National Aeronautics and Space Administration

# Structural Heat Intercept, Insulation, and Vibration Evaluation Rig (SHIIVER)


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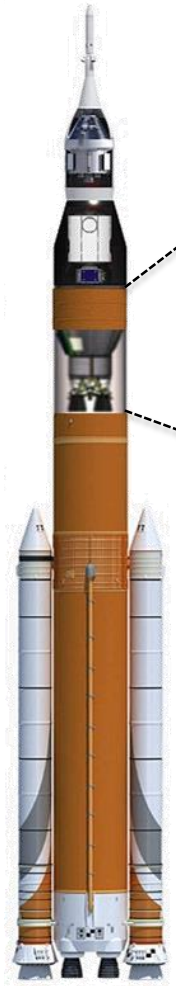
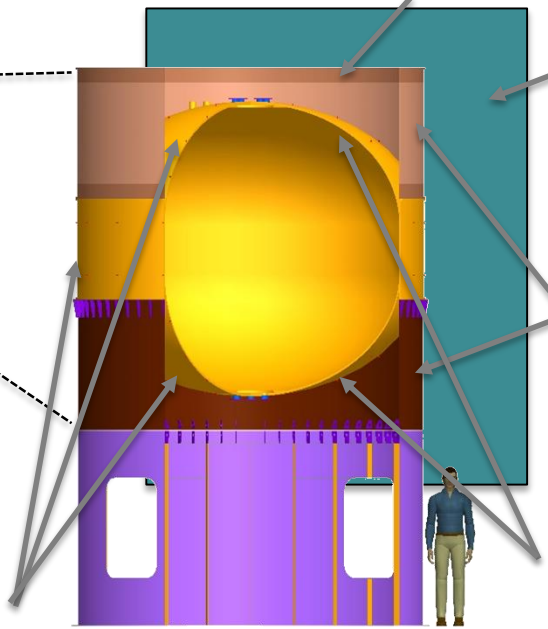
SLS

EUS

SHIIVER





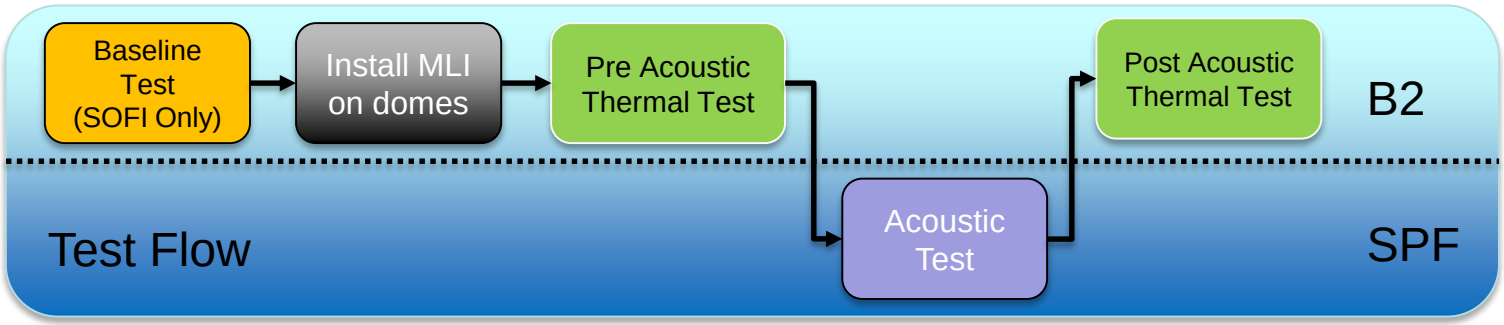
Boil-off vapor cooling on forward skirt

Curtain that can be lowered to simulate external MLI solution thermal benefit

Forward and Aft structural skirts
- Baselined for EUS

Traditional MLI on top and bottom domes

Spray on Foam Insulation on barrel and top and bottom domes
- Baselined for EUS



# Structural Heat Intercept, Insulation, and Vibration Evaluation Rig (SHIIVER)

**Objectives**:

- Perform sub-scale engineering development to ensure that the heat intercept approaches for the large-scale rig are stage-representative.
- Build a large stage-representative rig capable of testing cryogenic fluid management technologies.
- Perform an initial test of the large rig under mission-representative environmental conditions using one configuration of a possible stage-like heat intercept system (vapor cooling and multilayer insulation).

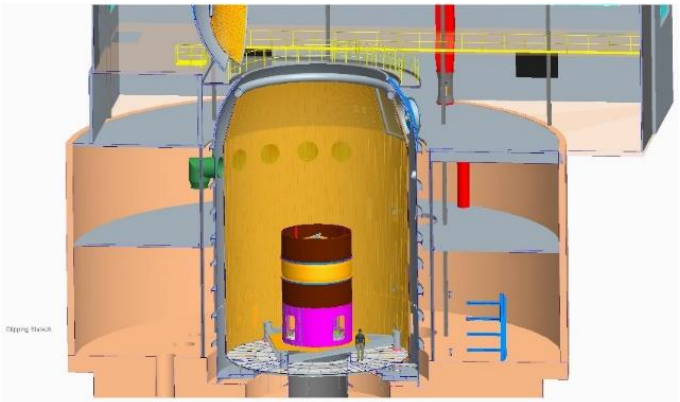
**Status**

- ✓ Tank Engineering Design Approved: Dec 2016
- ✓ MLI Preliminary Design Review: Feb 2017
- ✓ Stakeholders Reviews: June 2015, July 2016
- ✓ SHIIVER Concept Review: August 2015

**Schedule:**

- Receive Tank at MSFC: July 2017
- Finish Sub-scale Vapor Cooling Testing: Aug 2017
- SOFI Installation completed: October 2017
- Testing Starting: August 2018
- Testing Completed: May 2019
- Final Report: April 2020

| KPP | State of the Art | Project Goal |
|---|---|---|
| MLI Thermal Performance on a 4 m tank | SOFI baseline testing done by eCryo | 40% boil-off reduction after exposure to acoustic vibration loads |
| MLI Mass on a 4 m tank | Thick MLI has not been demonstrated in a manner representative of an upper stage flight application. | MLI added mass of not more than 2% of tank fluid mass |
| Vapor Based Heat Intercept Thermal Performance on a 4 m tank | Small flight helium dewars (<2 m). CRYOTE testing (0.75 m) | 15% boil-off reduction on 4 m tank at 50% full |
| Vapor Based Heat Intercept Mass on a 4 m tank | CRYOTE testing (.75 m tank) 9% of tank fluid mass (using LH2 density) | Not more than 5% of tank fluid mass |



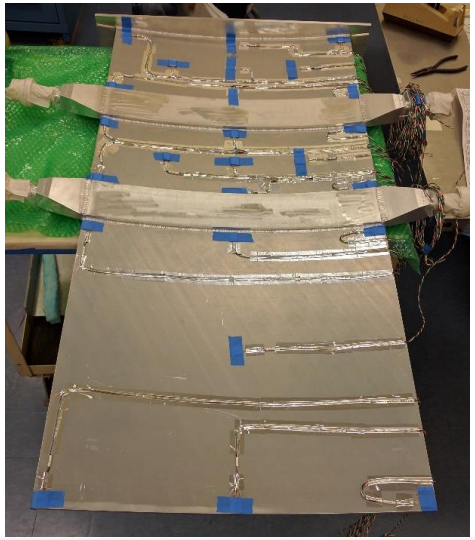
SHIIVER tank installed in B2

Subscale vapor cooling test (skirt section hanging below calorimeter)

SHIIVER is developing the baseline for thermal performance both of existing upper stages and technology enhancements

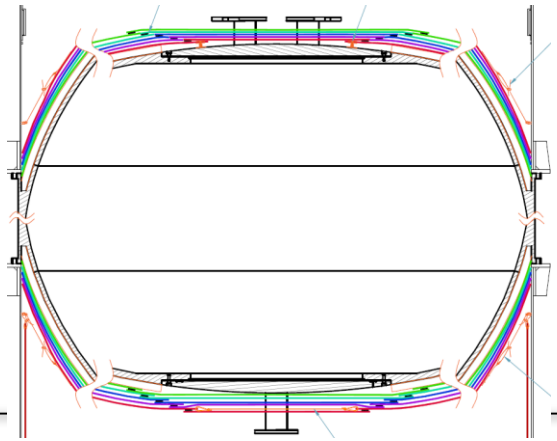
# Sub-scale Vapor Cooling Testing

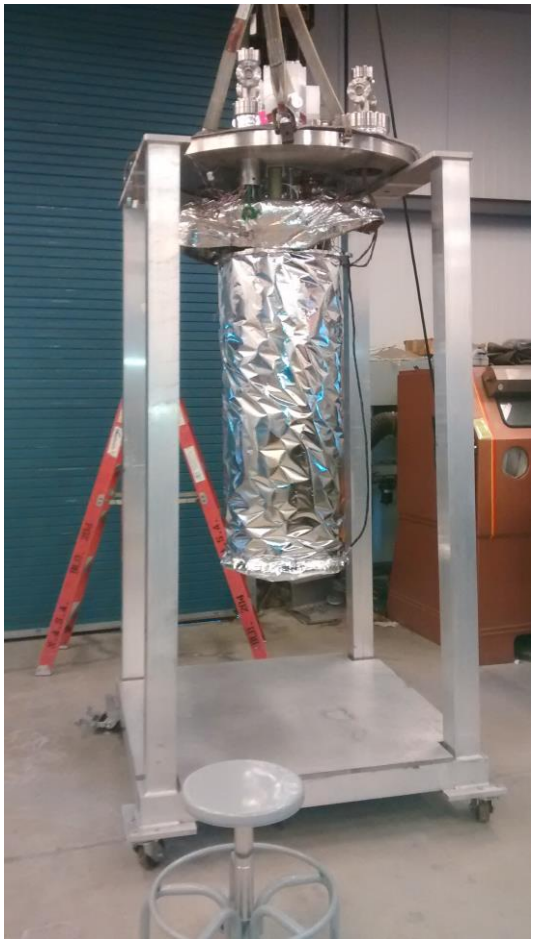
- **Looking at two different flow channels:**
  - Welded, with flow directly on skirt surface
  - Bolted channel assembly
- **Preliminary results from welded flow channel shows a 50%+ reduction in heat load through the skirt. Heat load appears to be more strongly correlated to the inlet coolant temperature.**
- **Remaining tests:**
  - Bolted channel assembly – July 2017



# Multilayer Insulation

- **Design, Fabrication, and Install by Aerospace Fabrication and Materials**
  - Three pieces:
    - MLI for domes – needed for pre-acoustic thermal vacuum testing
    - MLI for curtains – needed for baseline testing
    - MLI for interior of skirts – needed for baseline testing
  - Coupon Testing Feb – June 2017 to verify performance and help scale/analyze data
- **Specifications**
  - 30 layers
  - Attached at outer diameter on skirts
  - Attached near inner manway
  - Expected heat flux less than 1 $W/m^2$
- **Current projected mass: 40 kg**





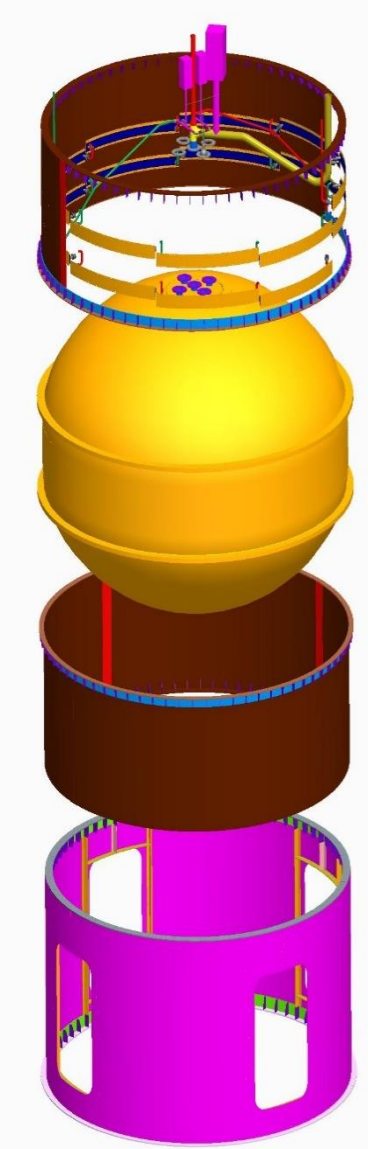
# SHIIVER Components

Forward Skirt w/ cooling loops

4 m tank

Aft Skirt

B2 Support Structure



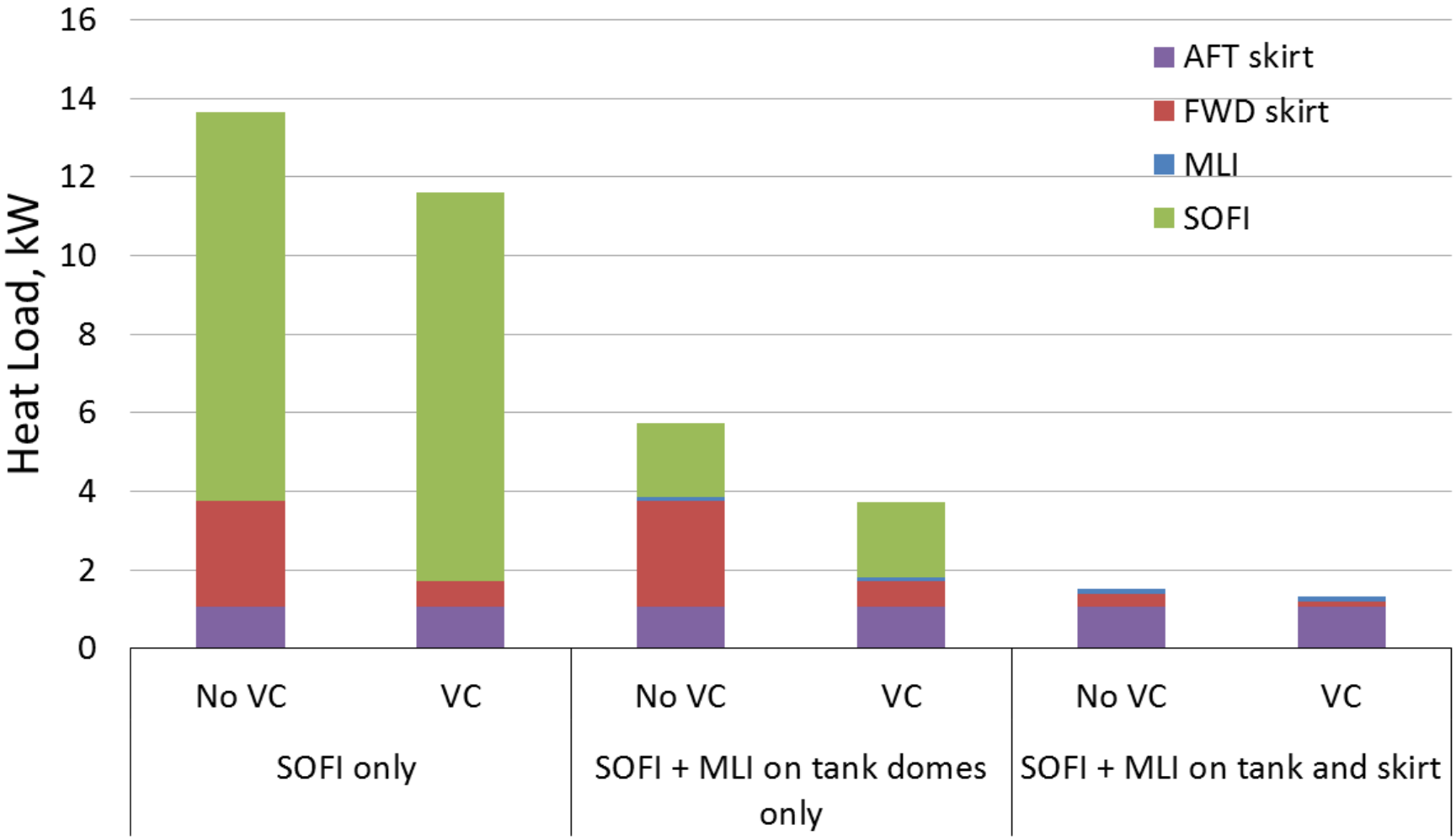
Forward Skirt:
- Design in progress (dependent on SLICE activity)
- Fabrication planned at GRC
- Anticipated Delivery: 12/17

Test Tank:
- Includes manways & “shipping skirts”
- Awarded to Didion on 10/16
- Fabrication completed
- Cold shock completed
- Cleaning/leak test prior to shipment
- Anticipated Delivery to MSFC: 7/17

Aft skirt:
- Design complete
- Fabrication at MSFC/Votaw
- Anticipated Delivery: 9/17

Support structures (3 – 1 for B2, 1 for RATF, 1 for transportation):
- B2 support structure design complete
  - Fabrication in progress @ GRC
  - Anticipated Delivery: 9/17
- Transportation Support Stand
  - Anticipated Delivery: 2/18
- RATF Support Stand
  - Initial requirements evaluated
  - Design not started
  - Anticipated Delivery: 2/18

# Predicted Benefits from Heat Intercept Technology



# Hardware & Testing


SHIIVER Tank During Cold Shock

Machining Tank Flanges


Evolvable Cryogenics (eCryo)
GHC
MSFC
DCST • IPUSI • SHIVER • RFMG • ATK

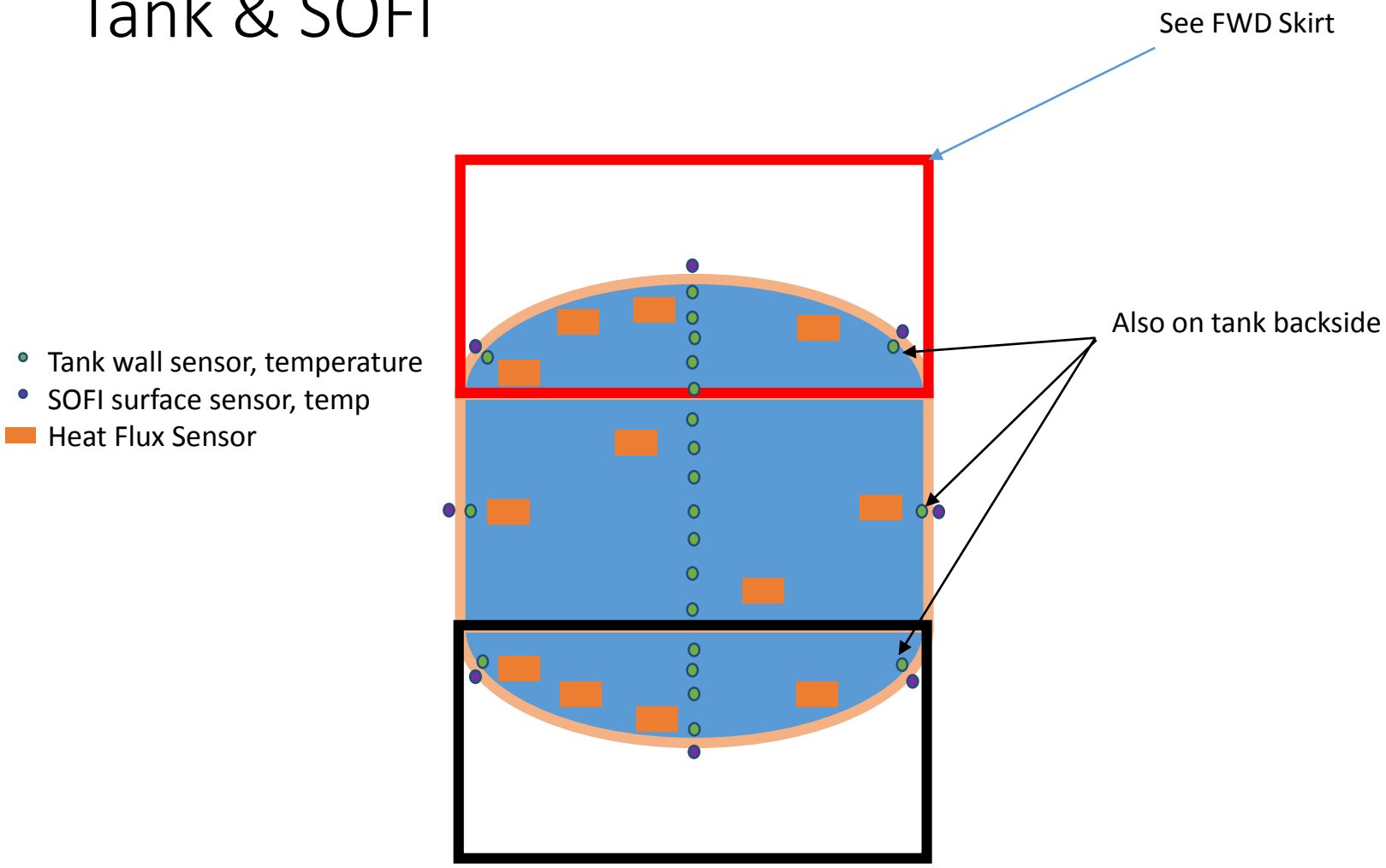

NASA

# TEST PLAN

# SHIIVER Instrumentation

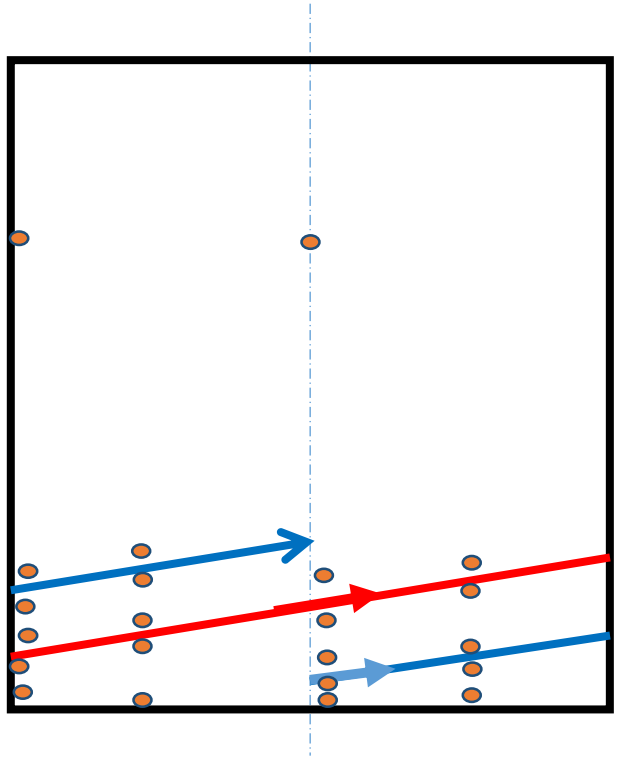
- **Temperature**
  - 190 silicon diodes ordered and delivered in FY16
    - +/- 0.1 K: 4 K < T < 30 K
    - +/- 0.5 K: 30 K < T < 400 K
  - Ordered with ~13 ft leads to minimize extensions needed
  - Locations for 146 assigned diodes on test system have been identified and assigned by SN to P&ID
- **Liquid Level**
  - Capacitance probe ordered and delivered in FY16
  - RFMG installed to demonstrate scaling of hardware
  - Will also have diode rake every 5%
- **Heat Flux Sensors**
  - Heat flux sensors have been identified and purchased for comparative testing
  - Calibration to 20 K this summer
- **Accelerometers**
  - Accelerometers ordered and delivered in FY16
  - Locations still being worked by SHIIVER team
- **Boil-off and Vapor flow**
  - Flow meters have been identified and ordered
  - Covers range of expected heat loads on SHIIVER
- **Pressure**
  - Pressure transducers have been spec'd and identified
  - Quantity and locations on P&ID identified
  - Procurement and placement in B2 in progress

# Tank & SOFI


See FWD Skirt
Also on tank backside
Tank wall sensor, temperature
SOFI surface sensor, temp
Heat Flux Sensor

# FWD Skirt/Vapor Cooling Temperatures

- FWD skirt sensor, temperature



# Test Plan

**Testing split into four distinct categories**

- Baseline Testing:
  - Show system performance with SOFI only (sprayed to EUS dimensions and tolerances)
  - Demonstrate vapor cooling performance benefits with SOFI only
- Pre-Acoustic Testing:
  - Demonstrate performance benefits with MLI compared to baseline
  - Demonstrate vapor cooling performance benefits in conjunction with MLI
- Acoustic Testing:
  - Demonstrate that MLI survives SLS/EUS anticipated acoustic loads
  - Demonstrate that MLI survives transportation between facilities
- Post-Acoustic Testing:
  - Demonstrate performance losses due to acoustic loads on MLI system

# Thermal Vacuum Testing Priorities - Required

Tests required to meet KPPs:

- Insulation performance at 90% full
- Vapor cooling performance at 50% full

| Test Name | Vapor Cooling (On/Off) | Liquid Level (%) | Curtain (Up/Down) | Baseline Testing (SOFI) | Pre-Acoustic Testing | Post-Acoustic Testing |
|---|---|---|---|---|---|---|
| Fill of warm tank (in Vacuum) | Off | 0 – 90 | Up | X | X | |
| Boil-off/Heat Load High Fill | Off | 90 | Up | X | X | X |
| Boil-off/Heat Load Med Fill | Off | 50 | Up | X | X | X |
| Vapor Cooling max flow | On | 50 | Up | X | X | |
| Vapor Cooling – Nominal | On (partial flow) | 50 | Up | X | X | ? |

# Thermal Vacuum Testing Priorities - Needed

Without these tests SHIIVER may be programmatically successful, but leave infusion targets partially satisfied.

| Test Name | Vapor Cooling (On/Off) | Liquid Level (%) | Curtain (Up/Down) | Baseline Testing (SOFI) | Pre-Acoustic Testing | Post-Acoustic Testing |
|---|---|---|---|---|---|---|
| Boil-off/Heat Load High Fill w/curtain | Off | 90 | Down | X | X | X |
| Vapor Cooling/ High fill | On | 90 | Up | X | X | |
| Pressure Rise, High Fill | Off | 90 | Up | ? | X | |
| Vapor Cooling-Nominal/Curt | On | 50 | Down | X | X | |
| Transient Vapor Cooling | On | 70 | Up | X | X | |
| Transient No Vapor Cooling | Off | 70 | Up | X | X | |
| Fill of warm tank (in Vacuum) with cooling | On (partial flow) | 0 – 90 | Up | | | X |

# Thermal Vacuum Testing Priorities - Other

Desired

| Test Name | Vapor Cooling (On/Off) | Liquid Level (%) | Curtain (Up/Down) | Baseline Testing (SOFI) | Pre-Acoustic Testing | Post-Acoustic Testing |
|---|---|---|---|---|---|---|
| Cycling Flow | On | 50 | Up | | X | |
| Boil-off Low Fill | Off | 25 | Up | X | | X |
| Vapor Cooling – Low Fill | On | 25 | Up | X | | X |

# Acoustic Test Matrix

| Test Name | Profile | Duration |
|---|---|---|
| Launch | EUS | 40 s |
| Aero acoustics | EUS | 20 s |

# SHIIVER Conclusions

- The SHIIVER test articles are making progress in development including the beginning of fabrication
- Performance goals and targets are show with projected performance meeting all performance goals
- A prioritized test matrix is laid out to meet all project and performance needs
- Testing should begin in late 2018