KSC-STD-Z-0009
Revision D

DESIGN OF CRYOGENIC GROUND SYSTEMS AND GROUND SUPPORT EQUIPMENT,

STANDARD FOR

October 20, 2020

Engineering Directorate

National Aeronautics and
Space Administration

John F. Kennedy Space Center

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STANDARD FOR

Approved by:

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October 20, 2020

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RECORD OF REVISIONS/CHANGES

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D		Replaced outdated reference documents, eliminated duplicated requirements, updated to align with current design practices and standards.	October 20, 2020

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ABBREVIATIONS, ACRONYMS, AND SYMBOLS

AIA	Aerospace Industries Association
ANSI	American National Standards Institute
API	American Petroleum Institute
ARP	Aerospace Recommended Practice
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
CCAFS	Cape Canaveral Air Force Station
CO_2	Carbon Dioxide
Cv	Flow Coefficient
Deg	Degree
EGSE	Electrical Ground Support Equipment
EJMA	Expansion Joint Manufacturers Association
EMA	Electro-Mechanical Actuator
GH2	Gaseous Hydrogen
GHe	Gaseous Helium
GM	General Motors
GN2	Gaseous Oxygen
GO2	Gaseous Oxygen
GP	General Publication
gpm	Gallon per Minute
GSE	Ground Support Equipment
Hg	Mercury
in	Inch
JSC	Lyndon B. Johnson Space Center
kPa	Kilo-Pascal
KSC	John F. Kennedy Space Center
KTI	Kennedy Technical Instruction
LDE	Lead Design Engineer
LH2	Liquid Hydrogen
LHe	Liquid Helium
LN2	Liquid Hydrogen
LNG	Liquid Natural Gas
LO2, LOX	Liquid Oxygen
m3	Cubic Meter
M&P	Materials and Process
MAPTIS	Materials and Processes Technical Information System
MAWP	Maximum Allowable Working Pressure
MDP	Maximum Design Pressure
MIL	Military
MLI	Multi-Layer Insulation
mm	Millimeter
MOP	Maximum Operating Pressure
MPa	Mega-Pascal
MSFC	George C. Marshal Space Flight Center

NAS	National Aerospace Standards
NASA	National Aeronautics and Space Administration
NDE	Non-Destructive Examination
NFPA	National Fire Protection Assocation
Pa	Pascalppm Parts per Million
PQR	Performance/Procedure Qualification Record
psi	Pound per Square Inch
psia	Pound per Square Inch Absolulte
psig	Pound per Square Inch Gauge
SAE	Society of Automotive Engineers
sccm	Standard Cubic Centimeters per Minute
std-cc/sec	Standard Cubic Centimeters per Second, or sccs
SLS	Space Launch System
SPEC	Specification
STD, std	Standard
UV	Ultra-Violent
VC	Visibility Clean
VDC	Voltage-Direct Current
VJ	Vacuum Jacketed
WPS	Welding Procedure Specification
ºC	Degree Celsius
ºF	Degree Fahrenheit
µm	Micrometer (1 Micrometer equals 1 Micron)

1. SCOPE

KSC-STD-Z-0009 supplements KSC-DE-512-SM to establish engineering requirements for materials, processes, methods, practices, and designs to be applied to cryogenic Ground Systems (GS). KSC-STD-Z-0009 is based on the combined design experience gained during the Apollo, Shuttle, Constellation and Space Launch System programs.

Cryogenic systems in use at KSC operational facilities include Liquid Hydrogen (LH2), Liquid Oxygen (LO2), Liquid Nitrogen (LN2) and their respective vent gases. This standard also applies to Cold Gaseous Helium (CGHe), Liquid Natural Gas (LNG) and Liquid Helium (LHe) systems.

Individual provisions within KSC-STD-Z-0009 may be tailored to meet project needs. Requestor shall submit deviation/waiver request(s) including detailed justification and rationale to Office of Primary Responsibility Designee (OPRD) for evaluation.

1.1 Use of Shall, May, Should, and Will

In this standards manual, the terms “shall,” “may,” “should,” and “will” are defined in KSC-DE-512-SM.

2. APPLICABLE DOCUMENTS

The latest issuances of documents listed in this section contain provisions that constitute requirements of this standard as cited in the text. Notify the Lead Design Engineer of revisions to documents, or alternate standards, during the design that will affect the design or the construction costs, so that a proper evaluation of the changes may be accomplished.

2.1 Government Publications

76K04875	Stud Bolt Type 316 SST
76K04886	Gasket - LH2 and LO2 Cryogenic
76K04892	LOX Mech System-Pipe Flange-Fastener Assy
76K04932	LH2 ML and Launch Complex Pipe Flange-Fastener Assy
79K14672	Vacuum Valve Assembly
79K22280	Specification for Lubricant for 1,000-GPM LO2 Pump Bearings
GP-425	Fluid Fitting Engineering Standards

K0000090115	SLS Induced Pad Environments, Pad 39B
K0000132092-ANA	SLS Mobile Launcher Exhaust Plum Induced Environment, - Acoustic and Vibration, Volume 1
KDP-P-2762	Oxygen Compatibility Assessment for Oxygen and Breathing Air Systems
KSC-C-123	Specification for Surface Cleanliness of Ground Support Equipment Fluid System
KSC-DE-512-SM	Facility Systems, Ground Support Systems, and Ground Support Equipment, General Design Requirements
KSC-NE-13557	Assess Pad B Subsystems for Induced Environments
KSC-STD-G-0003	Standard for Qualification of Launch Support and Facility Components
KSC-STD-Z-0005	Standard For Design of Pneumatic Ground Support Equipment
KSC-STD-Z-0015	Standard for Engineering Analysis
KSC-STD-Z-0017	Standard for Thermal/Fluid Engineering Analysis
KTI-5210	Material Selection List for Oxygen Service
MIL-PRF-25567	Leak Detection Compound, Oxygen Systems
MIL-PRF-27401	Performance Specification, Propellant Pressuring Agent, Nitrogen
MIL-PRF-27407	Performance Specification, Propellant Pressuring Agent, Helium
MPCV 70156	Cross Program Fluid Procurement and Use Control Specification
MSFC 20M02540	Assessment of Flexible Lines For Flow Induced Vibration
NASA-STD-5008	Protective Coating of Carbon Steel, Stainless Steel, and Aluminum on launch Structures, Facilities, and Ground Support Equipment

NASA/TM-2008-215633	Terrestrial Environment (Climatic) Criteria Guidelines for Use in Aerospace Vehicle Development, 2008 Revision
SLS-SPEC-159	Cross-Program Design Specification For Natural Environments (DSNE)

2.2 Non-Government Publications

ANSI/AIAA G-095	Guide to Safety of Hydrogen and Hydrogen Systems
ANSI/MSS SP-134	Manufacturer's Standardization Society of the Valves and Fittings Industry, Valves for Cryogenic Service Including Requirements for Body/Bonnet Extensions
API 579	ASME Fitness-For Service (FFS)
API 598	American Petroleum Institute, Valve Inspection and Testing
ASCE 7	American Society of Civil Engineers, Minimum Design Loads for Buildings and Other Structures
ASME B16.5	American Society of Mechanical Engineers, Pipe Flanges and Flanged Fittings
ASME B16.34	Valves – Flanged, Threaded and Welding End
ASME B31.3	American Society of Mechanical Engineers, Process Piping
ASME BPVC Section VIII, Division 1 or 2	American Society of Mechanical Engineers, Boiler and Pressure Vessel Code (BPVC), Rules for Construction of Pressure Vessels, Division 1 or 2
ASTM A240	Standard Specification for Chromium and Chromium-Nickel Stainless Steel Plate, Sheet, and Strip for Pressure Vessels and for General Applications
ASTM A312	Standard Specification for Seamless, Welded, and Heavily Cold Worked Austenitic Stainless Steel Pipes
ASTM A580	Standard Specification for Stainless Steel Wire

ASTM A967	Standard Specification for Chemical Passivation Treatments for Stainless Steel Parts
ASTM B575	Standard Specification for Low-Carbon Nickel-Chromium-Molybdenum, Low-Carbon Nickel-Chromium-Molybdenum-Copper, Low-Carbon Nickel-Chromium-Molybdenum-Tantalum, Low-Carbon Nickel-Chromium-Molybdenum-Tungsten, and Low-Carbon Nickel-Molybdenum-Chromium Alloy Plate, Sheet, and Strip
ASTM C549	Standard Specification for Perlite Loose Fill Insulation
ASTM D1193	Standard Specification for Reagent Water
ASTM D4745	Standard Classification System and Basis for Specification for Filled Polytetrafluoroethlyene (PTFE) Molding and Extrusion Materials Using ASTM Methods
ASTM D7194	Standard Specification for Aerospace Parts Machined from Polychlorotrifluoroethylene (PCTFE)
NFPA 55	National Fire Protection Association – Compressed Gases and Cryogenic Fluids Code
NFPA 70	National Fire Protection Association - National Electric Code
ISO 14952	Space systems — Surface cleanliness of fluid systems

3. GENERAL DESIGN REQUIREMENTS

All provisions and requirements of KSC-DE-512-SM will be followed in the design of new equipment, and in the modification of equipment designed in accordance with this standard. In the event of a conflict with the requirements of KSC-DE-512-SM, and any lower-level document, KSC-DE-512-SM will take precedence unless lower-level document imposes more stringent requirements.

In addition with this standard, cryogenic GS shall conform to the requirements of NFPA 55.

3.1 Vent, Drain and Purge System Design

a. Vent lines will be provided at the system high points.

b. The vent system will be equipped with either a GN2 or GHe purge system designed to dissipate a static fire and prevent atmospheric intrusion.

c. Drain lines will be connected at system low points and sloped to drain all liquid from the system.

d. Purge gas for hydrogen systems in their operational configuration shall be GHe.

When GN2 is used in hydrogen systems for either maintenance, to dissipate a static fire or to prevent atmospheric intrusion, particular care must be exercised to prevent nitrogen migration upstream of the vent. GHe purging and subsequent system sampling will be required to verify GN2 content is reduced to acceptable levels.

e. Purge gas for oxygen systems shall be either GN2 or GHe.

GN2 is preferred based on cost and availability.

f. Neither GN2 nor LN2 will be introduced into any LH2 line without a minimum of two closed isolation valves from the hydrogen source.

Design intent is to provide double block, or isolation, precluding nitrogen from being introduced into hydrogen systems during hydrogen operations. Nitrogen will solidify when exposed to liquid hydrogen temperatures.

g. Mixing of media between common purge lines will be precluded by use dual check valves with test ports in-between to prevent backflow from a system into a purge distribution manifold.

For example, the installation of dual check valves at the connection point where either nitrogen (for LO2 system only) or helium gas is used to purge a LO2 or LH2 line. Design intent for dual check valves to preclude either LO2 or LH2 migrating too far into purge supply system.

3.2 Fluid System Cleanliness

Ports should be provided for cleaning and inspection especially in dead-ended sections and dirt traps. Installation of isolation valves, blind flanges or other methods to facilitate maintenance (e.g. systems cleaning) should be considered.

Cryogenic GS installed downstream of final filter will meet, as a minimum, the fluid purity and particulate requirements established by the Program for the flight hardware. Other cryogenic GS shall be cleaned in accordance with KSC-DE-512-SM to the following fluid system cleanliness levels.

3.2.1 Cryogenic Fuel Systems

a. Storage vessels, piping, flex hoses and components of Launch Pad Element including vent systems, clean to level visibly clean (VC).

b. For components, piping and flex hoses upstream of final filter and for vent systems, clean to level 300.

3.2.2 Cryogenic Oxidizer Systems

a. Storage vessels, piping, flex hoses and components of Launch Pad Element including vent systems, clean to 1000A.

b. For components, piping and flex hoses upstream of final filter and for vent systems, clean to level 300A.

3.2.3 Inert Cryogenic Fluid Systems

Components, piping, and flex hoses, clean to level 1000.

3.2.4 Vacuum-Jacketed Pipe Field Closure Cans

Prior to installation, field cans shall be cleaned in accordance with ISO 14952 to Visibly Clean (VC) using cleaning agents that will not off-gas under vacuum conditions. Cleanliness will be maintained during installation.

3.2.5 Cryogenic Purge Gas System Design

GN2 and GH3 systems used for purging cryogenic systems shall meet the requirements of KSC-STD-Z-0005.

3.2.6 Flushing

All flushing will be toward the system low point.

3.3 Useful Service Life

When useful service life of GS designs is not specified by the Program, designs will meet a minimum 20-year service life when exposed to the environmental conditions given in NASA/TM-2008-215633.

3.4 Cyclic Service Life

Cryogenic piping and components will be designed to withstand 7000 pressure and thermal cycles over the useful service life of the hardware without damage to structure, assemblies, or components.

a. Pressure cycle defined as from ambient to MAWP, or Design Pressure, and return to ambient.

b. Thermal cycles defined as from ambient to minimum design temperature and then return to ambient.

4. DETAILED DESIGN REQUIREMENTS

4.1 Piping Systems

a. Installed piping systems will be capable of being completely drained, or trapped sections will have manual drain vent plumbing.

b. Relief valves, pressure ports, and temperature ports will be designed to minimize conduction (i.e. heat leak) into the piping systems.

4.1.1 Piping

4.1.1.1 Double Wall Piping

a. Outer line, or jacket, pipe shall be austenitic stainless steel dual grade 316/316L (UNS 31600/UNS 31603) in accordance with ASTM A312.

   Given the natural humid, ocean-side and launch-induced i.e. (SRM residue) environments experienced at KSC, 316/316L is selected over 304/304L because of its enhanced corrosion resistant properties.

b. All inner line welds and all outer line welds attached to the inner line shall meet the requirements for severe cyclic service per ASME B31.3.

   Inner line welds that cannot produce a readable or interpretable radiograph shall be reviewed on a weld-by-weld basis. In addition to visual examination in accordance with ASME B31.3, welds shall successfully complete alternative nondestructive test methods such as pressure/leak testing, cold shock and MSLT at a minimum.

c. All outer line welds including welded field closure cans shall meet the requirements for normal fluid service per ASME B31.3, and shall be 100% dye penetrant examined.

   Outer jacket welds that cannot be radiographically examined shall be reviewed on a weld-by-weld basis. Welds shall complete 100% VT, 100% PT examination, and MSLT testing at a minimum.

4.1.1.2 Vacuum-Jacketed (VJ) Piping

Piping in direct contact with cryogenic fluid, or gas, will be VJ design and constructed with an inner and outer line, or jacket, separated by a vacuum annular space except where insulated single-wall piping is allowed per this standard.

a. Helium shall not be permitted in the annular space.

   Helium mass spectrometer leak testing is performed on inner pipe and outer jacket welds. From engineering experience, helium introduced into the annular space of VJ components has been found to be difficult to remove. Annular space must be free of helium in order to obtain an accurate leak test result.

b. For VJ piping and components, the specified design pressure will be coincident with full vacuum (.01 torr) in the annular space.

c. When selecting the inner-line wall thickness the thermal mass required to be cooled and the solid conduction heat leak will be considered to minimize line chilldown requirements.

   Schedule 5 and 10 are commonly used for this application.

d. Welds located in, or exposed to, the vacuum annulus shall not be dye penetrant inspected.

e. The outer jacket piping and bellows will be designed for external pressure of 14.7 psia with .01 torr (full vacuum) annular space pressure, and for an annular space (internal) pressure of 35 psia with 14.7 psia external pressure.

f. Each section of VJ pipe and field welded vacuum closure can will be equipped with a vacuum valve assembly conforming to 79K14672, or Engineering directorate-approved equivalent assembly qualified in accordance with KSC-STD-G-0003. The function of the vacuum valve assembly will be accomplished with a single penetration into the pipe annulus. The assembly will be accessible for personnel to perform normal operations and maintenance.

g. After system installation, visual observation for frost patterns will be performed and vacuum readings will be taken on a periodic basis to ensure proper system performance and track vacuum trends. All operational vacuum sections shall be kept below 1000 microns (at ambient temperature).

4.1.1.2.1 VJ Metallic Bellows

a. Expansion bellows are prohibited from being located in the inner line of VJ pipe.

   A concern is for failure, cyclic or otherwise, of the inner bellows, and the associated cost and schedule to remove and replace.

b. Bellows will accommodate the movements between the inner and outer lines and will be located to minimize stress at fittings and welds.

c. Longitudinal seams on expansion bellows shall be 100% radiographed, or by other volumetric examination approved by NASA M&P, prior to the forming process. Acceptance criteria shall meet the requirements of ASME B31.3 for severe cyclic conditions.

d. Metallic bellows shall be designed in accordance with either ASME B31.3, appendix X, or Standards of the Expansion Joint Manufacturers Association (EJMA), as applicable.

e. Bellows shall be single-ply construction using Hastelloy C22 (UNS N06022) conforming to ASTM B575, or engineering approved alternate material.

4.1.1.2.2 VJ Field Joints

a. Field VJ piping installations will accommodate a field welded vacuum closure can to enclose the inner line terminations. Other insulators may be employed in the field joint enclosure instead of a vacuum, as long as the total heat leak (i.e. heat load, or thermal requirements) for the entire system are satisfied.

An example for an alternative insulator is the use of a passively insulated field can using aerogel insulation material beads/blankets with MLI and ambient pressure CO2 backfill.

b. Field VJ joints will include a minimum of 4 inches extra pipe length beyond joint for field fit up, and a closure ring welded to outer jacket.

c. When inner pipe material is Invar, in accordance with this standard, consideration should be given to attaching either 304/304L or 316/316L stainless steel pipe stub ends to Invar pipe spool sections at planned field joint locations. Stainless steel pipe ends will extend beyond outer jacket-to-inner pipe closeout such that no Invar pipe is exposed at field joint.

Design intent is to protect the Invar from direct environmental (rain, humidity, salt, etc.) exposure by terminating the Invar pipe within the outer vacuum jacket, thus, only exposing the stainless steel pipe ends. Corrosion of Invar pipe accelerates in this environment.

d. Field weld closure can installation will not be performed until all field fabrication, including repairs, and examinations have been completed, and after satisfactory completion of cold shock and pressure/leak test of system installations.

4.1.1.2.2.1 VJ Annual Space

a. The inner line of VJ pipe will be supported with spacers that center it within the outer jacket, and minimize heat leakage and off-gassing.

b. The thermal efficiency of the vacuum insulation will meet the overall system requirements. Information pertaining to thermal performance testing of cryogenic insulation systems and guide for the use of thermal insulations can be found in ASTM C1774 and ASTM C740, respectively.

c. A chemical gettering system consisting of desiccant, molecular sieve and hydrogen converter will be used to assist in maintaining required vacuum levels. The molecular sieve packets will be held in place with stainless steel wire in accordance with AIA/NAS NASM20995.

4.1.1.2.3 Gas-Filled Annual Space

a. Double-wall piping with a sealed annulus filled with gas may be used in applications that require less stringent heat-leak levels, or where MLI and High Vacuum is not practical to achieve due to design/fabrication constraints or installation restrictions, but prevention of liquid air formation on the outer pipe is desired. An annulus pressure monitoring device will be included if needed for long-term maintenance. The gas will be high-purity Argon for LH2 service or high-purity carbon dioxide for LO2 service.

For applications in locations subject to wide variations in ambient temperature (such as outdoors), this type of insulation system is difficult to monitor and troubleshoot.

b. For these installations, either the outer jacket is rated to the same inner line design pressure, or pressure relief devices for the jackets will be provided.

4.1.1.3 Insulated Single-Wall Piping

Insulated single wall piping may be used if concluded acceptable by the total system heat leak analysis for system performance, control, and safety. The amount and type of thermal insulation (e.g. foams, cellular glass or aerogel blanket) will be determined from the system thermal requirements. Adequate performance will be maintained while exposed to moisture, repeated cryogenic cycles, UV exposure, corrosion under insulation (CUI), vibration or mechanical impact and field conditions, and vacuum level degradation, as applicable.

a. In LH2/GH2, LHe, LN2 or CGHe, the insulation will prevent the formation of liquid air. If insulation cannot be used, then drip pans, or Engineering directorate-approved protective thermal wrap, or sleeve, will be furnished to protect high-carbon structural materials, electrical or instrumentation cables or other sensitive hardware located below piping from liquid air contact. Design of the insulation system will include an analysis for each of the following basic considerations: long-term thermal effectiveness, mechanical integrity, environmental compatibility, and life-cycle operation and maintenance.

4.1.2 Piping Material

All new piping, with the exception given below, shall be austenitic stainless steel dual grade 304/304L (UNS 30400/UNS 30403) or 316/316L (UNS 31600/UNS 31603) in accordance with ASTM A312.

a. The use of seamless pipe is preferred when it is available.
b. For straight seam welded pipe, seam welds shall require 100% radiographic examination.
c. Seam welds and heat affected areas shall be cleaned and passivated in accordance with ASTM A967.

4.1.2.1 Invar

Invar (UNS K93603, 36% nickel-iron alloy) conforming to ASTM F1684 may be used for the inner pipe of VJ piping to minimize thermal contraction effects.

Long-lead time and increased material costs should be considered and realized before specifying selection of Invar pipe.

4.1.2.2 Aluminum

All new aluminum pipe in accordance with ASTM B241 shall be a listed aluminum alloy meeting the design pressure and strength requirements in accordance with ASME B31.3.

4.1.3 Flanges and Fittings

a. Pipe end flanges and fittings, including bayonets, shall be the same material and grade as the piping material to which they are attached.

b. Stainless steel flange material shall be in accordance with ASTM A182.

c. Aluminum flange material shall be in accordance with ASTM B247.

d. Stainless steel pipe fittings, such as tees, elbows, crosses, or reducers, shall be in accordance with ASTM A403, class WP-S, WP-W or WP-WX.

e. Aluminum pipe fittings shall be constructed of type WP6061 in accordance with ASTM B361.

4.1.4 Mechanical End Connections

Mechanical end connections in piping systems will be of the butt weld, hub, bayonet, or flanged design. The use of brazed, expanded, mitered, slip-on, socket, cast, and iron fittings will not be used for VJ inner pipe lines. Flared tube KC fittings and straight threaded fittings with suitable O-ring packing may also be used.

a. Butt-weld fitting designs shall meet the requirements of ASME B16.9 and B16.25.

b. All flanged joints shall be either weld neck or lap-joint design in accordance with ASME B16.5. A weld neck flange bolted to a lap joint flange should be used where necessary to allow correct bolt hole alignment between the two flanges.

c. Flange facings shall be raised faced with concentric serrations in accordance with ASME B16.5. Flanged joints using spiral wound or pressure energized type gaskets may have smooth raised faces. Flat faces and spiral serrations are prohibited. The following raised face flange serration dimensions have proven effective at KSC and will be selected based on system installation requirements:

Table 1. Flange Serration Dimensions

	LO2 or LH2	LH2 Only
Pitch (inches)	0.045 +/- .005	0.032 +/- .005
Angle (degrees)	90	60
Flat (inches)	0.005 max	0.008 max
Depth (inches)	0.020 +/- .005	0.021 +/- .005

d. Hub joints will be made as follows (in accordance with GP-425); KC159 butt weld hubs of type F316/316L material in accordance with ASTM A182, KC155 clamp assemblies of type F304 material in accordance with ASTM A182, and KC162 seal rings of Teflon-coated type 17-4PH material, and will be installed in accordance with KC163.

e. Bayonet end fittings shall be constructed from stainless steel material to same grade which they are attached. A low heat-leak design is needed. Analysis will include heat leak calculation for the appropriate warm side and cold side boundary temperatures. When using bayonets, mating male and female bayonet end fittings, including design pressure-rated caps, will also be procured.

4.1.5 Fasteners

a. Stainless steel stud bolt types used in KSC ML and pad cryogenic installations will be in accordance with 76K04875.
b. For KSC ML and pad installations, pipe flange joint fasteners will be installed in accordance with 76K04892 for LO2 systems, and 76K04932 for LH2/GH2 systems.
c. For cold gaseous helium and LN2 systems, adhere to same requirements as LO2.

4.1.6 Gaskets

Gaskets used in cryogenic systems at KSC will be fabricated in accordance with 76K04886. Gaskets will not be reused.

4.2 Components

a. Design of piping components shall be in accordance with ASME B31.3 for listed component standards.
b. Components used in cryogenic GS will be fabricated using either type 304, 304L, 316 or 316L stainless steel.

4.2.1 Valves

a. Unless pressure-temperature ratings are established by the method set forth in ASME B16.34, pressure design of valves will be qualified as requirement by ASME B31.3 parts 304.7.2(c) and (d). Qualification via part ASME B31.3 304.7.2(e) will not be used to qualify components new to KSC.
b. Valves will have PCTFE seat/seal conforming to ASTM D7194 and PTFE stem packing conforming to ASTM D4745.

4.2.1.1 Pneumatic or Electrical-Mechanical Actuated (EMA) Valves

a. The actuator will be capable of opening or closing the valve under full design flow and pressure. A pneumatic actuator will be designed to function at 100 psig nominal, unless otherwise specified. EMAs will be powered from 24 VDC and meet KSC-DE-512-SM EGSE design standards.
b. Flow control will be capable of positioning and maintaining the valve at any setting between open and closed.

c. The actuator will have a fail-safe spring capable of returning the valve to its normal position under system operating conditions without pneumatic pressure or electrical power (for EMA's). The actuator will be equipped with open and closed limit switches. Switch housings will conform to class 1, division 2 per NFPA 70.

4.2.1.2 Manually Operated Valves

The manual actuators will be capable of opening and closing the valve under full-system flow and pressure with minimal force applied by operator.

4.2.1.3 Check Valves

Check valves will be either the spring-loaded poppet disc or the horizontal swing-check type as needed to meet the given differential pressure requirements.

4.2.2 Expansion Joints

a. Expansion joints shall be designed, manufactured and installed in accordance with either ASME B31.3, appendix X, or Standards of the Expansion Joint Manufacturers Association (EJMA), as applicable.
b. Bellows shall be single-ply construction using either 304L or 316L stainless steel conforming to ASTM A240.
c. Axial expansion joints will include flow liners whenever possible. A means of compressing the expansion joint must be included for installation, removal and maintenance.
d. All expansion joints will be of single-ply construction with a minimum thickness of 0.56 mm (0.022 in).
e. After expansion joint installation and welding, heat-affected areas will be passivated in accordance with ASTM A967.

4.2.3 Flexible Hoses

a. All convoluted portions of flexible hoses will be covered with braided wire reinforcement constructed from 316L stainless steel in accordance with ASTM A580.
b. Welded seams on bellows shall be 100% radiograph inspected, or by alternate volumetric inspection approved by NASA M&P, prior to the forming process. Acceptance criteria shall meet the requirements of ASME B31.3 for severe cyclic conditions.

4.2.3.1 Single Wall

Single wall flexible hoses shall be single-ply construction 304L or 316L stainless steel conforming to ASTM A240.

4.2.3.2 Double Wall

a. The inner flexible hose shall be single-ply construction using either 304L or 316L stainless steel conforming to ASTM A240.

b. The outer flexible hose shall be single-ply construction using either Hastelloy C22 (UNS N06022) conforming to ASTM B575, or 316L stainless steel conforming to ASTM A240.

c. The wire braid covering the inner bellows (which contains the greatest internal pressure) must be designed to be the main load-carrying braid assembly.

d. Flexible hose compression length will be designed to include braid tension required for full engagement of convolutes with vacuum pressure in annulus, inner hose at minimum design temperature, and 0 psig in inner hose.

e. The overall flexible hose length will be defined, recorded and physically measured under the following conditions: At ambient temperature and pressure with the annulus evacuated to a pressure of 50 microns or less, measure the length of flexible hose in the straight position.

4.2.4 Filter Design

a. The cryogenic system filter-cartridge assembly will be capable of withstanding full-system differential pressure in either direction without rupture or damage.

b. Fasteners, locknuts and other internal parts for filter elements will be secured by lockwire, or otherwise positively attached, to preclude their entering the flow stream.

c. Filters will have drain and vent ports to facilitate system cleaning. Non-drainable sumps should be avoided.

d. Filter element integrity will be established in accordance with SAE ARP 901 (special care should be used with filters over 20 μm to ensure that the gas pressure probe placed in the filter is measuring the pressure in the gas pocket). A final filter should be subjected to a qualification test to verify its integrity in accordance with SAE ARP 900. Storage Vessels.

4.3 Storage Vessels

4.3.1 Inner Vessel

a. The inner storage vessel shall be designated with an ASME BPVC Section VIII U-stamp and registered with the National Board upon completion.

b. The specified design pressure will be coincident with full vacuum (.01 torr) in the annular space.

c. Inner storage vessel and supporting structure shall be constructed using either 304L or 316L stainless steel conforming to ASTM standards.

d. The inner vessel will have a corrosion allowance of none.

e. A minimum storage vessel liquid level will be determined to prevent gas ingestion into the liquid outlet (main transfer) line at maximum specified flow rates during all phases of fluid transfer operations, to prevent geysering during fluid back flow into vessel from main transfer line at maximum specified detank flow rates and to prevent/reduce full thermal cycles.

f. Minimum ullage volume will be 7% of full liquid rated capacity to preclude over-pressurization and flowing liquid into vapor lines.

g. The inner sphere support structure will be designed and constructed to minimize product loss due to heat transfer, and provide structural support and stability for the inner sphere.

4.3.2 Outer Vessel

a. The outer sphere does not require an ASME BPVC Section VIII U-stamp.

b. Outer sphere shall be constructed from any listed carbon steel specified in ASME BPVC Section VIII Division 1 or 2.

c. The outer sphere will be designed for following load cases:

   (1) Vacuum: An internal pressure of full vacuum (.01 torr) with an external pressure of 14.7 psia

   (2) Positive Pressure: An internal pressure of 29.7 psia with an external pressure of 14.7 psia.

d. The outer sphere will have a minimum corrosion allowance of 1/16 inch.

e. The outer sphere will be designed to support the inner sphere, full liquid capacity, weight of the annular space insulation system, and the loads and forces of attached appurtenances.

f. Additional localized metal thickness above that reinforcement area required per ASME BPVC Section VIII, Division 1 or Division 2 will be provided in any area that is expected to remain wet or collect water (e.g. single wall press/vent line penetration).

4.3.3 Annular Space

a. The annular space between the two shells will be purged or evacuated depending on the cryogen to be stored and the heat leak for the thermal requirements of the fluid contained to minimize boil-off (reduce the net evaporation rate - NER) Helium will not be permitted in the annular space.

b. The annular space between inner and outer spheres will be filled with either expanded perlite for evacuated cryogenic service in accordance with ASTM C549, or NASA approved equivalent insulation (e.g. glass microspheres or bubbles or aerogel particles) depending on application. No voids, gaps or air pockets permitted. The selection of an alternate, equivalent insulation requires customer approval. Evacuated insulation materials include high density perlite powder or glass bubbles. Non-evacuated (that is, purged) insulation materials include low density perlite powder, glass bubbles, or aerogel particles.

c. Perlite density, temperature and moisture content will be customer approved prior to and during installation. The insulation will not at any time come in contact with the atmosphere or moisture after it has been expanded.

d. If the annulus is purged (not allowed for LH2 vessels), the purge system will utilize GN2 and be designed to maintain a slight positive gage pressure of approximately 0.50 kPa (2 in of water) in the annulus. If densified LO_2 is being stored in a vessel using a purged annulus, then a GHe annulus purge is required.

Densified LO2 storage vessel should ideally use vacuum annular space. If densified LO2 is being stored in a vessel using a purged annulus, then a GHe annulus purge is required. GN2 shall not be used to avoid liquefying nitrogen and accumulating LN2 resulting in risks of brittle failure of outer vessel and support rods.

e. The annulus will be provided with a vacuum breaker and a relief device set at a gage pressure of approximately 1.0 kPa (4 inches of water). If the annulus is evacuated (required for LH2 vessels), provision for monitoring the vacuum level will be included. Vacuum level monitoring will be provided at multiple locations (top, middle and bottom) of storage vessel and will be easily accessible for personnel to perform routine operations and maintenance.

4.3.4 Interconnecting Pipe

a. All liquid lines passing through the annular space will be designed with vapor traps to prevent liquid from entering the line and contacting the vessel block valves during storage periods.

b. The interconnecting pipe will have a corrosion allowance of none.

c. Interconnecting liquid pipe will be vacuum-jacketed upon exiting from the outer sphere, and will terminate at point parallel to and readily accessible from grade. The vacuum space of the exposed pipe protruding from the outer vessel will be independent from the storage vessel annular space.

4.3.5 Sampling

Provisions to sample the liquid contents from the bottom, or low point, of the vessel must be included and accessible to personnel.

4.3.6 Bleed Trapped Gas

For the LO2 and LN2 service, the system design will permit bleeding of the trapped gas around the block valve (prior to opening the block valve) by means of a bypass loop.

4.3.7 Block Valves

Block valves will have seats to preclude frequent change out (which requires draining the storage vessel) and will be installed so that the valve stem packing is downstream of the valve seat to allow stem packing replacement without storage tank drain.

4.3.8 Low-Point Drain

A low-point drain capability will be provided.

4.4 Pumps

a. Cryogenic pumps will be of the centrifugal-type design. Pump housings shall be made of austenitic stainless steel (except type 303 stainless steel); however, aluminum alloy may be used for LN2 pumps. LO2 pump bearings will be isolated from the liquid being transferred.

b. The pump housing design will include supports that do not affect pump shaft alignment during transients from ambient to cryogenic temperature.

c. Seals used in LO2 pumps will be oxygen compatible in accordance with KTI-5210 and MAPTIS. Lubricants used for LO2 pump bearings will be in accordance with KSC Drawing 79K22280, or approved equivalent.

d. Consult NASA M&P for approved equivalent seals and lubricants, and access to MAPTIS.

e. The pump suction line will include a strainer to protect the pump from debris.

f. The piping systems will not transfer any excessive forces or moments to the pump. The adjacent connecting piping and components should be designed to allow change out without affecting pump shaft alignment. An integral, close-coupled pump and motor assembly should be utilized. A pump that is not close-coupled to its motor should be designed with a flexible/jointed drive shaft to minimize alignment problems.

g. Vibration levels of pump and motor systems will be rated “good” or better as measured on the General Machinery Vibration Severity Chart in accordance with GM Specification No. V1.0.

5. DESIGN ANALYSES

a. Flow and thermal analyses will comply with KSC-STD-Z-0017.

b. Content and format of design analysis reports will be in accordance with KSC-STD-Z-0015.

6. PRODUCT ACCEPTANCE TESTS

6.1 General Requirements

a. Testing will begin after all shop fabrication, including repairs, and examinations have been completed. If repairs or additions are made following the test(s), then the test(s) will be repeated.

b. Test records will be taken, including date of test, identification of piping system, test gas, and description of test method. The test results will be certified by a qualified examiner serving as an independent test observer.

c. Testing commodities will conform to following specifications, or NASA approved alternate:

   (1) Gaseous helium per MIL-PRF-27407D, Type I, Grade A

   (2) Gaseous nitrogen per MIL-PRF-27401G, Type I, Grade B

   (3) Liquid nitrogen per MIL-PRF-27401G, Type II, Grade B

d. Deionized water conforming to ASTM D1193, Type I-III (all grades), will be used for hydrostatic testing.

   Hydrostatic testing may be impractical because of the increased hydrostatic head pressure and the extreme difficulty in removing all the water after the test. Consequently, pneumatic pressure testing is allowed for assembled, or installed, cryogenic systems. A pneumatic pressure test must be evaluated and approved by NASA prior to performing.

   Use of potable water, for hydrostatic test will be evaluated on a case-by-case basis with NASA approved cleaning and drying procedures.

e. Testing will be performed sequentially in the order listed. Any changes to the sequence will be submitted with detailed justification and rationale for Government approval prior to conducting of the test.

6.2 Piping and Components

For VJ products during cold shock and pressure/leak testing, vacuum annulus readings will be recorded at regular intervals before, during and after the test. Vacuum annulus pressure reading prior to and after the test shall be per Table 2. Vacuum pressure readings after the test above that specified in Table 2 indicates an unacceptable condition.

Table 2. Maximum Allowed Vacuum Annulus Pressure (microns)

VJ Product	Prior to Test	After the Test
Individual component, or assembly (Shop Fab)	10	50
Assembled, or installed, at system level	50	100

6.2.1 Cold-Shock Testing

Cryogenic GS shall be cold-shock tested using LN2 either as individual assemblies, components, after shop fabrication, or as part of the assembled system after field installation. During cold-shock testing, the LN2 will be introduced into the inlet and the exit will be directed to a place or area where no damage or deformation of surrounding structure or equipment takes place. For example, special considerations will be made to preclude cryogenic fluid contact with carbon steel structure.

a. Individual assemblies, or components, such as pipe spools, valves, filters or flex hoses will be tested by introducing the LN2 into the assembly, or component, inlet and filling the component until a steady stream of LN2 is forced out the exit. The LN2 supply will then be maintained, allowing the assembly to cold-soak for 1 hour minimum. No evidence of deformation or leakage is allowed.

   (1) Vacuum annulus pressure readings will continue until assembly returns to ambient temperature.

   (2) Evidence of either frost or condensation at any outer jacket surface also indicates an unacceptable condition.

b. Installed piping systems that include field welds will be tested in place with the LN2 introduced at the lowest available point in the system, and the boil off gas allowed to escape from the highest point. The chill down and filling of the system will continue until either a steady stream of LN2 is forced out the high point, or a pre-determined cryogenic temperature can be attained. The LN2 supply will then be maintained, allowing the system to cold-soak for 1 hour minimum. No evidence of leakage is allowed.

In some cases it's an acceptable alternative to locally cold shock a field weld by flowing LN2 through a coil wrapped around the weld joint. This method is used predominantly on inner pipe field welds where vacuum closure cans are used.

   (1) Vacuum annulus pressure readings will continue until assembly returns to ambient temperature.

   (2) Evidence of either frost or condensation at any outer jacket surface also indicates an unacceptable condition.

6.2.2 Pressure Testing

Pressure testing is performed in accordance with ASME B31.3 either as individual assemblies, or components, after shop fabrication, or as part of the assembled system after field installation.

a. Evidence of leakage into the vacuum annular space indicates an unacceptable condition.

b. If hydrostatic testing is performed, then all wetted internal surfaces will be vacuum dried to less than 1 kPa (4 inches of water) and blown dry using GN2 until a dew point of -54 deg C (-65 deg F) at 1 atmosphere (24 ppm of water maximum) or less is achieved. The system dew point must be re-verified after a system lockup period of at least 24 hours.

6.2.3 Leak Testing

Upon completion of pressure testing, all welded joints and connections are leak tested in accordance with ASME B31.3, and examined for damage and/or leaks. The assemblies or components undergoing test shall exhibit no leakage while undergoing testing and show no permanent deformation or damage as result of the testing. The pneumatic leak test will be performed using either GN2 or GHe for LO2 systems, and GHe only for LH2 systems. All welds and mechanical joints will be leak tested using a solution meeting the requirements of MIL-PRF-25567, Type I, leak detection compound. No visible evidence of leakage allowed.

6.2.4 Valve Ambient Leak Tests

Following successful pressure and leak test, an ambient shell and internal seat closure tests at design pressure using either GN2 or GHe shall be performed in accordance with ASME B16.34. No visible evidence of leakage allowed for duration of tests.

6.2.5 Mass Spectrometer Leak Testing (MSLT)

Mass spectrometer leak testing may be performed in lieu of, or in addition to, pneumatic leak testing as system requirements dictate. Testing will be performed at design pressure. For VJ, double wall or single wall components or assembled systems, mass spectrometer leak testing must be used for troubleshooting and to identify the location of leaks. All welded joints are to be left uninsulated and exposed for examination during construction testing, and will be left unprimed and unpainted prior to and during system acceptance testing.

a. Prior to the test of VJ components or assembled systems, the vacuum annulus pressure shall be established per Table 2.

b. Gaseous helium will not be directly introduced into the annular space.

c. The outer jacket will be tested by surrounding outer jacket with 100% GHe atmosphere.

   Field testing of component or system installations should involve creating a sealed isolated volume by securely wrapping or bagging the area to be tested, then introducing test gas into enclosure.

d. For leak checks with 100% GHe, acceptable leakage shall be less than or equal to 1 x 10-7 std-cc/sec using a mass spectrometer sensitive enough to detect 1 x 10-9 std-cc/sec leakage. If a mixture of 10% GHe and 90% GN2 is used, then acceptable leakage shall be less than or equal to 1 x10-9 std-cc/sec using a mass spectrometer sensitive enough to detect 1 x 10-10 std-cc/sec leakage.

e. For component or system installations where leak testing of mechanical joints is performed use the following leak criteria;

   (1) *Using 100% helium, the helium leakage indication shall be below 1x 10-4 std-*cc/sec. To accomplish this test, a helium leak detector capable of sensitivity to $1x10^{-6}$ std-cc/sec will be used. When using 10% helium/90% nitrogen as an option, the helium leakage indication shall be below 1x 10^{-5} std-cc/sec. To

accomplish this test, a helium leak detector set capable of sensitivity to $1x10^{-7}$ std-cc/sec will be used.

6.2.6 Valve Low-Temperature Tests

Cryogenic valves shall be tested in accordance with ANSI/MSS SP-134 Annex A, Low Temperature Cryogenic Testing, or NASA approved equivalent. Minimum test pressure will be design pressure. No visible evidence of leakage allowed during shell leak tests. Acceptance criteria for seat closure leak tests shall be as follows:

a. For valves 0.5-inch NPS and smaller, internal seat leakage shall not exceed 0.5 sccm.
b. For valves 1.5-inch NPS and smaller, internal seat leakage shall not exceed 1 sccm.
c. For valves larger than 1.5-inch NPS, internal seat leakage shall not exceed 10 sccm per inch valve NPS (e.g. 4-inch = 40 sccm, 10-inch = 100 sccm).
d. Following cold tests, repeat ambient seat closure and shell tests. No visible evidence of leakage allowed.

6.2.7 Vacuum Retention Tests

After final fabrication of pipe assemblies or components including completion of necessary repairs, examinations and retests, the vacuum annular space will be established and maintained at 10 microns or less prior to continuing. Vacuum measurements will be made at ambient temperature (measurements for smaller annulus volumes may require correction if ambient temperature fluctuations are significant). The vacuum level within each vacuum annulus space will be measured and recorded every twenty-four (24) hours at approximately the same time of day for a period of at least seven (7) days. The final pressure at the end of the test period within each vacuum annulus space shall remain at or below 50 microns pressure to be acceptable.

6.2.8 VJ Pipe Field Weld Closure Can Leak and Vacuum Retention Tests

a. After installation of the field closure can over the field weld, each vacuum annular section will be evacuated, established and maintained at 50 microns or less for twenty-four (24) hours minimum prior to continuing.
b. Field closure can welds will be tested using 100% helium. Mass spectrometer leakage indication for all welds, joints and components shall be below $1x10^{-7}$ std-cc/sec.
c. The vacuum level within each section shall be measured and recorded every twenty-four (24) hours for a period of at least seven (7) days. The final pressure at the end of the test period within each section shall stabilize at or below 100 microns pressure to be acceptable.

6.3 Storage Vessel

The following test standards were developed for a field-erected, double-walled, vacuum-jacketed, spherical, all welded cryogenic storage vessel. These standards can be tailored for a shop-fabricated, cylindrical storage vessel.

Any air used in conjunction with any test, or for purging of the inner sphere after cleaning of the inner sphere, or used for purging the annular space prior to the installation of the insulation, or purging and testing of the annular space after installation of the insulation, will be dry (dew point of -65 deg F (24 ppm) and oil-free and its use will be approved by the procuring agency.

All tests, except for final leak testing of final weld closures used for access and admitting insulation, will be completed before insulation is installed in the annular space which occurs prior to initial cryogenic fluid load.

6.3.1 Pressure and Leak Test of Inner and Outer Spheres

a. Annular space pressure readings will be recorded at regular intervals before, during and after the inner sphere pressure test. No evidence of leakage is allowed.

b. If hydrostatic, or combined hydrostatic and pneumatic, testing is performed, then all wetted internal surfaces will be vacuum dried to less than 1 kPa (4 inches of water) and blown dry using GN2 until a dew point of -65 deg F (24 ppm) at 1 atmosphere. The system dew point will be verified prior to continuing.

6.3.2 Inner Sphere and Internal Pipe Cold Shock

a. Evacuate, establish and maintain annular space pressure to 50 microns or less prior to continuing.

b. Annular space pressure readings will be recorded at regular intervals before, during and after this test. Readings will continue until assembly returns to ambient temperature. No evidence of leakage is allowed.

c. The inner vessel and internal pipe will be uniformly filled from top of vessel and cooled to LN2 temperature while monitoring the vacuum annular space pressure. Volume of LN2 accumulating in the inner vessel will be recorded and limited to ensure the weight of the loaded LN2 does not exceed design loads of the inner sphere’s suspension system.

d. The vessel will be allowed to reach a stabilized temperature defined as less than or equal to 5 degrees per hour variation in temperature prior to beginning hold time. Record starting test temperature.

e. To pass this test, the inner vessel shall maintain atmospheric pressure for 48 hours minimum with no evidence of leakage in the annular space, nor evidence of condensation or wetting on the outer sphere surface. Evidence of condensation or wetting will be noted and submitted for evaluation.

f. Upon satisfactory completion of above test, the vent valve will be closed and the inner sphere will be pressurized to MAWP. To pass this test, the inner sphere will be held at MAWP for one hour minimum and the vacuum annular space pressure shall not rise above value recorded at start of this test.

g. Upon completion of these tests, LN2 will be removed, and the inner vessel and piping will be allowed to warm to ambient temperature.

6.3.3 Leak Test of Storage Vessel Interconnecting Pipe

Prior to mass spectrometer leak test of inner sphere, the attachment welds of each interconnecting pipe will be isolated and leak tested independently from all other tests using either a 10 percent helium/90 percent nitrogen mixture or 100% helium. Acceptable leakage shall be $1x10^{-7}$ std-cc/sec or less with a mass spectrometer minimum sensitivity of $1x10^{-10}$ std-cc/sec.

6.3.4 Inner and Outer Sphere Mass Spectrometer Leak Test

a. Vacuum annulus will be evacuated, established and maintained at 50 microns or less pressure prior to continuing.

b. The annular space will be back purged with dry GN2 to a dew point of -65 deg F (24 ppm) to 1 atmosphere. Then the annular space will be re-evacuated to 50 microns or less pressure.

c. Vacuum annulus pressure will be recorded at regular intervals before, during and after this test.

d. The inner vessel and internal pipe will be pressurized to MAWP to obtain a minimum 10% by volume helium mixture. Measure and record the leakage into the annular space from the inner sphere and internal piping. Acceptable leakage shall be $1x10^{-6}$ std-cc/sec or less.

e. After satisfactory completion, calibration of system will be performed by introducing a known leak into the annular space through the outer sphere at a point furthest from the mass spectrometer. The indication on the mass spectrometer will show that a leak of $1x10^{-6}$ std-cc/sec or less could have been detected had it existed.

f. Test the outer sphere by purging all the gas mixture out of the inner sphere and then evacuating the annular space to 50 microns or less pressure. Install envelopes over all outer sphere fitting connections and areas of likely leaks. The areas to be tested will be approved by customer.

g. Fill each envelope with 100% helium and check for leakage using mass spectrometer. Acceptable leakage shall be $1x10^{-6}$ std-cc/sec or less.

h. Evacuate, establish and maintain annular space at 50 microns or less pressure.

6.3.5 Insulation Fill

Vacuum annulus will be filled with insulation prior to initial fill of cryogenic fluid to be stored. Insulation material properties and loading conditions will be verified prior to beginning fill, and final fill level shall be confirmed by Government inspection prior to close-out of the vessel.

After final closure of the insulation fill ports and other fittings have been tested, the annular space will be re-evacuated to a pressure of 50 microns or less.

6.3.6 Final Vacuum Retention Test

a. The vessel vacuum annular space pressure shall be established and maintained at 15 microns or less prior to continuing.
b. The vacuum annulus pressure reading will be recorded at each sensor location every twenty-four (24) hours for a period of at least seven (7) days.
c. The final vacuum annulus pressure at the end of the test period shall be at or below 50 microns pressure to be acceptable.

6.3.7 Boil-Off Testing

a. A performance test to determine the boil-off rate for LH2 vessels shall be performed.
b. The inner sphere will be filled to design capacity and, after a suitable stabilization period, the boil-off test will be performed to determine compliance with the design boil-off requirements.
c. During this test, the annulus pressure will be monitored at each sensor location.
d. The final vacuum annulus pressure at the end of the test period must be at or below 50 microns pressure to be acceptable.

7. QUALITY ASSURANCE PROVISIONS

The quality assurance provisions for cryogenic GS will begin with the evaluation of the engineering design in order to define the quality requirements for inclusion in the engineering documentation. Quality assurance of procurement and manufacturing will be accomplished by in-process inspections and acceptance tests. Quality assurance will include the functions of quality engineering, inspection, quality program control, quality procurement control, and a corrective action system.

All functional components will be serialized for traceability of component performance from testing back to component acceptance tests. Identification tags must be rugged enough to withstand field conditions.

a. Design and Development Controls – The design agency will ensure that the following controls are specified to ensure the inclusion of quality requirements in the engineering design:

(1) Inspection and test criteria (including specific nondestructive test methods, test equipment, environmental conditions, and sample size)

(2) Identification and data retrieval requirements

(3) Identification of critical hardware characteristics necessary for procurement and fabrication.

(4) Performance and tolerance limits

(5) Applicable specifications for cleanliness/contamination control

(6) Applicable process specifications, standards, and procedures.

(7) Limited-life requirements

(8) Acceptance/rejection criteria

(9) Handling, storage, preservation, marking, labeling, packaging, packing, and shipping requirements

(10) Equipment to be placed under integrity control

b. Government Mandatory Inspection Points (GMIPs)

(1) When this standard is invoked in a contract, GMIPs will be identified within the contract bid documents (e.g. drawings, specifications) with appropriate monitoring and scheduling requirements. Examples of GMIPs include critical tests that require witnessing by Government representatives (e.g. structural connections requiring explicit torque values, electrical and mechanical routing, connections and inspections prior to inaccessibility).

(2) Inspections include, but are not limited to, visual examination of product, witnessing product fabrication or acceptance test, and on-site review of production documents. Inspections will be either of a representative single component, installation, and/or test, or the inspection of multiple units, and will be conducted per supplier. Inspection methods may also include photography and/or video recording.

(3) Examples of past cryogenic GS GMIPs, for consideration, are listed in Table 3:

Table 3. Cryogenics GS GMIPS

GMIP Description
Vacuum-jacketed inner pipe, and valve, insulation and support systems prior to outer jacket installation so that components are fully accessible.
Component cold shock test.
Remote and manual valve leak and functional acceptance tests.
Dimensional compliance check of components (e.g. pipe spools, flex joints & valves) prior to component packaging for final shipment from production facility. Component will be 100% accessible for inspection.

GMIP Description
Review of preliminary Acceptance Data Package (ADP) documents prior to component packaging for final shipment from production facility. Component will be 100% accessible for inspection, if necessary. Preliminary ADP documents include those generated during component fabrication, examination and acceptance testing, and may exclude final cleaning and packaging documentation.
Installation of insulation system and close-out can on field weld joint closures.

8. PACKAGING, STORAGE AND TRANSPORTATION

a. All assemblies upon successful completion of required tests are to be stored at vendor's facility until subcontract administrator provides further shipping direction.

b. Storage at both vendor and KSC will be indoors in an environmentally controlled area, when possible. Outdoor storage is permitted only when airtight water proof covers are provided.

c. Packing list will be provided with all deliveries.

d. Bellows will have protective shipping covers.

e. All pipe spools will be furnished with stainless steel protective pressure caps to prevent damage, or contamination during storage, transportation and handling. Capability will be provided to field monitor blanket pressure, isolate pressure gage and re-establish any lost blanket pressure. All components and fittings will be cleaned to fabricated component level or better.

f. Exposed field joint inner pipe ends will be protected from direct exposure to water, sand, dust or other contaminants during storage, transportation and handling by either providing a special pipe end closure or wrap.

g. All components or assemblies will be packaged per KSC-C-123, ISO 14952, or NASA approved equivalent. Level of cleanliness for packaging operations and materials will be at least equal to level of cleanliness of item being packaged. Packing design will be approved by the NASA prior to use.

h. For VJ components, all vacuum levels will be checked and recorded prior to shipment for validation at KSC receiving site prior to acceptance. Vacuum levels at delivery to the owner shall be 50 microns pressure or less to be acceptable. Provide vacuum records as part of the ADP, Evidence of Acceptance. Storage items will be visually examined for evidence of damage and corrosion, and vacuum levels checked and maintained on a monthly basis.

i. Internal cleanliness will be maintained. Seal inner pipe ends, ports and tubing with pressure retaining caps equipped with pressure gage and gas charging tee (1 set per volume as required). Caps will be added to each pipe not terminated by an existing flange. Establish a minimum dew point of -65 deg F (24 ppm) using pre-filtered MIL-PRF- 27401F, Type I, Grade B GN2 in accordance with Test Method III (A.3.3) of KSC-C-123 then establish a 5 +/-2 psig GN2 blanket pressure. Leak check will be performed on pressure ports using MIL-PRF-25567 Type 1 or 2 leak check fluid.

Verify no bubble formation for one minute minimum. Blanket pressure levels at delivery to the owner shall be 5 +/-2 psig to be acceptable. Provide verification of completion with the ADP, Evidence of Acceptance. Storage items will be checked and maintained on a monthly basis.

Pre-filtered drying and testing gas is filtered to specified particulate size for cleanliness level being maintained. For example, drying or test gas for a component cleaned to level 100 will be filtered to 25-micron.

j. The vendor will protect individual pipe spool assemblies and the entire skid assembly by packaging in a hard sided container, at a minimum wood crate construction. Individual pipe and skid components will be supported and braced within the container as necessary to prevent damage during shipping.

k. The vendor will package each vacuum-jacketed flexible hose section within a hard sided container (at a minimum wood construction) using standard commercial practice, ensuring each vacuum-jacketed flexible hose section is protected against damage during shipment. Entire flexible hose section length must also be protected against damage using isolation / separation means between segments during shipment. Flexible hoses may be shipped on saddle supports with hold-downs, or equivalent means. More than one flexible hose may be contained in a box.

l. Shipping containers will conform to freight classification rules and applicable container specifications, and will be strong enough to support being picked up using a forklift and/or lifting straps. The shipping containers should be capable of being stacked, and do not need to be weatherproof.

9. ACCEPTANCE DATA PACKAGE (ADP)

Upon satisfactory completion of product fabrication and testing, the contractor will obtain, maintain, and deliver to the Engineering directorate, the following documents:

a. Material Test Reports will include:

(1) Provide material reports for all materials used in construction to ensure compliance with ASME B31.3 paragraph 323.1 and ASME BPVC Section VIII Div. 1 or Div. 2. Material reports will contain mechanical and chemical properties.

(2) Provide impact test results for all materials and welding procedures requiring impact test per API 579-1/ASME FFS-1, ASME BPVC Section VIII Div. 1 or Div. 2 for storage vessels and ASME B31.3 paragraph 323.2.2.

(3) Material thickness used in calculations will match actual ordered thicknesses

(4) Identify heat treatment state for materials

(5) Material certification of conformance

(6) Material certification records for all material and components traceable to original vendor

b. Provide welding procedure specifications (WPSs), procedure qualification records (PQRs) and welder performance qualification records (WPQRs) in accordance with ASME B31.3 and ASME BPVC Section VIII Div. 1 or Div. 2.

c. Provide written letter that welding materials are maintained in accordance with ASME B31.3 paragraph 328.3, 328.3.2, 328.3.3 and ASME BPVC Section VIII Div. 1 or Div. 2 as applicable.

d. Provide product technical data sheets including operating and maintenance instructions for all components used in the assembly/system.

e. Provide as-built shop drawings showing weld details in accordance with ASME B31.3 paragraph. 328.5 and ASME BPVC Section VIII Div. 1 or Div. 2.

f. Weld traceability maps of welder and procedure number at each joint including weld and welder identification, weld details, base material callouts and NDE performed with results, will be provided for each weld.

g. Provide inspector's and examiner's qualifications in accordance ASME B31.3 paragraphs 340 and 342, and ASME BPVC Section VIII Div. 1 or Div. 2.

h. Provide nondestructive evaluation (NDE) report for each examination method defined in accordance ASME B31.3 paragraph 344, ASME BPVC Section VIII Div. 1 or Div. 2 and specified by the engineering design.

i. Provide test report for each testing method defined in accordance with ASME B31.3 paragraph 345, ASME BPVC Section VIII Div. 1 or Div. 2 and specified by the engineering design.

j. Provide lifting plan for each spool including center of gravity annotated, lifting points and any special lifting or handling equipment.

k. Provide heat leak data for all Bayonets.

l. Digital radiograph negatives may be used, in lieu of film, provided digital formats satisfy ASME B31.3 and ASME BPVC Section VIII Div. 1 or Div. 2 for clarity in detecting "severe cyclic" flaw sizes, or have no associated compression algorithm that loses resolution upon file handling. Viewing software program will be provided with computer operating system requirements. Native files will be provided Two-dimensional (2-d) graphical data will be delivered in one of the following lossless image format:

   (1) Portable network Graphics (image/png)

   (2) Tagged image Format File (Image/tiff)

   (3) Joint Photographic Experts Group (Image/jpg)

   (4) Computer Graphics Metafile (image/cgm)

m. Provide packaging protection, and transportation plans to KSC.

n. Provide Certificate of Conformance to the SOW and procurement specification.

o. Provide Historical log/Notes/Comments.

p. Provide Form DD250/Form 1149 or equivalent material receiving inspection checklist.

q. Provide all Requests for Information (RFIs)

r. Provide all deviations/waivers.

s. Provide all Nonconformance and unexplained anomalies.

10. SYSTEM DESIGN CONSIDERATIONS

The design of cryogenic GS will include an analysis for each of the following basic considerations, as applicable.

a. General Requirements
   (1) Vehicle interfaces
   (2) Liquid storage capacity based on operational requirements
   (3) Stored Energy Calculations
   (4) Storage tank ullage pressure
   (5) Pump and motor system configuration based on operational requirements
   (6) Venting and purging capacities and durations
   (7) Instrumentation
   (8) Vehicle servicing (timelines and sequences)
   (9) Leak and fire detection (and leakage allowances)
   (10) Installation of pressure/purge ports or temperature, pressure and flow sensors at locations defined by NASA. Design of pipe and flexible hose assemblies includes branch connections, or welded attachments, used for these purposes.

b. Thermal/Fluid Analysis
   (1) Line sizing (flow rate)
   (2) Heat-transfer limitations
   (3) Two-phase flow effects
   (4) Geysering potential and effects
   (5) Vaporizer capacity
   (6) Net positive suction head for pump
   (7) System cool down time
   (8) Effects of fluid siphoning that could cause system malfunction
   (9) Flow-induced vibration
   (10) Propellant densification effects
   (11) Gaseous vent sizing to meet interface pressure requirements

c. Mechanical Analysis

(1) Static, dynamic, blast, acoustical, and water hammer loads

(2) Thermal due to contraction/expansion

(3) System drain capability

(4) Pump and motor system alignment

(5) Impact forces of fluid hammer on partially open valves

(6) Adequate provisions for pressure-relief

(7) Hydrogen traps within the facility that must be eliminated

(8) Location of filters and strainers to keep debris out of vehicle piping

d. Operational Procedures Analysis

(1) Adverse two-phase conditions (such as slug flow due to saturation of fluid in transfer line)

(2) System cool-down sequence to preclude choked flow conditions

(3) Vehicle venting to meet ullage pressure and flight mass requirements

(4) Use of relief valves for trapped cryogens due to component failure or operational error

e. Operational/Maintenance

(1) Failure Modes and Effects Analysis and Critical Items List

(2) System Safety Assurance Analysis

f. Reliability, Maintainability and Availability

(1) Maintenance and checkout time versus operational time constraints

(2) Component accessibility for maintenance (including tool clearances)

g. Environmental Factors

(1) Launch- and wind-induced vibration effects

(2) Safe disposal or venting of cryogenic fluids

(3) Corrosion processes

(4) Life cycle costs (including component and material procurement, fabrication, operations, maintenance, and disposal costs)

11. NOTES

11.1 Intended Use

This document is intended to be used in the establishment of uniform engineering practices and methods and to ensure the inclusion of essential requirements in the design of cryogenic equipment used to support the servicing and launch of space vehicles and payloads at KSC.

This standard defines the requirements for the design of cryogenic GS for handling LO2, LH2, CGHe, LNG, or LN2 and does not constitute a specification for the procurement, fabrication, or installation of the system or elements.

Custodian:

NASA – John F. Kennedy Space Center
Kennedy Space Center, Florida 32899

Preparing Activity:

John F. Kennedy Space Center
Engineering Directorate
Exploration Systems and Operations Division