Statement of Work (SOW)
Evolvable Cryogenics (eCryo) Tank Design
November 19, 2015

1. Background

This document itemizes the design and fabrication requirements for a cylindrical tank to be used with liquid hydrogen and other cryogenic liquids. Conceptual drawings of the tank design to be designed and fabricated by the manufacturer/vendor are attached. The document covers the manufacture, testing, ASME Code stamping, and delivery of the tank.

1.1. Operational Concept

The tank and associated hardware will be manufactured by the vendor and shipped to a NASA facility in Huntsville, Alabama. Upon arrival in Huntsville, the tank will be supported in various orientations using the forward or aft Y-flanges.

Instrumentation such as thermocouples will then be attached to the tank. The tank will have foam insulation applied to the exterior surfaces. The foam installer will support the tank using the forward and aft manway flanges. The tank will afterwards be shipped by truck to a NASA facility in Sandusky, Ohio. Upon arrival in Sandusky, Multi-Layer Insulation (MLI) will be applied to the exterior of the tank.

The tank and supporting skirt will be placed inside a vacuum chamber where the tank will be filled with cryogenic liquids including Liquid Hydrogen (LH2), Liquid Nitrogen (LN2), or Liquid Oxygen (LO2). Inside the vacuum chamber, the tank will be supported by the skirt at the bottom of the tank. The vacuum chamber is maintained at a pressure of 1.0 $x10^{-6}$ Torr during testing while the tank is filled with cryogenic propellant.

2. Vendor Deliverables

In accordance with this requirements document, the vendor shall supply the following deliverables and equipment to the NASA Marshall Space Flight Center in Huntsville, AL.

2.1. Hardware:

2.1.1 Vessel: The vendor shall supply one cylindrical tank.

2.1.2 Material Sample: The vendor shall supply representative samples of material used to construct the tank including weld coupons.

2.1.3 Miscellaneous Hardware: The vendor shall supply the bolts and blind flanges required for testing and shipping of the tank.

2.1.4 Seals: The vendor shall furnish a minimum of two sets of c-seals for all manway closure and nozzle joints.

2.1.5 Shipping Skirts: The vendor shall provide skirts for shipment of the tank.

2.1.6 Skirt Shipping Covers: The vendor shall provide covers for the shipment of the skirts and tank.

2.2. Documentation

The vendor shall supply all the following documentation upon delivery of finished tank, all to be delivered in the specified electronic format:

2.2.1 Models/Drawings: If the work is performed using solely 2-D design tools, the vendor shall supply as-designed drawings with any approved manufacturing deviations. If the work is performed using 3-D design tools, both the models and drawings shall be supplied in a CREO-readable format.

2.2.2 Applicable manufacturer's U-1 form (PDF): Registered with the National Board of Boiler and Pressure Vessel Inspectors.

2.2.3 Design calculations, analysis, and specifications. (PDF)

2.2.4 Mill test reports. (PDF)

2.2.5 Impact test results. (PDF)

2.2.6 Inspection and Non-Destructive Examination (NDE) reports. (PDF)

2.2.7 Hydrostatic pressure test reports. (PDF)

2.2.8 Helium leak check test reports. (PDF)

2.2.9 LN2 cold shock test reports. (PDF)

2.2.10 Welding Procedure Specification (WPS), Procedure Qualification Record (PQR), and Welder Performance Qualification (WPQ). (PDF)

2.2.11 Handling and Shipping Fixture Design Documentation.

3. General Requirements for Tank

3.1. Tank Design

The tank shall be designed, tested and stamped to the latest edition of ASME Boiler and Pressure Vessel Code, Section VIII, Division 1 or Division 2. The tank shall be stamped with the maximum allowable working pressure for which the tank qualifies. The ratio of the tank radius to tank dome height shall be √2:1.

3.2. Materials

The material used in the construction of the tank shall be 304/304L or 316/316L stainless steel.

3.3. Weight Minimization

The tank shall be designed to minimize weight.

3.4. Tank Geometry

The tank geometry shall be based on the attached sketch of the tank, which is provided for quotation purposes. The sketch is provided for reference purposes only. Exact dimensions, tolerances, geometry, and details will be finalized during the vendor design period of performance.

3.5. Operating Conditions

3.5.1 Minimum Design Metal Temperature: The tank shall be designed with a minimum design temperature of -423 ^{o}F.

3.5.2 Maximum Design Metal Temperature: The tank shall be designed with a maximum design temperature of 200 ^{o}F.

3.5.3 Maximum Pressure: The tank shall be designed to a maximum operating pressure of 85 PSID.

3.5.4 Vacuum Pressure: The tank shall be designed to operate with an internal vacuum (-15 PSIG).

3.5.5 Oxygen Service: The tank shall be designed for oxygen service.

3.5.6 Shipping/transportation: The design of the tank and shipping skirt assembly shall account for shipping and handling load factors for transport by truck as follows:

Fore/aft loads: +/- 2g
Lateral loads: +/- 2g
Vertical loads: +3g / - 1 g

Vertical (+) acceleration is up, vertical (-) acceleration is down. Vertical (+) acceleration means the force of the carrier (truck bed) is pushing up on the assembly. Factors shall be applied simultaneously in each direction, at the center of gravity of the assembly. The shipping assembly shall also account for a 30 knot wind load in combination with these load factors. The assembly must be restrained from sliding or tipping during shipping. Restraints (hold down straps, cables, etc.) must be capable of withstanding the resultant loads with these factors applied.

3.5.7 Hoisting: Lifting attachments capacity shall apply a load factor of +1.33g to hoist loads. This is in addition to safety factors already applied for static loads.

3.6. Descaling

Each tank shall have all surfaces de-scaled per ASTM A-380 or approved equivalent.

3.7. Passivation

Each tank shall have all surfaces passivated per ASTM A-967, or approved equivalent.

3.8. Surface Finish

The tank shall have a surface finish less than 128 micro-inches.

3.9. Required Testing

3.9.1 Cold Shock Test: The tank shall be cold shock tested with LN2. All welds shall be visually inspected to verify freedom from cracks.

3.9.2 Pressure Test: After the cold shock test, the tank shall be pressure tested according to ASME Boiler and Pressure Vessel Code, Section VIII, Division 1.

3.9.3 Material Impact Test: The material used in the construction of the tank shall be material impact tested in accordance with the ASME Boiler and Pressure Vessel Code, Section VIII, Division 1. (*Rationale: Section VIII, Division 1, Section UHA 51(g) requires that Stainless Steel be impact tested if the material is to be used below -320 ^{o}F)*

3.9.4 Helium Leak Check: After the hydrostatic test of the tank, the tank shall be helium gas leak tested per ASTM E-499, Method B. The maximum allowable helium leak rate for the tank assembly is 1 x 10^{-6} standard cubic centimeters per second.

3.9.5 Welding: All welds shall be qualified per ASME Section IX.

3.9.6 Non Destructive Examination (NDE) Testing: Welds used to fabricate the tank shall be examined using the NDE testing required by ASME Boiler and Pressure Vessel Code, Section VIII, Division 1, Subsection B, Part UW.

3.9.7 Weight: The tank shall be weighed using a calibrated scale, with the tank weight metal stamped on the tank name plate.

3.9.8 Volume: The volume of the tank shall be measured at room temperature and permanently stamped on the tank name plate.

4. Detailed Design Requirements

4.1. Tank Diameter

The tank cylindrical section shall have an internal diameter of 157” to 157.5” shown in detail section A-A of eCryo-SCM-0086.

4.2. Tank Height

The tank shall have an external height, not including manway penetrations, of at least 134” and not more than 135.4” shown in eCryo-SCM-0086.

4.3. Y-Flange Tank Support

The tank shall be supported by the upper or lower Y-flange shown in eCryo-SCM-0086, under section A-A and details G and F. The Y flanges shall be designed to accommodate the total weight of the tank filled with liquid oxygen (71.2 lb/ft^3), the associated insulation attached to the tank (600 lbs), and the weight of the upper skirt and associated hardware of 3,400 lbs.

4.3.1 Bolt Circle Diameter: The Y-flange shall have a bolt circle diameter. The bolt circle diameter and bolt size will be determined between NASA and vendor during the design stage of the contract.

4.3.2 Y-Ring Flatness: The Y-ring’s shown in details G and F shall have a flatness level of or below 0.030”.

4.3.3 Y-Ring Perpendicularity: The Y-ring’s shown in details G and F shall have a perpendicularity level to the tank surface below 0.030”.

4.4. Manway Flanges

The tank shall contain 24” flanged manways on the forward and aft sections of the tank shown in details H and J in eCryo-SCM-0086.

4.4.1 C-Seal Flanges: The tank shall utilize flanges that have redundant C-seals shown in details K and N. The flanges shall have a circumferential groove between the C-seal grooves.

4.4.2 Leak Port: The flange shall contain a leak port connected to the circumferential groove between the C-seal passages shown in details K and N. The leak port shall contain a 4” tube stub.

4.5. Forward Manway Flange Nozzles

The forward manway shall have five 3” ASA flat faced flange nozzles. Exact locations shall be determined between NASA and vendor during the design stage of the contract. The standoff height of the flanges shall be 1.5”shown on details H and J in eCryo-SCM-0086.

4.6. AFT Manway Flange Nozzles

The aft manway shall have three 3-inch ASA flat faced flanged nozzles. Exact locations shall be determined between NASA and vendor during design.

4.7. Blind Nozzle Flanges

The vendor shall furnish eight 3-inch blind flanges for pressure/leak testing of the manway nozzles. The blind flanges shall contain redundant C-seal grooves. The flanges shall be designed to the same operational conditions as the tank.

4.8. Blind Manway Closures

The vendor shall furnish one set of blind manway closures for pressure testing and shipping of the tank. The closures shall be rated for the same operating conditions as the tank, and shall contain identical seal configuration as the ported manway closures.

4.9. Leakage Requirement

C-seal joints shall be design for a maximum seal leakage rate of 2.0 $x10^{-6}$ SCCM helium per linear inch at -423°F and 35 PSIG.

4.10. Forward Manway Counterbore

The tank shall contain a counterbore for supporting an internal mounting ring shown in details H and J. The man way and tank heads shall be designed to accommodate a total weight of 500 lbs distributed circumferentially around the manway. The counterbore shall contain three dowel pin holes to be used for alignment purposes.

4.11. Exterior Attachment Studs

The tank shall have a total of one hundred and forty four (144) 5/8-inch diameter threaded studs, ½ to ¾ inch tall, arc welded to the tank exterior surface. Exact location of studs will be determined between NASA and vendor during the design stage of the contract.

4.12. Interior Attachment Studs

The interior of the tank shall have up to twelve mounting studs arc welded to the tank. Exact location of studs will be determined between NASA and vendor during the design stage of the contract.

4.13. Lifting and Rotation Rings

The vendor/supplier shall provide on each flange four threaded blind holes centered axially on the flange and drilled radially into the outer circumference to attach D-rings for lifting and rotation of the vessel shown in detail P in eCryo-SCM-0086. The D-rings shall be removable and replaceable with ordinary hand tools (ex. threaded attachments). The D-rings shall be clocked at 90 degree increments on each flange, and the rings of the forward flange shall align axially with those of the aft flange. During handling operations and breakaway maneuvers, each ring shall be capable of supporting the full weight of the empty tank assembly.

4.14. Shipping Skirts

The vendor shall include in this procurement, forward and aft tank skirts to be used for shipping and for handling and support during application of foam insulation and instrumentation shown in section D-D in eCryo-SCM-0086. The skirts shall be attached to the tank flanges by bolts. Each skirt shall extend six inches in the axial direction beyond the manway cover (there should be six inches clearance between the manway cover and the skirt cover). The skirts shall each be equipped with four D-rings for installation onto the tank and removal of the skirt from the tank. Skirt D-rings shall be clocked at 90 degree increments and located axially on the end opposite that of the flange for attachment to the tank. The skirt D-rings may be permanently affixed or removable. The skirts shall be inherently corrosion resistant, or shall include a barrier to inhibit corrosion and protect the tank from contamination foreign metals or oxides, manufactured from carbon steel. The overall height of the tank-skirt assembly in the vertical orientation shall be not more than 12 feet 6 inches.

4.14.1. Structural Factor of Safety: The shipping skirts shall designed with a structural factor of safety of 3 on yield material strength and 5 on ultimate material strength.

4.15. Shipping Covers

The vendor shall provide covers to protect the tank and shipping skirts during storage and transportation from environmental hazards such as precipitation, road salt, and foreign object damage.

4.16. Preparation for Shipment Requirements

4.16.1 Cleaning: Tank interior and exterior surfaces shall be cleaned per SSPC Surface Preparation Standard Number 1 to a visibly clean condition. Water-break testing per ASTM F22 shall be performed at a minimum of (4) interior and (4) exterior locations of at least 4 square feet area each. Exact locations of water-break inspection locations shall be agreed upon between NASA and vendor prior to cleaning.

4.16.2 Sealing: After cleaning, the tank shall be sealed for shipment using the blind flanges and filled with clean, dry, inert gas at 2 psig.

5. Schedule Requirements

5.1. Fabrication Schedule

Within 14 calendar days of award of contract, the vendor shall provide one copy of the vessel design and fabrication schedule and the tank cleaning procedure.

5.2. Biweekly Progress Reports

The vendor shall provide a copy of progress reports every other week, using normal in-house formats. At major fabrication stages, digital pictures of the tank shall be provided to the NASA GRC technical representative.

5.3. Engineering Documents and Drawings

Within 100 calendar days of award of contract, the vendor shall provide engineering calculations, stress analysis, and detailed drawings, in PDF format. The customer will respond with "approved" or "approved as noted" within 10 working days of the cleaning procedure, calculations, and drawings receipt.

5.4. Final Drawings

Within 7 calendar days of fabrication completion, the contractor shall provide the as-designed drawings with any NASA approved manufacturing deviations.

5.5. Witness Testing

NASA will have the option to witness the tests and attend periodic plant visits.

5.6. Tank Delivery

The tank shall be delivered to Marshall Space Flight Center by December 6, 2016.

6. Shipping Requirements

Delivery for one tank shall be to following location:

Marshall Space Flight Center
Huntsville, AL

7. Options

The vendor shall provide proposals on contract impacts (overall contract cost and more importantly, impact to the tank design period and delivery date) for the following options. Tank requirements will be maintained, other than what is noted in the text below.

7.1 Option 1 – Tank Dome Heads

The vendor shall provide a proposal noting contract impacts for utilizing 2:1 elliptical heads rather than √2:1 elliptical heads.

7.2 Option 2 – Flange Attachments

The vendor shall provide a proposal noting contract impacts for welding flanges to the tank shell rather than a Y-ring.

7.3 Option 3 – Shipping Skirts

The vendor shall provide a proposal noting contract impacts for fabricating shipping skirts from 304/304L stainless steel rather than carbon steel.

7.4 Option 4 – Financial Incentive

The vendor shall provide a proposal noting contract impacts if an additional 10% of contract value premium incentive was included at contract award to accelerate schedule.