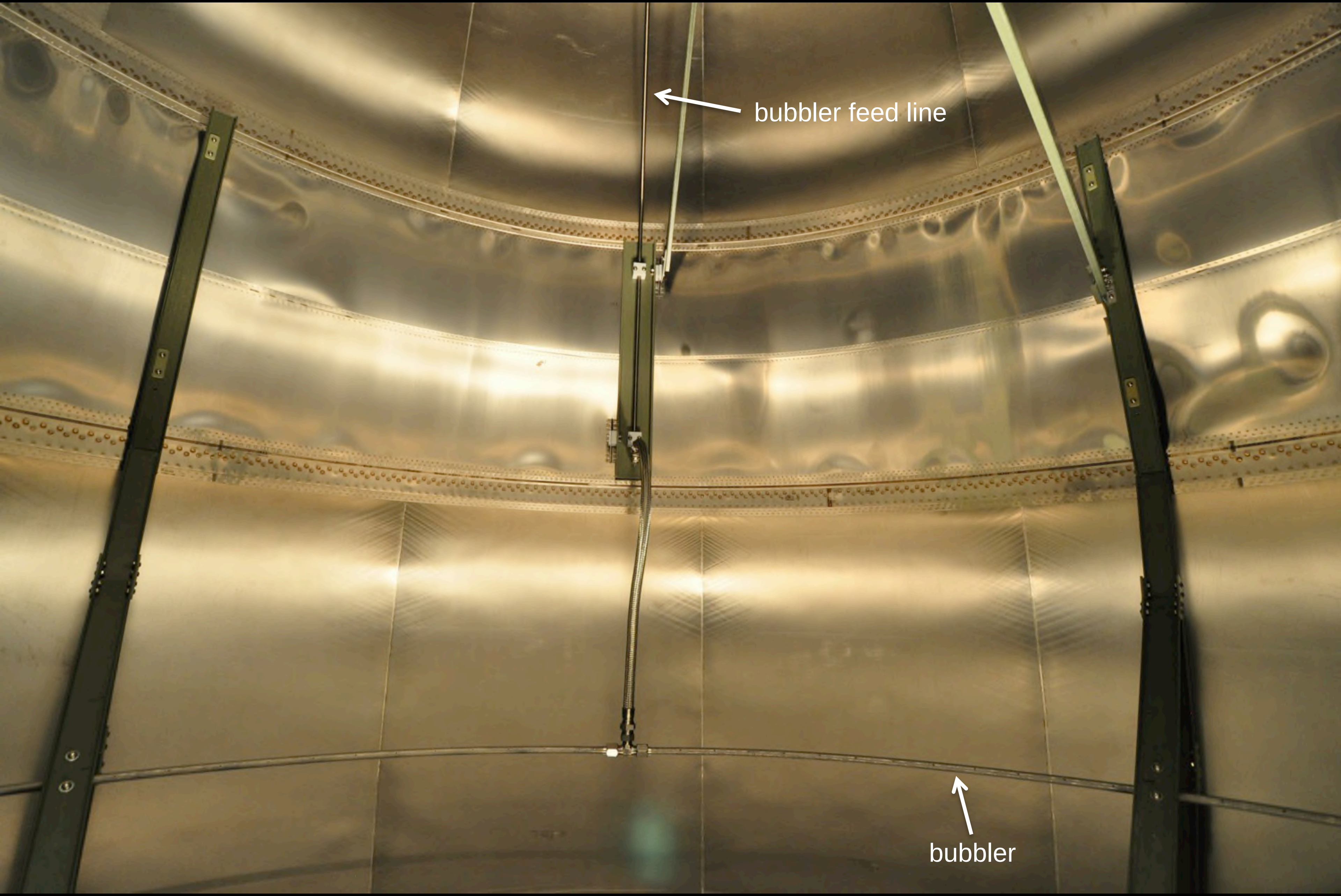

Camera
Diffuser
Bubbler Supply
Light


Cable Bundle and
FOSS Penetration
Vent


"Back" side of
conformal rake


"Front" side of
conformal rake


bubbler
bubbler feed line
penetration with tank
bubbler


bubbler feed line
bubbler

CRYOTE3 transportation from MSFC 4205 to the East Test Area

Test Site (facing away from blast wall)


CRYOTE3 placement at TP308 in the MSFC East Test Area

# CRYOTE3 Schedule for LN2 and LH2 Testing in Atmosphere

| Task | % Complete |
|---|---|
| Administration | 70% |
| **Task #1 Test Article Build and Checkout** | |
| **Milestone #4 Integration** | |
| Tank in Fixture | 100% |
| Tank Innards | 90% |
| Tank Wall Instrumentation | 100% |
| FOSS Installation | 100% |
| Internal Tank Plumbing | 70% |
| Remove Internal Platform | 0% |
| Insulation Installation | 70% |
| Purge Bag Installation | 0% |
| Install Tank Dome Doors | 50% |
| **Milestone #5 Check Outs** | |
| Component Tests | 100% |
| Sub-Assembly Tests | 100% |
| Sensor Check Outs | 100% |
| **Task #2 Liquid Nitrogen Testing** | |
| **Milestone #2 Test Set Up** | |
| Transport to Test Site | 0% |
| Connections | 0% |
| FOSS Connections | 0% |
| Final Check Outs | 0% |
| Safety | 0% |
| **Milestone #3 LN2 Test** | |
| Test Readiness Review | 0% |
| LN2 Test 1 | 0% |
| LN2 Test 2 | 0% |
| LN2 Test 3 | 0% |
| **Milestone #4 Report** | |
| Test Data Analysis and Report | 0% |
| **Task #3 Liquid Hydrogen Testing** | |
| **Milestone #1 Test Design** | |
| Test Objectives/Test Matrix | 100% |
| Instrumentation Design Modifications | 100% |
| Test Area Coordination | 100% |
| Test Requirements Document | 50% |
| **Milestone #2 Test Article Preparation** | |
| Material Compatibility Evaluation | 20% |
| Safety for Hydrogen Testing | 0% |
| System Modifications (if necessary) | 0% |
| Checkouts | 0% |
| **Milestone #3 LH2 Test** | |
| Test Readiness Review | 0% |
| LH2 Test 1 | 0% |
| LH2 Test 2 | 0% |
| **Milestone #4 Report** | |
| Summary Report | 0% |