

**Document
Number:** GLP-QS-8715.1-7

Revision: C w/Change 2

Effective Date: 11/15/2019

Expiration Date: 11/15/2025

Glenn Safety Manual – Chapter 7

Pressure Systems Safety w/Change 2 (11/15/2024)

Approved by: QS/Chief, Safety and Health Division

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Change Record

Rev.	Effective Date	Expiration Date	GRC25, Change Request #	Description
B	12/19/2012	12/19/2017	120	Bi-annual Review/Revision
Change 1	6/27/2014	12/19/2017	N/A	Administrative change to add front cover and change history log to comply with NPR 1400.1. Deleted "The authority for the pressure system safety program at GRC comes from the following:" and inserted "The GRC shall follow the requirements of:" in Section 4.1 NASA Policy Documents. Section 4.3 "Waiver", revised to further define requirements of the GRC waiver process. Section 4.4 "Pneumatic Testing", added to correct mis-typed policy information regarding pneumatic testing.
Change 2	9/30/2015	12/19/2017	N/A	Administrative change to remove hyperlinks.
Change 3	6/28/2017	12/19/2018	N/A	Administrative change to extend the expiration date to December 19, 2018, to allow more time to address the chapter revisions; changed document number from GLM-1700.1.7 to GLP-QS-8715.1.7.
Change 4	11/28/2018	12/19/2019	N/A	Administrative change to extend the expiration date to December 4, 2019, to allow more time to address the chapter revision and GSM chapter consolidation.
C	11/15/2019	11/15/2024	19-020	Updated references, some section formats and training due to deletions or course changes.
Change 1	5/11/2021	11/15/2024	N/A	Administrative change to update NPR and Neil A. Armstrong Test Facility
Change 2	11/15/2024	11/15/2025	N/A	Administrative change to extend expiration date one year to complete substantive changes per GLPR 1410.1

***Include all information for each revision. Do not remove old revision data. Add new rows to table when space runs out by pressing the tab key in the last row, far right column.*

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Chapter 7—Pressure Systems Safety

***NOTE:** The current version of this chapter is maintained and approved by the Safety and Health Division (SHeD). The last revision date of this chapter was November 2019. The current version is located on the Glenn Research Center intranet within the Business Management Systems (BMS) Library. Approved by Chief of Safety and Health Division.*

1.0 PURPOSE

This chapter provides reference to the standards and codes containing NASA and Glenn Research Center (GRC) requirements for all aspects of pressure vessels and pressurized systems (PVS) operation. This includes certification and recertification, design, construction, operation, inspection, and maintenance of PVS. Because of the extensive detail of the regulations covering these systems, specific requirements of NASA standards and national consensus standards (NCSs) are not repeated in this document. The users of this document must refer to the appropriate standard for specific requirements. The chapter also provides the following:

- a. GRC policy and guidelines for use and certification of flexible hoses
- b. GRC policy and guidelines for system pressure testing
- c. GRC mandatory pneumatic testing permit process
- d. A method to calculate the restricted distance required during pneumatic testing (Appendix B)
- e. Basic cryogenic system and vessel information

2.0 APPLICABILITY

Applicability of this chapter follows that of NASA Standard (STD) 8719.17, Requirements for Ground-Based Pressure Vessels and Pressurized Systems (PVS), specific to organizations owning, operating, or designing ground-based PVS at or for GRC at Lewis Field (LF) and Neil A. Armstrong Test Facility (GRC-ATF). In this chapter, all mandatory actions (i.e., requirements) are denoted by statements containing the term “shall.” The terms “may” or “can” denote discretionary privilege or permission, “should” denotes a good practice and is recommended but not required, “will” denotes expected outcome, and “are” or “is” denotes descriptive material.

3.0 BACKGROUND

3.1 Codes and Standards

NCSs such as the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code (B&PV Code), ASME B31 series piping codes, and National Board Inspection Code (NBIC) NB 23 have been established to ensure the structural integrity of PVS through establishment of rules for design, construction, operation, inspection, and maintenance of vessels and systems. NASA directives and standards, given below, require compliance with the applicable NCSs as well as certification of systems. Exclusion and waiver processes are also in

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effect for systems that are outside the scope of the standards or cannot be immediately certified but have met risk and hazard assessment requirements.

3.2 Pressure Testing

A large portion of this chapter gives guidance on mandatory pressure testing of new or altered PVS at GRC. Because of the inherent danger of pneumatic testing, test procedures and equipment use must be carefully planned and reviewed. ASME codes provide test pressures and procedural requirements; however, this chapter provides additional safety guidelines and calculations for the establishment of exclusion zones. A test authorization permit is required for all pneumatic testing at GRC, and the procedure for obtaining the permit is provided.

3.3 GRC Pressure Systems Office

The GRC Pressure Systems Office (PSO) website provides background information on PVS certification processes, risk assessment procedures and checklists, and supplemental information on preparing pressure system waivers, exclusions, and pneumatic test documentation.

4.0 POLICY

4.1 NASA Policy Documents

The GRC shall follow the requirements of the following:

- a. NASA Procedural Requirement (NPR) 8715.1, NASA Safety and Health Programs
- b. NASA-STD 8719.17, NASA Requirements for Ground-Based Pressure Vessels and Pressurized Systems (PVS)
- c. Glenn Safety Manual (GSM), Chapter 1, Glenn Safety Permit Program

4.2 Pressure System Certification

Owners and/or operators (NASA or contractor) of PVS at GRC shall design, acquire, fabricate, inspect, test, install, repair and alter, operate, and maintain all ground-based PVS in accordance with the applicable codes, standards, guides, and regulations as detailed in NASA STD-8719.17. It is policy to certify all ground-based PVS in accordance with NASA-STD-8719.17 prior to operation.

4.3 Waiver

NOTE: NASA does not have approval authority for waivers to Federal, state, or local regulations (e.g., OSHA, Ohio State Law), nor to consensus standards that are required by Federal regulations that apply to NASA. Any waiver of a Federal, state, or local regulation must be reviewed by NASA Headquarters Office of Safety and Mission Assurance prior to submittal to the appropriate Federal/state/local agency for approval.

4.3.1 Pressure vessels and systems which cannot be certified per, or excluded from, NASA-STD-8719.17 must be covered by an approved technical waiver prior to operation. Variation from the

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requirements of NASA-STD-8719.17 must also be approved by waiver. The PSO website (<http://www.grc.nasa.gov/psa/>) provides instructions on the waiver process.

4.3.2 Risk determination and risk assessment codes (RACs) utilized in waivers must comply with RAC determination requirements specified in NASA-STD-8719.17, para 4.9.2. This risk assessment criteria is consistent with facility system safety risk assessment criteria specified in GSM Chapter 3, Section 6.4.4.

4.3.3 Policy waivers must be approved as specified by NPR 8715.1. Technical waivers must be approved as specified in Table 4.1:

TABLE 4.1.—TECHNICAL WAIVER APPROVAL

	Risk assessment code (RAC)	
	1 and 2	3+
Headquarters Notification	X	X
Center Director Approval	X	
Safety and Mission Assurance Director Approval	X	X
Pressure Systems Manager	X	X
Program Manager/Owner	X	X

4.4 Pneumatic Testing

It is GRC policy to obtain a permit from the Pressure Systems Manager (PSM) prior to performing any pneumatic testing of PVS.

4.5 Measurement and Verification

Compliance with the responsibilities and requirements of this chapter are measured and verified through the use of programmatic self-assessments, regulatory and Agency audits, and internal field inspections.

5.0 RESPONSIBILITIES

5.1 General

Ensuring the safe operation of PVS involves specialized engineering, nondestructive evaluation (NDE), field verification, and documentation and configuration control. Maintaining safety and compliancy with standards also involves hazard assessment, risk analysis, training, establishing and following operating procedures, and other aspects of basic process safety management. At GRC this involves an extensive number of personnel, including the organization owning, operating, and maintaining the system, the GRC PSO, the GRC Safety and Health Division (SHED), as well as any outside contracted organization involved in the design, construction, or repair of a pressure system or pressure vessel. NPR 8715.1 outlines responsibilities of the Center Director, Center PSM, management of organizations responsible for ground-based PVS, and Center Safety Directors.

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5.2 Pressure System Owners and Users

5.2.1 NASA employees and contractors responsible for ground-based PVS shall ensure that their systems meet the requirements of NASA-STD-8719.17 relative to PVS. These requirements include all aspects of design, procurement, fabrication, installation, operation, maintenance, training, operating procedures, and configuration control.

5.2.2 Pressure system owners shall notify the PSO of new vessels or systems (including flexible hoses) and request certification (via work request) per the above standards.

5.2.3 Personnel using non-steel-braided flexible hoses will follow the requirements of Section 6.3.3 of this chapter, including recordkeeping.

5.2.4 PVS owner operators and or designated contractors shall follow the requirements for all pneumatic testing, including test request documentation, per Section 6.4 of this chapter.

5.2.5 At GRC, central utility systems as well as other institutional fluid systems are managed and maintained by the Facilities Division. Most test facilities and research labs are serviced by some of these systems. Test and research facility managers and personnel (owners) are responsible for ensuring the requirements outlined above for the equipment and piping systems within their facilities and labs are met.

5.2.6 For piping systems, the demarcation (or boundary) is generally defined by a valve designated the “System Boundary Valve.” Downstream of the System Boundary Valve, the responsibility for ensuring pressure system compliance lies with the system owner or user. The responsibility upstream of the valve and back to the source lies with the Facilities Division, specifically the system manager for that specific fluid system. If the System Boundary Valve has not yet been identified and marked for a particular system, test and research facility personnel shall contact the PSO (or system manager) to determine the boundary point between the institutional and research systems. This would generally occur when work orders are placed for test and research system initial certification or recertification.

5.3 Pressure Systems Manager

The GRC PSM is responsible for implementation of NASA-STD-8719.17. The PSM oversees the PSO activities that meet the above requirements. The PSM will also review and approve pneumatic test requests for proper justification over hydrostatic testing, technical content including pressure-relieving system, proper barricading of the exclusion zone, and test forms.

5.4 Pressure Systems Office Manager

The PSO manager, reporting to the PSM, is responsible for PVS engineering assessment, inspection, NDE, risk assessment, and documentation of certified systems and components. The mechanical integrity assessment of pressure vessels and systems via the technical implementation of NASA-STD-8719.17 is the primary responsibility of the PSO manager.

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5.5 Pressure Systems Office Pressure Systems Engineers

5.5.1 PSO pressure systems engineers are responsible for conducting the GRC PVS certification process in accordance with NASA STD-8719.17, and all applicable consensus codes and standards. These engineers recommend and evaluate NDEs and inspections performed on all PVS and determine suitable inspection and recertification frequencies. Pressure systems engineers are qualified in characterizing and analyzing flaws in accordance with the latest applicable code requirements and engineering practices, and they prepare necessary repair specifications to resolve safety issues. Pressure systems engineers resolve issues in dealing with the certification of existing pressure systems and vessels due to lack of existing system documentation and changes in consensus codes and standards in terms of safe design and construction acceptability. They are also responsible for creating specifications for system inspections.

5.6 Safety and Health Division Process Safety Engineer

The GRC SHed process safety engineer is responsible for assisting Center personnel with pressure system compliance, safety issues, and review of pressure system waiver requests. The SHed process safety engineer will

- Work with PSO engineers, system owners and operators, and safety committees to advise on, evaluate, and resolve pressure system operational, compliance, and safety issues
- Review waiver requests for proper content, including a description of the system and the hazards, overall risk assessment, and acceptability of the proposed mitigation
- Review pneumatic test requests for proper justification over hydrostatic testing, technical content including pressure-relieving system, proper barricading of the exclusion zone, and test forms

5.7 Area Safety Committee Members

The responsibilities of GRC safety committees are defined in GSM Chapter 1. Safety committees issue safety permits for process systems and test cells containing PVS only upon the pressure systems being certified, excluded from certification requirements, or an approved variance in place. This requires that verification of certification, an exclusion, or an approved variance be included in any permit application package containing a PVS. For test and research facility permit applications, the local pressure system piping fed from central institutional systems is bounded on the upstream side by a “System Boundary Valve” tagged as such in the field and generally identified on distribution system piping and instrument diagrams (P&IDs). Upstream of this valve the piping certification is the responsibility of the facilities division. Downstream, test facility personnel are responsible and status of systems shall be noted in the permit package. If the System Boundary Valve has not yet been identified and tagged, contact the PSO (or System Manager) for the “Boundary Location.”

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6.0 REQUIREMENTS

6.1 Training (*GSM Chapter 2, Safety, Health, and Environmental Training and Certification*)

6.1.1 PSO Engineers and Nondestructive Evaluation Technicians

See the PSO website for specific training, experience, and certification of pressure system engineers and NDE technicians.

6.1.2 PVS Operators

The following courses are recommended for operators of PVS at GRC. Not all classes may be applicable to all personnel. Courses are available through the System for Administration, Training, and Educational Resources for NASA (SATERN).

Class Number	Class Name
a. SMA-HQ-WBT-301	High Pressure System Operations and Flex Hose Safety Seminar
b. SMA-HQ-WBT-302	Safety of Compressed Gas Trailers and Compressed Gas Cylinders Seminar
c. GRC-4R2075	Hydrogen Safety Training
d. GRC-4R2074	Fire Hazards in Oxygen Systems
e. SMA-HQ-WBT-207	Cryogenics Safety
f. GRC-4R1045	Cryogenics Safety Training

6.2 Owners and Operators of PVS (*NASA-STD-8719.17*)

6.2.1 Owners and operators (NASA or contractor) of PVS at GRC shall design, acquire, fabricate, inspect, test, install, repair and alter, operate, and maintain all ground-based PVS in accordance with the applicable codes, standards, guides, and regulations as detailed in NASA-STD-8719.17. The standard requires compliance with ASME B&PV Code, ASME piping codes, Department of Transportation (DOT) regulations, NBIC, and other NCSs.

6.2.2 NASA-STD-8719.17 includes the following:

- Applicability of systems to the standard and certification. (The standard applies to all ground-based equipment designed for, or operating at, positive or negative gauge pressure that is not specifically excluded.)
- Exclusions to certification requirements
- General requirements of PVS certification
- Design and construction requirements for new PVS
- PVS integrity assessment
- PVS risk assessment
- Specific component requirements

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6.3 Flexible Hoses (*NASA-STD-8719.17*)

6.3.1 General

6.3.1.1 Flexible hoses in use at GRC shall be suitable for the specific application (i.e., material and fluid compatibility, pressure, temperature, etc.). A common hose construction for high-pressure or hazardous services at GRC is a polytetrafluoroethylene (PTFE) (e.g., Teflon™ brand (The Chemours Company FC, LLC)) liner or tube with a stainless steel overbraid. Reinforced rubber or thermoplastic compositions are also used for appropriate applications.

6.3.1.2 Flexible hoses shall be used only when required for connection of portable equipment or for vibration isolation when no other feasible means is available. Hazards associated with flexible hoses include flying debris and violent whipping action of the hose due to rupture. Additionally, failure of such hoses could result in hazardous commodity leakage and loss of system control. Therefore, flexible hoses in many applications must be specified correctly and periodically inspected and certified. Hoses must be identified with physical marking to verify proper application and facilitate inspection and tracking.

6.3.2 Hose Assembly Requirements

6.3.2.1 A hose shall be purchased for the specific fluid that flows through it. Because manufacturers rate hoses for suitability with specific fluids, these compatibility ratings and the manufacturers' pressure and temperature ratings shall be used for determining acceptability.

6.3.2.2 The maximum allowable working pressure (MAWP) of the hose must meet or exceed the maximum design pressure (DP) of the system. The burst pressure of the hose must be specified by the manufacturer to be at least four times the MAWP.

6.3.2.3 At the time of fabrication, steel-braided (overbraid covering) hose assemblies shall be pressure tested by the manufacturer according to applicable NCSs. Documentation of such testing must be included with each hose assembly. This does not apply to standard hydraulic hose or other rubber or thermoplastic hose that the manufacturer has certified to be manufactured, tested, and assembled to a national standard such as SAE International or International Organization for Standardization (ISO). Individual assemblies of these hoses are generally not tested by the manufacturer.

6.3.2.4 Hose assemblies shall be tagged with a permanent stamped metal tag or marked along the length of the hose (generally hydraulic or utility hoses). The tag or marking shall show the date of the pressure test (if applicable), the maximum DP and temperature, the manufacturer and part number, and the fluid it will accommodate. The burst pressure may be given on the hose exterior if clearly identified (not to be confused with operating pressure).

6.3.2.5 All hoses that may whip and cause equipment damage or physical injury to personnel shall have restraints installed in accordance with manufacturers' recommendations to prevent excessive whipping action should breakage occur. Kellems® (Hubbell) restraints are an example of what may be used.

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6.3.2.6 Restraints shall be placed at each end and at least every 6 feet (1.83 meters) of longer hoses. An evaluation of the potential force should be made to ensure adequate strength of the restraint and anchor points.

6.3.2.7 The manifold or other pressure piping shall not be used as an anchor. Tube trailers are provided with anchoring points for harnesses.

6.3.3 Inspection and Certification

6.3.3.1 All flex hoses except those in excluded categories (as outlined below) must be certified by the PSO. In general, hoses requiring certification are the steel-braided type and are in service conveying any commodity over 210 °F (372 K), fluids over 150 psig, gas over 150 psig, or in piping larger than ½ inch (1.27 centimeters) in diameter, oxidizers, toxic or flammable commodities, cryogenic fluids, or other fluids that may be hazardous to human tissue per ASME B31.3, Process Piping.

6.3.3.2 Flex hoses in the following service categories are excluded from PSO certification:

- a. Flex hoses of ½-inch internal diameter and smaller that convey air or inert gas at 150 psig or lower pressure at roughly ambient temperature (less than 210 °F)
- b. Hoses conveying water, hydraulic oil, lubrication oil, or nontoxic and noncryogenic liquids at operating pressures of 150 psig or lower and 210 °F or lower. (There is no hose size and limit for this exclusion; however, the hose must be rated by the manufacturer for the service pressure and temperature and must meet general requirements outlined above.)
- c. Hydraulic hoses specifically manufactured for hydraulic service. (The hoses must be rated and stamped or marked by manufacturer for hydraulic service as outlined above.)

6.3.3.3 Flex hoses that meet all of the below criteria can be excluded from PSO certification by the GRC PSM via a GRC4027 Exclusion Request. A formal GRC4029 Certificate of Exclusion must be issued for the exclusion to be valid. The criteria are as follows:

- a. A documented risk assessment has been made to determine potential injury, mission, and environmental risks associated with the flex hose.
- b. The risk assessment has determined the following:
 - (1) There are no credible whipping hazards.
 - (2) There is no unacceptable hazard to personnel in event of hose rupture.
 - (3) Flex hoses are assembled and tested per hose manufacturer specifications (especially important in circumstances where third party hose vendor assembles custom hoses to order).
 - (4) Hose rupture would not present any unacceptable hazard to personnel or risk to mission.

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6.3.4 Certification Requirements

6.3.4.1 All flex hoses not excluded per Section 6.3.3 must be certified by the PSO. Certification is valid for a 5-year period and shall include the following:

- a. Manufacturers' pressure test records and certification documents (to be provided in lieu of PSO initial pressure test)
- b. Documentation including identification tag number or serial number, manufacturer, nominal size, material of construction, rated working pressure and temperature, and material compatibility with working fluid
- c. Regular external visual examination on a schedule determined by the PSO. (PSO will inspect entire length of the hose for evidence of damaged fittings, kinks, broken wire braid, or other signs of degradation. Hose assemblies shall be removed from service upon evidence of damage or misuse.)
- d. Installation per manufacturer's and/or NCS requirements
- e. Inspection records per manufacturer recommendations and/or NCS requirements
- f. Visual examination (shall be performed by a certified American Society for Nondestructive Testing Level II Non-Destructive Examiner in accordance with the applicable NCS)
- g. Hoses shall meet all required commodity and pressure specifications

6.3.4.2 Recertification (renewal for another 5-year term) by the PSO shall include the following:

- a. Documentation review
- b. External visual examination and internal visual examination with a fiber scope
- c. Visual examination shall be performed by a certified American Society for Nondestructive Testing (ASNT) Level II Nondestructive Examiner in accordance with the applicable NCS
- d. A pressure test at the MAWP by the PSO. (Hoses shall be replaced if any degradation is found. The dates of inspection shall be documented and maintained by the PSO.)

6.3.5 Noncertified Flex Hoses

Noncertified hoses include non-steel-braided (general utility type, reinforced rubber, or thermoplastic hose), hydraulic system hoses, and those in service for low-pressure water and air applications as specified in Section 6.3.3. For these hoses, the owner operators shall ensure the hose is installed, maintained, and operated in accordance with manufacturer recommendations. This requires the following:

- a. Documentation including manufacturer, nominal size, material of construction, rated working pressure and temperature, and material compatibility with working fluid
- b. Installation per manufacturer's and or NCS requirements
- c. Inspection records per manufacturer recommendations and/or NCS requirements

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- d. Hydraulic system hose assemblies shall be conventional, commercially manufactured hydraulic hose and fittings.
- e. Pressure testing of new hydraulic hose assemblies is not required. A leak check at operating pressure shall be done when first put into service and whenever a system is repressurized after downtime.
- f. Hydraulic hoses shall have the manufacturer's burst pressure identified on the external hose diameter.

6.3.6 NCS Hose References

See Section 8.0 for further information.

6.4 Pressure Testing (*NASA-STD-8719.17, ASME B&PV Code Section VIII, ASME B31.3*)

6.4.1 Applicability

6.4.1.1 The following defines testing requirements for existing and new ground-based pressure vessels and piping systems at GRC. NASA requires compliance with NCSs and standards to maintain the highest degree of safety for personnel and property.

6.4.1.2 All pressurized systems at GRC must be pressure tested as noted below. The purpose of the test is to verify structural integrity and pressure tightness. With appropriate NDE, design and construction, and documentation, the pressure test gives assurance that potential hazards to personnel and property are at a minimum.

6.4.1.3 Cold-shock testing must be performed on all systems in cryogenic service. Before any pressure is applied to the system, it must be chilled to cryogenic temperatures and observed for leakage. After successful completion of the cold-shock test, a pressure test is performed.

6.4.2 Systems Requiring Testing

6.4.2.1 A pressure test is required to verify the integrity of all newly installed or altered pressure vessels and piping systems at GRC. In accordance with the applicable NCS, repaired systems may be required to undergo a pressure test. Most PVS at GRC will be tested per the ASME B&PV Code, Section VIII or ASME B31.3.

6.4.2.2 In the following situations, a pressure test is required:

- a. Installation of a new pressure system that uses either new or reused components
- b. Alteration of an existing PVS. (The NBIC defines an alteration as any change that affects the pressure-containing capability of the system. Some nonphysical changes, such as an increase in the maximum allowable working pressure or design temperature, are considered alterations. A reduction in minimum temperature such that additional mechanical tests of system materials are required is also considered an alteration.)
- c. Physical relocation of a stationary pressure vessel

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- d. Repair of an existing pressure system if the system engineer or the NCS requires it (The NBIC defines a repair as any work necessary to restore a system to a safe operating condition, provided there is no deviation from the original design.)

6.4.2.3 A pressure test may be required for periodic recertification of a PVS.

6.4.2.4 In addition to PVS following ASME B&PV Code Section VIII or ASME B31.3, systems with other specific testing requirements include the following:

6.4.2.4.1 Mobile Pressure Vessels

Compressed gas cargo tanks (mobile tube trailers) and cryogenic liquid cargo tanks (mobile Dewars) are classified as mobile pressure vessels. These vessels fall within the cognizance of DOT requirements in 49 CFR, which requires periodic pressure tests and specifies allowable repairs. The periodic pressure tests specified in 49 CFR shall be performed by an organization qualified in accordance with 49 CFR to perform such testing.

6.4.2.4.2 DOT Specification Cylinders

Specification cylinders fall within the cognizance of DOT requirements of 49 CFR, which requires periodic pressure tests and specifies allowable repairs (see also Compressed Gas Association (CGA) C-1, Testing of Compressed Gas Cylinders).

6.4.2.4.3 Unique Piping Systems

Piping systems for certain commodities are designed to specific ASME piping codes. These codes have requirements that relate to those commodities, including pressure test requirements. Some specific codes applicable to GRC are ASME B31.2, Fuel Gas Piping; B31.5, Refrigeration Piping and Heat Transfer Components; B31.8, Gas Transmission and Distribution Piping Systems; and B31.9, Building Services Piping Code. For such piping systems, the pressure test requirements of the appropriate code shall be used directly.

6.4.3 Test Methods

6.4.3.1 A hydrostatic pressure test is the baseline requirement for pressure testing of a PVS. Before any pressure test is started, appropriate NDE of the system shall be performed in accordance with the applicable NCS. This will minimize potential hazard or delay during the pressure test.

6.4.3.2 In addition, all systems for use in cryogenic service shall be cold-shock tested before being pressure tested.

6.4.3.3 The hydrostatic pressure test shall be conducted in accordance with the applicable NCS. The unique nature of the research conducted at GRC may require alternate test methods (other than hydrostatic), which are summarized in Table 6.1 along with the primary hydrostatic method.

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TABLE 6.1.—ALTERNATIVE TEST METHODS AT GRC

Test	Test method
Cold-shock test	For cryogenic systems only; expose system to liquid nitrogen temperatures (–320 °F) (78 K) to verify compatibility of design and materials for cryogenic service
Primary pressure test (Hydrostatic)	An optional low-pressure gas-leak test followed by a hydrostatic pressure test conducted in accordance with the applicable National Consensus Standard.
Alternate pressure test (Pneumatic)	An optional low-pressure gas-leak test followed by a pneumatic or combination hydrostatic and/or pneumatic pressure test conducted in accordance with the applicable National Consensus Standard.

6.4.3.4 Pressure testing is done to verify the structural integrity of a vessel or piping system. The ultimate benefit is to ensure personnel safety; therefore, considerations of time or funding are not sufficient reasons to request use of the alternate test methods or to waive any test requirements.

6.4.3.5 No pneumatic test shall be conducted until a written procedure incorporating appropriate safety procedures has been approved by SHed and the PSM (see Section 6.4.12).

6.4.4 Pressure Terminology

6.4.4.1 Different terms exist for the maximum allowable pressure in a pressure system. ASME Code, Section VIII, Division I uses MAWP, whereas Division II uses DP. ASME piping codes also use DP. This document uses MAWP to describe the maximum pressure at which a component or system is designed to operate, unless referring to a specific code.

6.4.4.2 The term “operating pressure” is not synonymous and should not be interchanged with the terms DP or MAWP, as a system or vessel typically operates below the DP or MAWP to allow a sufficient margin between the operating pressure and the relief device set pressure. This is evident in the definition of operating pressure as defined in ASME Section VIII, Division I, and is as follows:

Operating pressure.—The pressure at the top of a vessel at which it normally operates. It shall not exceed the maximum allowable working pressure, and it is usually kept at a suitable level below the setting of the pressure-relieving devices to prevent their frequent opening.

6.4.5 Cold-Shock Testing

6.4.5.1 All vessels or lines designated for cryogenic service shall be subjected to a standard cold-shock test as described in this section. A cold-shock test is the initial test in the sequence for testing of cryogenic systems. It is to be performed before any pressure test is considered. The recommended fluid for cold-shock testing is liquid nitrogen (LN₂). Alternate fluids, for special cases only, are nitrogen or helium gas cooled to at least –150 °F (172 K) by an LN₂ heat exchanger.

NOTE: CAUTION. When using LN₂ in the pressure testing procedures for liquid hydrogen (LH₂) systems, be aware of the weight and temperature differences between the two fluids.

6.4.5.2 The purpose of cold-shock testing is to verify compatibility of materials, equipment, and fasteners for cryogenic service. Cold-shock testing of recommended cryogenic materials at LN₂

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temperatures (–320 °F) (78 K) will produce at least 93 percent of the total thermal contraction that would be obtained with LH₂ (–423 °F) (20 K) and liquid helium (–452 °F) (4 K). This contraction in the system being tested may reveal defects, such as inadequate design, incompatibility of materials, etc., leading to brittle fracture or physical distortion. The following precautions will help prevent injury to personnel and failure of the system:

- a. Inspection.—The vessel, component, or piping system shall be inspected for correct assembly, weld quality, correct torque on threaded fasteners, and trapped liquids. The pressure of liquids trapped in cavities and frozen by cryogenic temperatures may cause failure of the system.
- b. Personal protection.—The principal hazards of cold-shock testing are the extremely low temperatures involved and the potential for asphyxiation. The following requirements apply:
 - (1) All personnel shall be dressed in personal protective equipment before chilling the system.
 - (2) Gloves that are relatively impenetrable and loose fitting shall be worn for handling LN₂ equipment or LN₂-cooled parts.
 - (3) Handlers of LN₂ shall also wear a face shield that will stop splashes from all directions.
 - (4) An apron of nonabsorbent material shall be worn when splashing is a possibility.
 - (5) Trousers shall be cuffless and worn outside leather high-top shoes.
- c. Ventilation.—To prevent asphyxiation of personnel, cold-shock testing shall be done outdoors or in adequately ventilated areas.
- d. Procedure.—The preferred cold-shock testing method is immersion, but if such is not possible, the cold-flow method may be used.
- e. Immersion.—Whenever possible, the system shall be completely immersed in an open LN₂ container fabricated from material approved for use with cryogenic fluids. The system shall be immersed slowly to prevent LN₂ splashing.
- f. Cold flow.—If the configuration of a system prohibits complete immersion in LN₂, flow low-pressure LN₂ (as close to atmospheric pressure as possible) through the system or fill it with an LN₂-cooled gas.

NOTE: CAUTION. *If the system being cold-shock tested has been designed for a cryogen other than LN₂ (e.g., LH₂), the design engineer shall determine the amount of LN₂ to be used so as not to overload the structure with heavier fluid.*

6.4.5.3 The piping that runs from the LN₂ container to the system being cold-shock tested shall be as short and direct as possible. The initial flow of LN₂ should be established directly into the system under test, rather than through a precooled line, so as to provide maximum temperature induced shock.

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6.4.5.4 Adequate venting capacity of the system shall be ensured during the cold flow test. The initial surge of LN₂ into the system will cause the initial venting rate to exceed the normal venting rate.

6.4.5.5 The system shall remain in the LN₂ environment until it is completely chilled. A completely chilled system is defined as one immersed in LN₂ until excessive bubble formation ceases or until monitoring equipment indicates no further temperature decrease with extended duration of cold flow (15 minutes).

6.4.5.6 Post-Cold-Shock Testing Procedures

Completion of the cold-shock test shall be documented after the following procedures have been accomplished:

- a. System warm-up.—Remove the system from the cold environment and allow it to warm to ambient temperature. On some systems, it may be advantageous to use auxiliary heating devices, a water spray, or gas purge to reduce the warming time. If a water spray is used, it should be maintained until the system is above the freezing point of water, since the ice coating will act as an insulator and lengthen warm-up time (CAUTION—Remove all traces of water).
- b. Retorquing.—After the system has reached ambient temperature, all threaded fasteners and components should be retorqued.
- c. Inspection methods.—Inspect the entire system for any evidence of failure. Particular attention should be given to welds and joints of dissimilar metals. Repair all defects.
- d. Repaired systems.—All defective portions of any system shall be subjected, after repair, to another cold-shock test before any other test is considered.

6.4.6 Low-Pressure Gas-Leak Testing

6.4.6.1 A low-pressure (5 to 10 psig) gas-leak test is optional for systems that are hydrostatically tested; however, all other systems shall be subjected to such a test. A suggested piping diagram for low-pressure gas-leak testing is shown in Figure D.1 (Appendix D).

6.4.6.2 For cryogenic systems, the low-pressure leak test shall be performed after the cold-shock test and before the pressure strength test. It is the initial test to be performed on all noncryogenic systems.

6.4.6.3 The purpose of the low-pressure gas-leak test is to indicate possible failure sites in a system before any form of high-pressure testing is undertaken. Although the system pressure is low, this test will indicate cracks and gross porosity in welds, leakage through threaded components, and improper sealing of gaskets, O-rings, and other joints.

6.4.6.4 The soap bubble test is recommended as a part of the low-pressure gas-leak test, because it is easy to do, is quick, does not need exotic equipment, and is sensitive. The bubble test is performed by pressurizing the system to 5 psig or less with air and applying a film of bubble-

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testing liquid or a soap and water solution. Leaks are indicated by the bubbles formed by the leaking gas. Standard prepared bubble-testing solutions or commercial Leak-Tec™ (American Gas & Chemicals, Inc.) fluid is recommended.

6.4.6.5 Simple equipment is required for a bubble test. Air or nitrogen gas shall be used for pressurizing the system. Helium gas is not recommended because the extra sensitivity is marginal and the cost of the gas is high.

6.4.6.6 The suggested procedure for a low-pressure gas-leak test is as follows:

- a. Document performance of the test on the appropriate hydrotest or pneumatic test form.
- b. Ensure that the system temperature is above the freezing point and below the boiling point of the bubble-testing liquid.
- c. Clean the exterior of the system with an approved commercial solvent. Appropriate safety and environmental precautions shall be followed when solvents are being used. The surface must be clean before the bubble-testing liquid is applied, because oil films or small amounts of soldering flux will destroy the liquid's bubble-producing capability.
- d. Pressurize the system to 10 percent of the normal working pressure of the system, but do not exceed 5 psig. High pressures are not necessary for the leak test. Small leaks can be pinpointed without the hazards of high-pressure testing.
- e. Apply bubble-testing liquid to all joints and seams of the system. Watch for the formation of bubbles. The gas bubbles will form at the leak, showing its precise location.
- f. Repair all leaks before continuing the test sequence.

6.4.7 Hydrostatic Pressure Testing Guidelines

This section provides basic information and guidelines for hydrostatic testing of pressure systems and vessels. These hydrostatic test guidelines apply to pressure systems and vessels designed for liquid, gas, steam, or cryogenics. The guidelines are based on ASME B&PV Codes and the ASME Piping Codes. The test pressure for a system or vessel (as well as fluid and ambient temperature requirements) should be found in the applicable code. Testing guidelines include the following:

- a. Before any pressure tests are considered, all new or altered cryogenic pressure vessels and piping systems shall be cold-shock tested.
- b. Furthermore, before any hydrostatic pressure test is done, a low-pressure gas-leak test is recommended for detecting gross leaks.
- c. All high points in the system shall be provided with valves to bleed possible air pockets while the system is being filled with test fluid. If the system cannot be vented, safety measures equivalent to those taken with a pneumatic test must be implemented.
- d. During application of hydrostatic pressure, nonessential personnel shall be restricted from the test area, and the area shall be barricaded or patrolled to enforce such restriction. Test

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personnel must take shelter behind structures, walls, or proper supports and take precautions against the potential danger from fluid leakage.

- e. Hydrostatic test results shall be documented on appropriate forms (see Section 6.4.11.)

6.4.8 Hydrostatic Pressure Test Equipment

A typical schematic for a hydrostatic pressure test is shown in Figure D.2 (Appendix D).

Equipment requirements include the following:

- a. A safety relief device having a set pressure of the test pressure plus 50 psi or 110 percent of the test pressure, whichever is lower, shall be provided.
- b. The flow capacity of the relief device shall be at least equal to the output of the hydrostatic pressure source.
- c. Water shall be used as a test medium.
- d. Test water shall be clean and of a quality that minimizes corrosion of the materials in the system under test.
- e. In the rare cases where water would contaminate or otherwise harm the system, consideration may be given to testing with another nontoxic fluid.
- f. Testing with a fluid other than water requires specific approval of the PSO and SHed.
- g. A calibrated pressure gauge shall be used to indicate test pressure.
- h. The gauge shall be visible to the operator of the pressure source.
- i. The gauge shall be calibrated against a standard deadweight tester or a calibrated master gauge.
- j. Gauges shall be recalibrated periodically or at any time there is reason to believe they are in error.
- k. The range of the pressure gauge used to indicate test pressure should be about double the test pressure, but not less than 1.5 times the test pressure nor greater than 4 times the test pressure.
- l. Digital pressure gauges may be used if their accuracy is comparable to a calibrated dial pressure gauge.
- m. For large vessels or systems where more than one pressure gauge is required, a recording gauge is recommended and may be substituted for one or more of the indicating gauges.

6.4.9 Hydrostatic Pressure Testing Preliminary Considerations

- a. Equipment that is not to be subjected to the pressure test shall be either disconnected from the system or isolated by a blank or similar device. Valves may be used for this purpose provided the valve closure is suitable for the proposed test pressure.
- b. Isolated equipment and piping not being tested shall be vented.

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- c. All welded, flanged, and threaded joints and connections not previously pressure tested shall be left uninsulated and exposed for examination during testing.
- d. All stress loadings that may exist during this test shall be determined before the final hydrostatic test pressure is specified.
- e. The system shall never be subjected to stresses greater than the predetermined limit.
- f. To locate major leaks in the system, a preliminary low-pressure gas-leak test not exceeding 5 psig may be performed before the hydrostatic pressure test.
- g. All leaks shall be repaired before proceeding with the hydrostatic pressure test.
- h. Systems designed for gas or vapor may require temporary support or bracing to withstand the weight of the test fluid used in the hydrostatic pressure test. Adequate drainage or other provisions shall be available to remove the test fluid at the conclusion of the hydrostatic test.
- i. Hydrostatic tests with water shall not be conducted when ambient temperature is below 40 °F (278 K).
- j. The temperature of water shall not be higher than 120 °F (322 K), unless a higher test temperature is specified and approved.
- k. If a hydrostatic test is conducted with a water temperature higher than 120 °F, the final, close visual examination at the test conclusion shall be conducted only after the water temperature falls below 120 °F.
- l. Before hydrostatic pressure is applied, the test equipment shall be examined to see that it is tight.
- m. All low-pressure filling lines and other components of the test equipment that should not be subjected to test pressure shall be disconnected or blanked off.

6.4.10 Hydrostatic Pressure Testing Procedure

- a. The hydrostatic pressure shall be increased gradually until the system is subjected to 50 percent of the test pressure.
- b. At this point, the manual isolation valve shall be closed and the pressure held until the test gauge stabilizes.
- c. The system shall be closely examined for leaks and other deficiencies. Leaking will be indicated by a continuous decrease in the system pressure.
- d. Temperature changes in the system shall be monitored to correct pressure changes.

NOTE: *WARNING. If signs of yielding or failure of the system are observed, pressure shall be slowly decreased to zero.*

- e. After 50 percent of the test pressure is reached, the system pressure shall be increased in 10-percent increments (60, 70, 80, 90, and 100 percent) to final test pressure.

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- f. At each pressure level, the manual isolation valve shall be closed and the pressure held until the test gauge stabilizes.
- g. The system shall be observed for an indication of leakage at each step. Observation shall be carried out from a safe distance.
- h. Continue increasing pressure until the full test pressure is applied. After maximum test pressure is reached, the isolation valve of the hydrostatic pump shall be closed and the full test pressure continuously maintained for a minimum of 15 minutes.
- i. During this time, the system shall be observed for indications of leakage. Observation shall be carried out from a safe distance.
- j. Following the application of full hydrostatic test pressure, the pressure shall be reduced to a value not less than the MAWP of the vessel or system.
- k. A close visual examination for leakage shall be made at all welds and all flanged and threaded joints.
- l. Hydrostatic testing of a pressure vessel is a potentially hazardous procedure. All suitable safety precautions shall be taken to eliminate potential hazards to personnel and property.
- m. All joints and connections shall be examined for leakage.
- n. The piping system, exclusive of possible localized instances at pump or valve packing, shall show no visual evidence of weeping or leaking.
- o. Piping system expansion joints under test shall be provided with temporary restraints if the additional pressure load makes it necessary, or they shall be isolated with blanks or valving during the system test.

6.4.11 Hydrostatic Pressure Testing Documentation

A checklist and a report are to be filled out for every hydrostatic pressure test and sent to the PSM PSO Administrative Assistant. Use the following forms, as applicable:

- a. GRC4022, Pressure Vessel Hydrostatic Test Checklist
- b. GRC4016, Pressure Vessel Hydrostatic Test Report
- c. GRC4018, Piping System Hydrostatic Test Checklist
- d. GRC4012, Piping System Hydrostatic Test Report

6.4.12 Pneumatic Pressure Testing Guidelines

6.4.12.1 This section provides basic information and guidelines for pneumatic testing of pressure systems and vessels. These pneumatic testing guidelines apply to pressure systems and vessels designed for liquid, gas, steam, or cryogenics. The guidelines are based on the ASME B&PV Codes, the ASME Piping Codes, and the GSM. The test pressure for a system or vessel should be found in the applicable code as well as fluid and ambient temperature requirements.

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6.4.12.2 These general guidelines govern pneumatic pressure testing; however the decision to apply a pneumatic test instead of a hydrostatic test is restricted to the following situations:

- a. The pressure system is designed or supported in a manner that unquestionably cannot be safely filled with liquid.
- b. The configuration of the pressure system is such that it cannot be dried, and traces of the test medium cannot be tolerated.
- c. A hydrostatic test would damage linings, internal insulation, or other equipment.

NOTE: *Variance from these procedures requires PSO and SHeD concurrence.*

6.4.13 Pneumatic Pressure Test Authorization

Prior to any pneumatic test, a test procedure along with supporting documentation must be reviewed by SHeD and the PSM. The permit requestor must complete a Pneumatic Test Request form (NASA GRC802), and submit it along with attached documentation to the PSM or PSO Administrative Assistant. Once reviewed and found satisfactory, a Pneumatic Test Permit (NASA GRC804) is signed by the PSM and issued to the requestor. If insufficient information is provided, or procedures or calculations are incorrect, the requestor will be notified to make the corrections prior to issuance of the permit. A list of the required supporting documentation for most test cases is provided on the Pneumatic Test Request form. This includes system MAWP data, P&IDs, test diagram showing pressure source and connection to the system, restricted distance calculations, relief device information, barricade plan, etc. A restricted distance based on the method given in Appendix C must be given along with the calculation. An associated barricade plan containing a plan view of the area is also required.

6.4.14 Hazards of Pneumatic Testing

6.4.14.1 Use of compressed gas as test medium is hazardous. Precautions shall be taken to ensure that adequate protection is provided to prevent injury to personnel and damage to property from missile fragments, shock waves, or other consequences of a rupture or leakage during a pneumatic test.

6.4.14.2 Pneumatic testing shall always be conducted using the two-man buddy system (see GSM Chapter 22).

6.4.14.3 Personnel attempting a pneumatic test of any system should be aware of the following potential hazards:

- a. Fragmentation into shrapnel will result if the part under test breaks up. Because the shrapnel will travel at high velocity for long distances, the likelihood of injury to unprotected personnel or equipment is very high.
- b. An explosive noise will result from a large rupture, whereas noise of extended duration will result from a small-orifice failure. By reflex action from the sudden noise, personnel in the nearby area could expose themselves to injury. Another hazard to consider is the cutting action of a high-velocity, small-orifice air leak.

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- c. A pressure wave or pulse could develop from a gross rupture, presenting a hazard to personnel and possible damage to surrounding equipment and structures.
- d. Equipment motion resulting from a gross rupture can cause whip action from failure of a flexible pipe or hose, unless the system is securely fastened. In addition, a severe structural failure of a lightweight container or vessel could cause the part to act as a projectile, propelled by the resulting discharge force. Therefore, before any pneumatic test is conducted, the parts shall be securely fastened to prevent hazardous movement.

6.4.14.4 Appendix B of this chapter shows the recommended method for determining the restricted distance for pneumatic tests. The restricted distance is based on the distance where blast overpressure will equal 0.5 psi; this level of overpressure may shatter glass windows. Protection of buildings and major structures shall also be considered if they are inside the exclusion area.

6.4.14.5 The restricted area shall be barricaded or patrolled to control movement of all personnel in the area.

6.4.14.6 Restrictions for operation may be required to ensure safe operation of the system. These restrictions shall be developed for use both during the pressure test and during subsequent normal operation of the system. The restrictions may include physically isolating the system with blast walls, removing all personnel from a defined area when the system is pressurized, or placing the vessel in a remote location. Permanent signs and barriers should be considered. Other precautions may be required.

6.4.14.7 Combination hydrostatic/pneumatic pressure tests are as hazardous as pneumatic tests; therefore, identical precautions shall be employed.

6.4.14.8 Before any pressure tests are considered, all new or altered cryogenic pressure vessels and piping systems shall be cold-shock tested.

6.4.14.9 Furthermore, a low-pressure gas-leak test shall be performed before a pneumatic pressure test is considered.

6.4.14.10 Brittle materials shall not be subjected to pneumatic pressure tests. A brittle material is one that has either (1) less than 10 percent elongation in standard tensile tests or (2) a ductile-to-brittle transition temperature (as indicated by Charpy impact tests) that is above the test temperature. Some commonly used brittle materials are glass, cast iron, and most high-strength alloys. See the applicable NCS for examination requirements of components that are not pressure tested.

6.4.15 Pneumatic Pressure Test Equipment

A suggested piping diagram for the pneumatic pressure test is illustrated in Figure D.3 (Appendix D). Equipment requirements include the following:

- a. A safety relief device having a set pressure of the test pressure plus 50 psi, or 110 percent of the test pressure, whichever is lower, shall be provided.
- b. The flow capacity of the relief device shall be at least equal to the output of the pneumatic pressure source.

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- c. The gas used as the test medium shall be nonflammable and nontoxic. Air or nitrogen gases are the preferred pressurizing fluids.
- d. In addition, the gas shall not be vented in a confined area. This eliminates the possibility of breathing undesirable or hazardous materials that may reside within the hardware.
- e. A calibrated pressure gauge shall be used to indicate test pressure.
- f. The gauge shall be visible to the operator of the pressure source and shall be calibrated against a standard deadweight tester or a calibrated master gauge.
- g. Gauges shall be recalibrated at any time that there is reason to believe that they are in error.
- h. The pressure range of the test gauge shall not be less than 1.5 times the test pressure nor greater than 2 times the test pressure.
- i. Digital pressure gauges may be used if their accuracy is comparable to a calibrated dial pressure gauge. For large vessels or systems where more than one pressure gauge is required, a recording gauge is recommended and may be substituted for one or more of the indicating gauges.
- j. Before applying pneumatic pressure, the test equipment shall be examined to ensure that it is tight.
- k. All low-pressure filling lines and other components of the test equipment that should not be subjected to test pressure shall be disconnected or blanked off.

6.4.16 Pneumatic Pressure Testing Preliminary Considerations

- a. The temperature of the test medium used to apply a pneumatic test is determined differently for pressure vessels and pressure systems.
- b. All stress loadings that may exist during this test shall be determined before the final pneumatic test pressure is specified.
- c. The system shall never be subjected to stresses greater than the predetermined limit.
- d. Equipment that is not to be subjected to the pressure test shall be either disconnected from the system or isolated by a blank or similar device. Valves may be used for this purpose, provided the valve closure is suitable for the proposed test pressure.
- e. Isolated equipment and piping not being tested shall be vented.
- f. All welded, flanged, and threaded joints and connections not previously pressure tested shall be left uninsulated and exposed for examination during testing.

6.4.17 Pneumatic Pressure Testing Procedure

- a. To locate major leaks in the system, a preliminary low-pressure gas-leak test not exceeding 5 psig shall be performed before other methods of leak testing.

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- b. When the leak-test pressure of 5 psig has been reached, the system under test shall be isolated from the pneumatic pressure source with a hand valve.
- c. The test gauge shall be observed for at least 15 minutes to ensure the leak tightness of the system. Leaking will be indicated by a continuous decrease in the system pressure.
- d. Temperature changes in the system shall be monitored to correct for pressure change due to temperature change.
- e. The pneumatic pressure shall be increased gradually until the system is subjected to 50 percent of the test pressure.
- f. At this point, the pressure shall be held until the test gauge is stable.
- g. After 50 percent of the test pressure is reached, the system pressure shall be increased by 10-percent increments to the final test pressure (60, 70, 80, 90, and 100 percent).
- h. The manual isolation valve of the pneumatic pressure source shall be closed, and pressure shall be held until the test gauge is stable.
- i. At each step, the system test pressure gauge shall be observed from a safe distance for indication of leaks.

NOTE: *WARNING. If signs of yielding of failure of the system are observed, pressure shall be slowly decreased to zero.*

- j. After full test pressure is reached, the isolation valve of the pneumatic pressure source shall be closed, and the full test pressure shall be continuously maintained for a minimum of 15 minutes to ensure the quality of the system.
- k. During this time, the system test pressure gauge shall be observed from a safe distance for indications of leakage.
- l. Following the application of the full pneumatic test pressure, the pressure shall be reduced to allow for close visual examination.
- m. All welds and all flanged and threaded joints shall be examined for evidence of leakage.
- n. Local or close inspection of the system shall not be made while the test pressure is above the DP.

NOTE: *The applicable NCS must be referenced for the proper test and inspection pressures and temperatures for the specific system or vessel application. Typically the pneumatic test pressure is 110 percent of the MAWP or DP, ASME B&PV Code and B31.3, but the specific code and current version must be referenced by the designer specifying the test.*

6.4.18 Pneumatic Pressure Testing Documentation

A checklist and a report are to be filled out for every pneumatic pressure test and sent to the PSM PSO Administrative Assistant. Use the following forms, as applicable:

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- a. GRC4026, Pressure Vessel Pneumatic Test Checklist
- b. GRC4010, Pressure Vessel Pneumatic Test Report
- c. GRC4020, Piping System Pneumatic Test Checklist
- d. GRC4014, Piping System Pneumatic Test Report

6.4.19 Other Leak-Testing Methods

6.4.19.1 In general, all systems specified by the design engineer shall be leak tested.

6.4.19.2 The leak test is the final test in any test sequence described in this section. It shall be performed only after the system has been hydrostatically or pneumatically tested.

6.4.19.3 A leak test of greater sensitivity than the initial low-pressure gas-leak test shall be used as a final test of system integrity. This final test could be the high-pressure bubble test, the change-in-pressure test, or the mass spectrometer test. Only one of these tests is required for acceptance.

6.4.19.4 The design engineer may specify the test in which the system is pressurized to the normal working pressure of the system. The following equipment, conditions, and procedures are necessary.

6.4.20 The Bubble Test

6.4.20.1 Air or nitrogen gas shall be used for pressurizing the system. The extra sensitivity of helium gas may be warranted only for high-pressure helium and hydrogen systems. Standard NASA-prepared bubble-testing solutions are recommended. Commercial Leak-Tec™ fluid is equivalent to the NASA solution. The piping diagram for high-pressure bubble testing is illustrated in Figure D.4 (Appendix D).

6.4.20.2 The system shall be at a temperature that is above the freezing point and below the boiling point of the bubble-testing liquid.

6.4.20.3 The exterior of the system must be cleaned (when practical) with an approved commercial solvent. It is essential that the surface be clean prior to the application of the soap solution, because oil films or small amounts of soldering flux will destroy the bubble-producing quality of the soap solution. The system shall be slowly pressurized to the normal working pressure of the system.

6.4.20.4 The bubble-testing liquid should be applied to all joints and seams of the system. Watch for the formation of bubbles. The gas bubbles issuing from a leak will show its precise location. Depressurize the system and repair all leaks before continuing the test sequence.

6.4.21 Change-In-Pressure Test

6.4.21.1 This test is performed by evacuating the interior of the system and monitoring the rate of pressure increase with the pump isolated from the system. Although it is difficult to pinpoint the exact source of a leak with this test, the overall leak rate of the system can be easily established. Before this test is attempted, be certain that the system has sufficient strength to withstand evacuation.

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6.4.21.2 When the results of this test are analyzed carefully, exceedingly low leak rates can be measured. The sensitivity of this test is comparable to the high-pressure bubble test described previously.

6.4.21.3 The equipment necessary for this test is as follows:

- a. Vacuum gauge.—A thermocouple or Pirani gauge having a range of approximately 1 to 1,000 microns is required for this test. The gauge sensing tube shall be connected with as short a tube as possible to the system being evacuated. Because this type of gauge is somewhat inaccurate and the test is based on a relative change, the vacuum gauge does not have to be calibrated. For additional information on the operation of the gauge, check the manufacturer's literature.
- b. Vacuum pump.—For most applications, a mechanical (rotary) vacuum pump is desired.
 - (1) The vacuum pump should have a blank-off pressure of no more than 25 microns.
 - (2) The pump shall be connected to the system with as short a length of tubing as possible.
 - (3) To ensure a rapid pump-down time, the evacuation line shall be no smaller than the evacuation inlet of the pump.
 - (4) A flexible connection installed between the pump and the system will reduce vibrations.
- c. Vacuum valve.—A valve intended for vacuum usage is required to isolate the system under test. The valve should be located as close to the system as possible and have an opening at least equivalent to the inside diameter of the evacuation line.
- d. Thermometer.—A thermometer or thermocouple should be installed in the system to measure the temperature of the evacuated region.

6.4.21.4 Evacuate the system to a pressure of at least 100 microns. This will allow the pressure rise to be monitored for at least a tenfold increase with the vacuum gauge. Inability to evacuate the system to a pressure of 100 microns can usually be traced to one or more of the following conditions:

- a. High magnitude of leaks
- b. System contaminants, particularly water
- c. Inadequate evacuation system

6.4.21.5 Isolate the vacuum pump from the system by closing the vacuum valve. Monitor the time, system pressure, and temperature over a suitable time period to establish the leak rate. The leak rate calculation is illustrated in Figure D.5 (Appendix D).

6.4.21.6 The initial evacuation of any system is likely to result in gas evolution, which is often called "outgassing." The outgassing component of pressure rise may be easily separated from the leakage component by plotting the system pressure as a function of time. Two distinct degrees of curvature are evident in a typical system pressure plot (Figure D.5). Between points A and B, the system pressure rises at a continually decreasing rate; hence, a curve of decreasing

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slope is evident. Between points B and C, the straight line indicates a uniform rate of pressure increase.

6.4.21.7 The significance of each curve may be explained by considering the nature of both outgassing and leakage. The rate of outgassing is exponentially dependent on pressure. As the system pressure increases, the rate of outgassing decreases; however, the rate of leakage is constant over the pressure range because the same differential pressure of about 760,000 microns is maintained. Therefore, the initial curve from point A to point B represents both outgassing and leakage, with outgassing being the principal cause of the rate of system pressure rise near point A.

6.4.21.8 At point B, the system pressure has increased to above the vapor pressure of the outgassing source; therefore, the straight line between points B and C represents system leakage. Only the straight line section of the curve should be used for determining leak rates. The curve between points A and B should be ignored.

6.4.22 Mass Spectrometer

6.4.22.1 A mass spectrometer leak detector is an electrically tuned instrument for detecting the presence of a tracer gas. It is the most sensitive commercially available leak detector. These detectors use a helium tracer gas to detect leaks as low as 10^{-9} cm³/sec.

6.4.22.2 Ions of the tracer gas are produced in a source chamber by electron bombardment from a hot tungsten filament. The ions are accelerated electrostatically through an analyzer magnet field. The helium ions are deflected by a permanent magnetic field and collected on a target plate connected to the grid of an electrometer tube. The output of the electrometer tube is amplified and presented on a multirange output meter.

6.4.22.3 Liquid nitrogen traps, roughing and oil range diffusion pumps, and various valves are incorporated on the mass spectrometer to maintain proper operating conditions in the analyzer tube.

6.4.22.4 A standard leak is essential if quantitative measurements are to be made, because sensitivity can vary widely as the spectrometer tube becomes contaminated. Large decreases in sensitivity can be encountered when the leak detector is connected to large, separately pumped systems (only a portion of the trace gas entering the leak arrives at the spectrometer tube).

6.4.22.5 The helium probe consists of a 10^{-4} cm³/sec leak detector in a probe tube at the end of several feet of flexible tubing. It is used for testing devices that are filled with helium under pressure. Because of the rapid diffusion of helium coming out of a leak, it is unlikely that a leak smaller than 10^{-6} cm³/sec can be found by this method.

6.4.22.6 The pressure testing and procedure method of testing is useful in testing large tanks or objects that cannot withstand internal vacuum. The system is pressurized with helium tracer gas, and the exterior of the system is sniffed with the helium probe. When the probe is passed over a leak, the outflowing helium gas is detected. To proceed with the test, do the following:

- a. Pressurize the system with helium gas to 10 percent of the normal working pressure, but do not exceed 20 psig. High pressure is not desired for this test since it only increases diffusion in air. If the system is large, a tracer gas consisting of a combination of helium and nitrogen

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gas may be used for testing. The percentage of nitrogen gas to helium gas may be as large as 95 percent by volume.

- b. Carefully sniff the exterior of the system with the helium probe. Any helium entering the probe will be recorded as a leak. This test may be made more sensitive by surrounding the helium probe with a small enclosure. The enclosure will prevent wind from rapidly dispersing the helium and allow helium to build up in the enclosure until the concentration is sufficient to be detected by the mass spectrometer.

6.4.22.7 Vacuum testing is the most sensitive form of leak detection. Here, the system under test is evacuated either with the vacuum system in the leak detector or, if the system is of appreciable size, with an auxiliary pumping system. A helium jet is sprayed over the suspected areas of the system to locate the leaks. Proceed with the vacuum test as follows:

- a. Evacuate the system with either the pumping system incorporated in the mass spectrometer or an auxiliary pumping system. Generally, the lower the system pressure, the more sensitive the test. The most sensitive test occurs when the high-vacuum leak detector pumping system can solely maintain the vacuum in the system at or below 10^{-4} mm Hg.
- b. Spray the exterior of the system with the helium tracer gas. The tracer gas will be drawn into the system through the leaks and recorded on the mass spectrometer. The exact location of leaks may be determined by using a very fine helium jet or by bagging the suspected area to ensure the accumulation of a helium pocket.
- c. Repair each leak immediately on detection, either temporarily, or preferably, permanently. As each leak is repaired, the system pressure will be lowered and smaller leaks may be located.

6.4.22.8 The mass spectrometer is a highly complicated instrument. The outline for leak testing with a mass spectrometer presented herein is for general information only. Anyone attempting to use a mass spectrometer should be thoroughly familiar with its theory and operation. There is no substitute for properly applied experience in leak detection with a mass spectrometer.

6.5 Cryogenic Systems (*GSM Chapter 5, Oxygen Safety; GSM Chapter 6, Hydrogen Safety*)

6.5.1 This section discusses stationary cryogenic systems. The CGA defines cryogenic fluids as those with a normal boiling point lower than -238°F (123 K), but other authorities set higher boiling points as the criteria. At GRC, cryogenic systems are used to store and distribute cryogenic liquids such as those listed in Table 6.2

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TABLE 6.2.—CRYOGENIC FLUIDS USED AT GRC

Fluid	Approximate normal boiling point		
	°F	°R	K
Krypton	−243.13	216.54	120.29
Methane	−259	201	111
Oxygen	−297.34	162.32	90.18
Argon	−302.57	157.10	87.28
Nitrogen	−320.45	139.22	77.35
Neon	−410.91	48.76	27.09
Hydrogen	−423.19	36.48	20.27
Helium	−452.07	7.60	4.22

6.5.2 A typical cryogenic system consists of a pressure vessel (called a Dewar), pressure-relief devices, control valves, and distribution piping. The Dewar is a double-walled pressure vessel with the system fluid contained in the inner vessel. The space between the vessels is filled with a powdered insulation (or is super insulated) and is held at a vacuum with a vacuum pump, thereby providing an insulation barrier for the fluid in the Dewar. A control system and pressure building coil allow the Dewar to maintain an internal pressure. Cryogenic systems generally operate at pressures below 100 psig. Piping for cryogenic fluid distribution is either vacuum-jacketed or rigid foam insulated to reduce boiloff losses.

6.5.3 Requirements for Cryogenic Vessels and Systems

In addition to conforming to the general requirements for pressure system safety, cryogenic vessels and systems must adhere to specific and unique requirements as follows:

- a. Design.—Cryogenic vessels shall be designed in accordance with the ASME Code, Section VIII.
- b. Relief device.—The inner vessel of a multishell cryogenic vessel shall have relief devices designed and maintained in accordance with Section VIII of the ASME Code. The outer vessel shall have relief protection to allow for a leak or failure of the inner shell.
 - (1) Relief valves shall be mounted vertically and with sufficient standoff distance to prevent the valve from icing or failing to operate.
 - (2) Relief valves shall relieve into a vent system or into an area where no harm will come to personnel or equipment.
 - (3) Vacuum insulation spaces shall be provided with overpressurization protection in case of a leak in the pressure boundary of the inner transfer line.
- c. Oxygen.—Comprehensive information on oxygen service is described in GSM Chapter 5. Design and operation of systems for liquid oxygen storage shall also conform to requirements contained in National Fire Protection Association (NFPA) 55, Compressed Gases and Cryogenic Fluids Code.
- d. Hydrogen.—Comprehensive information on hydrogen service is described in GSM Chapter 6 and American National Standards Institute (ANSI)/American Institute of Aeronautics and Astronautics (AIAA) G-095, Guide to Safety of Hydrogen and Hydrogen Systems. Design and operation of systems for liquid hydrogen storage shall also conform to requirements contained in NFPA 55.

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6.5.4 Testing

To ensure the safety of personnel and equipment, testing and recertification of cryogenic systems are required. The following requirements apply:

- New, altered, and repaired systems shall be cold-shock tested to verify the compatibility of material, equipment, and fasteners for cryogenic service.
- Prior to cold-shock testing, the vessel, components, and piping to be tested shall be inspected for proper assembly.
- Cold-shock testing shall be done in well-ventilated areas, preferably outdoors, to prevent asphyxiation of personnel.
- Such tests shall be conducted in accordance with Section 6.5.
- Pressure testing of new, altered, and repaired systems shall also be performed in accordance with Section 6.4.

6.5.5 Safety Considerations

Because of the nature of cryogenic systems, the following precautions should be taken:

- Avoid contact with fluid or equipment cooled to cryogenic temperatures, since cryogenic systems contain fluids that are extremely cold.
- The vapors of many cryogenic fluids are heavier than air; therefore avoid areas in unventilated spaces where low pockets of cryogenic vapor may accumulate.
- Provide proper ventilation for all portable Dewar fill stations. Low-oxygen alarms should be used if proper ventilation cannot be provided.
- Vent relief devices to an area where no harm to personnel or equipment will result. Vent cans should be used wherever possible.
- Adhere to guidelines for personal protective equipment, given in GSM Chapter 15.

6.6 Safety-Related Switches and Pressure-Indicating Devices (*NASA-STD-8719.17*)

Pressure-indicating devices and transducers convey information on the operating state of associated systems and therefore require regular validation to assure accurate pressure indications. Failure of these devices to accurately convey system pressure information could result in unsafe actions that jeopardize equipment and personnel safety. The criticality of these devices must be assessed, and regular function verification must be performed by system owner/operators. Responsible organizations fall into four categories: Institution, Central Process Systems, Test, and Other.

6.6.1 Design and Installation

6.6.1.1 Safety-related pressure-indicating devices shall meet an appropriate NCS such as ASME B40.100, Pressure Gauges and Gauge Attachments; Underwriters Laboratory (UL) 404, UL

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Standard for Safety Gauges, Indicating Pressure, for Compressed Gas; or MIL-G-18997, Gauge, Pressure Dial, Indicating.

6.6.1.2 The minimum acceptable accuracy across the system design pressure range for each safety-related pressure indicator shall be in accordance with ASME B40.100 and the design specification.

6.6.2 Catastrophic Failure Potential

If catastrophic failure of a gauge is feasible in a manner that can cause personnel injury, the pressure gauge shall be equipped with a relief case/enclosure.

6.6.3 Function Validation

The accuracy of all safety-related pressure indicators shall be periodically verified as specified by category below.

6.6.3.1 Institutional Devices

Institutional pressure-indicating devices and transducers are those associated with facility systems, including steam (both facility low pressure and distributed high pressure); hot water; condensate; local service air; local hydraulics; domestic water; heating, ventilation, and air conditioning (HVAC); compressed natural gas (CNG); and so forth. Devices must be maintained in accordance with NPR 8831.2, Facilities Maintenance and Operations Management. Gauges and pressure-indicating devices must be function verified at the same interval as relief devices within the system. Generally, steam and hot water gauges are validated annually; air and domestic water gauges are validated no less frequently than once every 5 years. Function validation must be a documented part of the preventative maintenance plan. This is typically accomplished by noting the requirement in technician work instructions associated with the preventative maintenance plan. Records of completed work must be maintained in the computerized maintenance management system (MAXIMO, MP-2, enterprise asset management (EAM), etc.).

6.6.3.2 Central Process Systems

Central process systems pressure-indicating devices and transducers are those associated with distributed base-wide systems including 40/150/450-psig combustion air system (CAS), service air (sometime called shop air), altitude exhaust, and so forth. Devices must be maintained in accordance with NPR 8831.2. Gauges and pressure-indicating devices must be function verified at the same interval as relief devices within the system. Generally, air devices above 150 psig are validated no less frequently than every 3 years, and air devices below 150 psig are validated no less frequently than once every 5 years. Function validation must be a documented part of the preventative maintenance plan. This is typically accomplished by noting the requirement in technician work instructions associated with the preventative maintenance plan. Records of completed work must be maintained in the computerized maintenance management system (Maximo, MP2, EAM, etc.).

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6.6.3.3 Test Facilities

Test Facility pressure-indicating devices and transducers are those associated with test cells and discrete test facilities. Systems include end delivery of Central Process Systems (CPS) products (40/150/450 psig, for example), as well as standalone pressure systems such as K-bottle systems, local hydraulic systems, and so forth. For test operations, GRC regulations define inspection, measuring, and test equipment (IMTE) and require all IMTE associated with pressure system be assessed for risk and documented in a Quality and Safety Equipment list. This assessment is in conjunction with the GRC Safety Permit process and specifies mandatory calibration/accuracy requirements. Records of these calibrations are retained in the IMTE database or as specified in local policy documents below. Note that IMTE encompasses a broad range of transducers and instrumentation, not merely gauges. Pertinent documents include the following:

- a. GLPR-8730.6 Control of Inspection, Measuring, and Test Equipment
- b. GLP-FT-8080.13 Quality Manual for IN SITU Calibrations
- c. GLP-FT-8080.17 Planning and Execution of a Ground Test Project

6.6.3.4 Other (Uncategorized) Pressure-indicating Devices and Transducers

This category includes nontemporary devices that do not fall in any of the above categories. An example would be tenant-owned devices. These must be function verified on an interval no less frequent than that of the relief devices of the system. STD-8719.17 contains frequencies for various types of systems/commodities. Temporary contract equipment does not generally fall under this category. Such temporary equipment is covered by Health and Safety Plans (HASPs), local permit, and other GRC procedures specific to construction and similar temporary operations.

7.0 RECORDS

7.1 Pressure Systems Certification Documents

- a. Nondestructive examination (NDE) reports.—Maintained by Pressure Systems Office (PSO); Codes FDO/FXP.
- b. Risk assessment report.—Maintained by PSO (Codes FDO/FXP).
- c. System certification report.—Maintained by PSO (Codes FDO/FXP).
- d. Pressure system database.—Maintained by PSO (Codes FDO/FXP).

7.2 GRC Forms

- a. GRC83 Safety and Health Requirement Relief Request.—Maintained by Code Q, Safety and Mission Assurance.
- b. GRC802 Pneumatic Test Request.—Maintained by PSO (Codes FDO/FXP).
- c. GRC804 Pneumatic Test Permit.—Maintained by PSO (Codes FDO/FXP).

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- d. GRC4026 Pressure Vessel Pneumatic Test Checklist.—Maintained by PSO (Codes FDO/FXP).
- e. GRC4010 Pressure Vessel Pneumatic Test Report.—Maintained by PSO (Codes FDO/FXP).
- f. GRC4020 Piping System Pneumatic Test Checklist.—Maintained by PSO (Codes FDO/FXP).
- g. GRC4014 Piping System Pneumatic Test Report.—Maintained by PSO (Codes FDO/FXP).
- h. GRC4022 Pressure Vessel Hydrostatic Test Checklist.—Maintained by PSO (Codes FDO/FXP).
- i. GRC4016 Pressure Vessel Hydrostatic Test Report.—Maintained by PSO (Codes FDO/FXP).
- j. GRC4018 Piping System Hydrostatic Test Checklist.—Maintained by PSO (Codes FDO/FXP).
- k. GRC4012 Piping System Hydrostatic Test Report.—Maintained by PSO (Codes FDO/FXP).
- l. GRC4027 Exclusion Request.—Maintained by PSO (Codes FDO/FXP).
- m. GRC4025 Weld Request Form.—Maintained by PSO (Codes FDO/FXP).
- n. GRC4029 Certificate of Exclusion.—Maintained by PSO (Codes FDO/FXP).

8.0 REFERENCES

Document Number	Document Name
29 CFR 1910.119	Occupational Safety and Health Standards, Subpart H, Hazardous Materials, Process Safety Management of Highly Hazardous Chemicals
49 CFR	Department of Transportation (DOT) Regulations
NPR 8715.1	NASA Safety and Health Programs
NASA-STD-8719.17	NASA Requirements for Ground-Based Pressure Vessels and Pressurized Systems (PVS)
ANSI/AIAA G-095	American National Standards Institute (ANSI)/American Institute of Aeronautics and Astronautics (AIAA): Guide to Safety of Hydrogen and Hydrogen Systems
API 510	American Petroleum Institute (API) Pressure Vessel Inspection Code: In-service Inspection, Rating, Repair, and Alteration
API STD 520	Sizing, Selection, and Installation of Pressure Relieving Devices in Refineries

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API STD 521	Guide for Pressure-Relieving and Depressuring Systems
API STD 2000	Venting Atmospheric and Low-Pressure Storage Tanks
ASME B&PV-VIII	American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel (B&PV) Code, Section VIII: Rules for Construction of Pressure Vessels
ASME B31 Series	ASME Pressure Piping Codes
CGA E-4	Compressed Gas Association (CGA) Standard for Gas Pressure Regulators
CGA E-9	Standard for Flexible, PTFE-Lined Pigtails for Compressed Gas Service
CGA P-1	Standard for Safe Handling of Compressed Gases in Containers
CGA S-1.1	Pressure Relief Device Standards, Part 1: Cylinders for Compressed Gases
CGA S-1.3	Pressure Relief Device Standards, Part 3: Stationary Storage Containers for Compressed Gases
ISO 1436	International Organization for Standardization: Rubber Hoses and Hose Assemblies—Wire-Braid-Reinforced Hydraulic Types for Oil-Based or Water-Based Fluids—Specification
NFPA 55	National Fire Protection Association (NFPA): Compressed Gases and Cryogenic Fluids Code
SAE ARP1658	SAE Aerospace Recommended Practice (ARP): Hose Assemblies, Installed, Visual Inspection Guide for
SAE J517	Hydraulic Hose
SAE J1273	Recommended Practices for Hydraulic Hose Assemblies
NBBI NB 23	National Board of Boiler and Pressure Vessel Inspectors (NBBI) National Board Inspection Code (NBIC)
4400-B.1	Parker Safety Guide for Selecting and Using Hose, Tubing, Fittings and Related Accessories

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APPENDIX A.—DEFINITIONS

Certification.—The official approval process for ensuring and documenting the integrity of pressure vessels and pressurized systems.

Leak check.—A pre-pressure test of a system or vessel at a pressure of approximately 5 to 10 psig to identify assembly or fabrication defects before subjecting the system to test pressure.

Nondestructive examination (NDE).—The application of technical methods to examine materials or components in ways that do not impair future usefulness and serviceability in order to detect, locate, measure, and evaluate flaws; to assess integrity, properties, and composition; and to measure geometrical characteristics.

Operating pressure.—The pressure at the top of a vessel at which it normally operates. It shall not exceed the maximum allowable working pressure, and it is usually kept at a suitable level below the setting of the pressure-relieving devices to prevent their frequent opening.

Pressure Systems Manager (PSM).—The person responsible for implementation of NPD 8710.5, and NASA STD-8719.17 at a NASA facility.

Pressure test.—System or vessel test under conditions required by the applicable code. The specified test pressure usually exceeds the maximum allowable working pressure or design pressure.

Pressure vessels and pressurized systems (PVS).—Pressure vessels and pressurized systems within the scope of NPD 8710.5, Policy for Pressure Vessels and Pressurized Systems, and this standard.

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APPENDIX B.—ACRONYMS

AIAA	American Institute of Aeronautics and Astronautics
ANSI	American National Standards Institute
API	American Petroleum Institute
ASME	American Society of Mechanical Engineers
B&PV Code	Boiler and Pressure Vessel Code
CFR	Code of Federal Regulations
CGA	Compressed Gas Association
DOT	Department of Transportation
DP	Design Pressure
EAM	Enterprise Asset Management
GRC	Glenn Research Center
GSM	Glenn Safety Manual
IMTE	Inspection, Measuring, and Test Equipment
ISO	International Organization for Standardization
LH ₂	Liquid Hydrogen
LN ₂	Liquid Nitrogen
MAWP	Maximum Allowable Working Pressure
NBIC	National Board Inspection Code
NCS	National Consensus Standard
NDE	Nondestructive Examination
NFPA	National Fire Protection Association
NPD	NASA Policy Directive
NPR	NASA Procedural Requirement
OSHA	Occupational Safety and Health Administration
P&ID	Piping and Instrument Diagram
PSM	Pressure Systems Manager
PSO	Pressure Systems Office
PVS	Pressure Vessels and Pressurized Systems
RAC	Risk Assessment Code
SAE	Society of Automotive Engineers (now SAE International)

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SATERN	System for Administration, Training, and Educational Resources for NASA
SHeD	Safety and Health Division
STD	Standard
TNT	Trinitrotoluene

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APPENDIX C.—RESTRICTED DISTANCE FOR PNEUMATIC PRESSURE TESTING

C.1 Restricted Distance

C.1.1 Safety of personnel, buildings, and equipment must be of primary concern during a pneumatic pressure test. A sudden rupture will generate a pressure wave that can cause damage. Some consequences of blast overpressure are listed in Table C.1

TABLE C.1.—OVERPRESSURE EFFECTS

Overpressure, psi	Effect
0.5	Shatters glass windows
1	Knocks personnel down
1 to 2	Causes failure of standard house construction
2 to 3	Shatters concrete or block walls 8 in. thick
5 to 15	Ruptures eardrum
30 to 40	Damages lungs
130 to 180	Kills 50 percent of people

C.1.2 During the application of pneumatic test pressure, the following requirements apply:

- a. All personnel shall be located a safe distance from the test (outside of a predetermined restricted area).
- b. Buildings, major structures, and hardware or equipment inside this restricted area shall be protected, or the system to be tested shall be moved to a safe area.
- c. If this is not possible, the risk of damage shall be considered and accepted by the appropriate Glenn Research Center (GRC) or NASA program management.

C.1.3 Assuming a 0.5 psi or less overpressure is safe for personnel, we can determine the restricted distance for pneumatic tests. The restricted testing distance for a 1,000-cubic-foot (28.32-meter) system is given in Figure D.6 (Appendix D). The graph in Figure D.6 was derived from a curve showing pounds of open-field TNT-equivalent explosive per 1,000 cubic feet of gas as a function of rupture pressure. The figure was originally published in “Liquid Hydrogen Storage and Transmission,” by the Los Alamos Scientific Laboratory, Liquid Hydrogen Safety Committee. Although the curve was plotted for hydrogen gas, the difference in adiabatic expansion between air and hydrogen is slight. The TNT equivalent per 1,000 cubic feet of gas has been converted into restricted distance by information originally supplied by the Bureau of Mines, Boulder, Colorado.

C.1.4 Use of the curve in Figure D.6 is illustrated in Example 1. The curve can be applied to systems of other volumes. The restricted distance need not be strictly adhered to if alternate precautions are taken for personnel. Some alternate safety precautions include locating personnel behind adequate blast shields, sandbags, or other unmovable objects. However, these shields are primarily for protection from fragments and not blast waves (which will travel around the shield). Sample calculations for determining the restricted distance, adjusted for the effect of volume, during a pneumatic test are given below. A computer calculation is also provided on the

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PSO website (<http://www.grc.nasa.gov/ps/>) in the Pneumatic Tests section. (From the Calculations tab, select PVS Pressure Test Exclusion Zone.)

C.2 Example 1.—Method for Calculating Restricted Distance for a Pressure Vessel

Given the following:

$$\text{Pressure vessel volume } (V_{\text{vessel}}) = 300 \cdot \text{ft}^3$$

$$\text{MAWP} = 2000 \cdot \frac{\text{lb}}{\text{in}^2}$$

$$\text{Pneumatic test pressure } (P_{\text{test}}) = 2000 \cdot \frac{\text{lb}}{\text{in}^2} \cdot 1.1 = 2200 \cdot \frac{\text{lb}}{\text{in}^2}$$

From Figure D.6, the restricted distance for a 1,000-cubic-foot system with

$$P_{\text{test}} = 2200 \cdot \frac{\text{lb}}{\text{in}^2} \quad \text{is} \quad D_{1000} = 500 \cdot \text{ft}$$

The formula to obtain the restricted distance for the tank volume is

$$D_{\text{vessel}} = \frac{D_{1000} \cdot \sqrt[3]{V_{\text{vessel}}}}{10 \cdot \text{ft}}$$

Therefore, the restricted distance for the pressure test is

$$D_{\text{vessel}} = \frac{500 \cdot \text{ft} \cdot \sqrt[3]{300 \cdot \text{ft}^3}}{10 \cdot \text{ft}}$$

$$D_{\text{vessel}} = 334 \text{ ft}$$

C.3 Example 2.—Method for Calculating Restricted Distance for a Research Rig

1. Determine the total system volume.

Given the MAWP for the system:

$$\text{MAWP} = 240 \cdot \frac{\text{lb}}{\text{in}^2}$$

Given a 100-cm³ sample cylinder:

$$V_{\text{cylinder}} = 100 \text{ cm}^3 \quad \text{or} \quad V_{\text{cylinder}} = 3.531 \cdot 10^{-3} \cdot \text{ft}^3$$

Given system tubing with an outer diameter of 0.25 inch (0.64 centimeter) with a 0.035-inch (0.09-centimeter) wall, the cross-sectional area of the tube is

$$A_{\text{tube}} = \frac{\pi \cdot [0.25 \cdot \text{in.} - (2 \cdot 0.035 \cdot \text{in.})]^2}{4} \quad A_{\text{tube}} = 0.0254 \cdot \text{in.}^2 \quad \text{or} \quad A_{\text{tube}} = 1.767 \cdot 10^{-4} \cdot \text{ft}^2$$

Given a conservative estimate that there is 20 feet (6.10 meters) of tubing in the system, the volume of the tubing is

$$V_{\text{tube}} = 20 \cdot \text{ft} \cdot A_{\text{tube}} \quad V_{\text{tube}} = 3.534 \cdot 10^{-3} \cdot \text{ft}^3$$

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Therefore, the total system volume is

$$V_{\text{total}} = V_{\text{cylinder}} + V_{\text{tube}} \quad V_{\text{total}} = 7.065 \cdot 10^{-3} \cdot \text{ft}^3$$

2. Determine the restricted distance, given the test pressure and total system volume.

The test pressure to be applied to the system,

$$P_{\text{test}} = 1.1 \cdot \text{MAWP} \quad P_{\text{test}} = 264 \cdot \frac{\text{lb}}{\text{in}^2}$$

From Figure D.6, the restricted distance for a 1,000-cubic-foot system with

$$P_{\text{test}} = 264 \cdot \frac{\text{lb}}{\text{in}^2} \quad \text{is} \quad D_{1000} = 200 \text{ ft}$$

The correction formula to obtain the restricted distance for the actual system volume is

$$D_{\text{system}} = \frac{D_{1000} \cdot \sqrt[3]{V_{\text{total}}}}{10 \cdot \text{ft}} \quad D_{\text{system}} = \frac{200 \cdot \text{ft} \cdot \sqrt[3]{7.065 \times 10^{-3} \cdot \text{ft}^3}}{10 \cdot \text{ft}}$$

Therefore, the restricted distance for the pressure test is

$$D_{\text{system}} = 3.8 \text{ feet (1.16 meters)}$$

APPENDIX D.—FIGURES

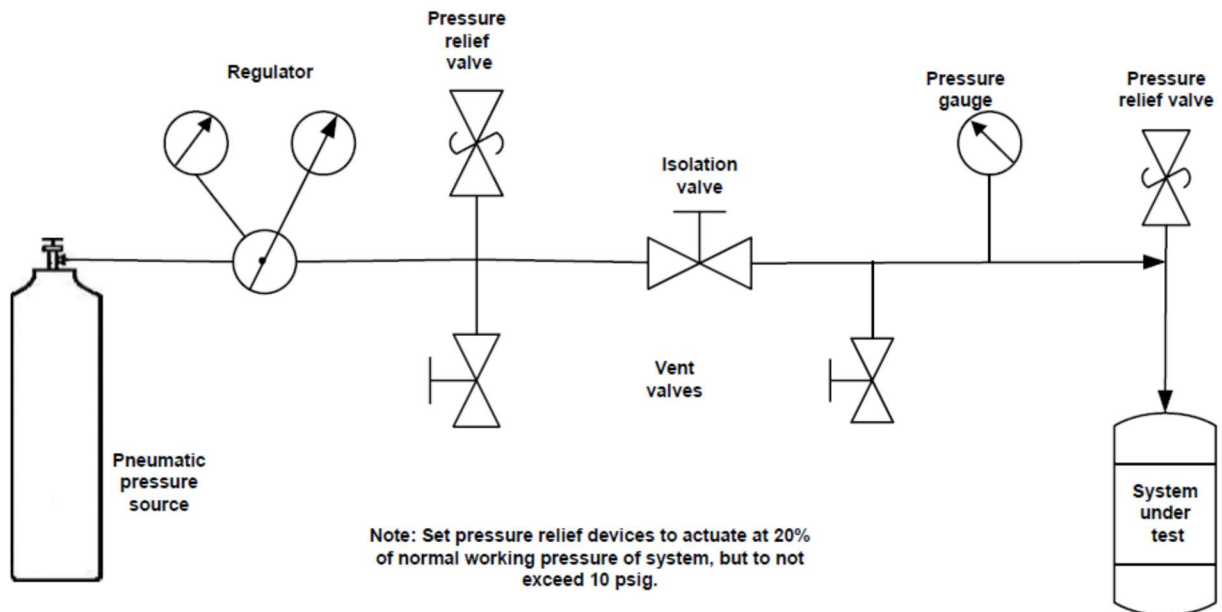


Figure D.1.—Typical piping schematic for low-pressure gas-leak test at 5 to 10 psig.

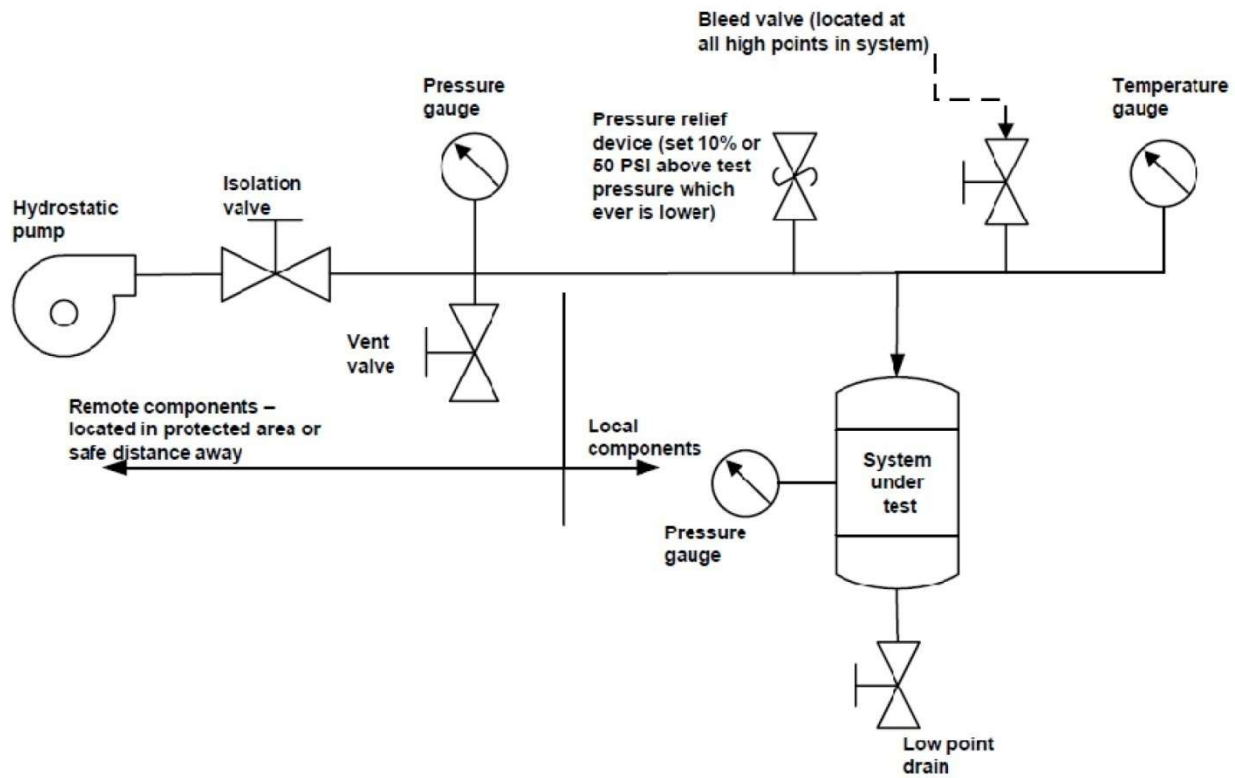


Figure D.2.—Typical piping schematic for hydrostatic pressure test.

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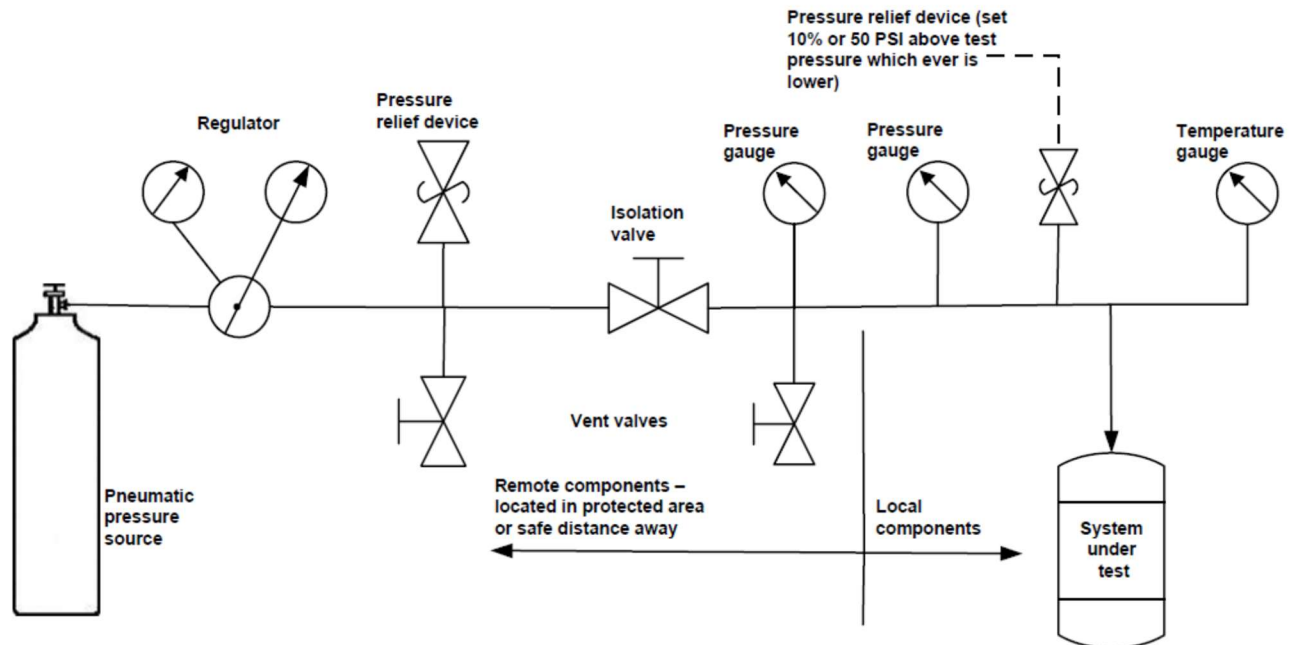


Figure D.3.—Typical piping schematic for pneumatic pressure test.

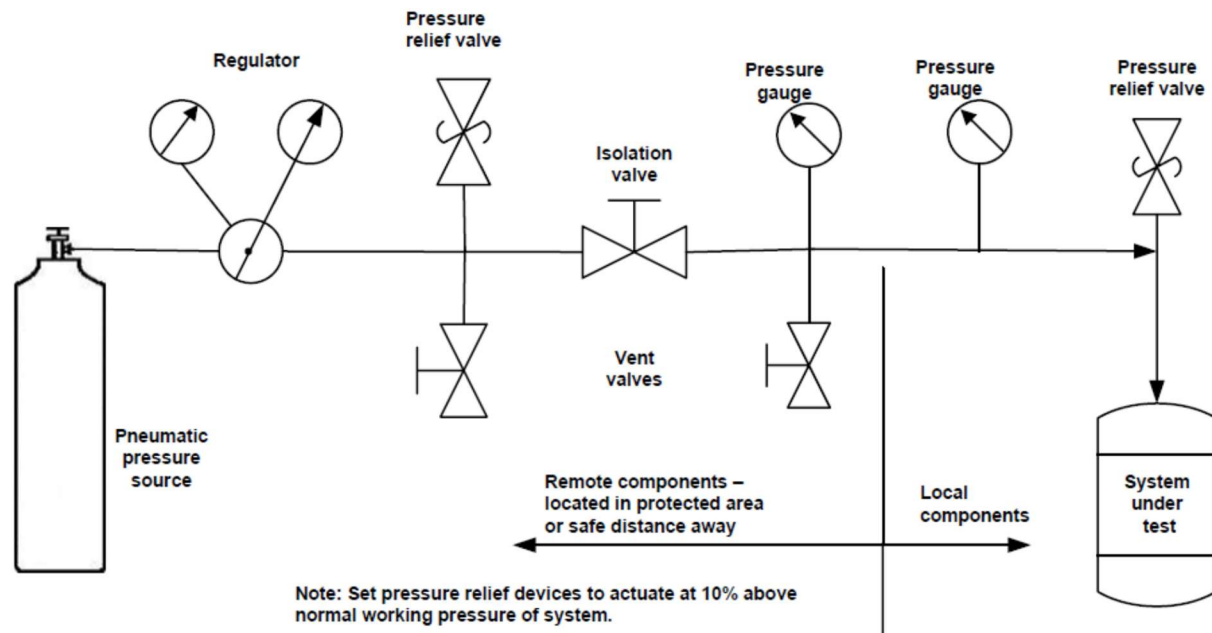
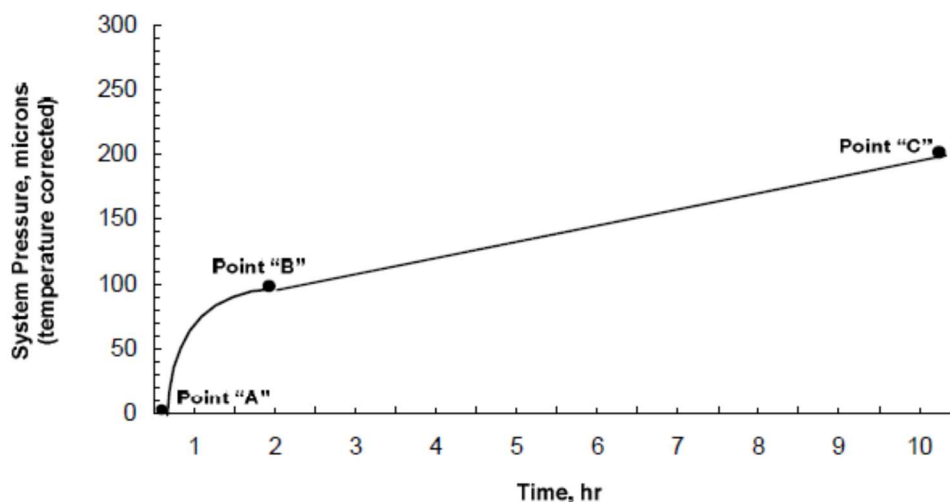


Figure D.4.—Typical piping schematic for operating pressure test.

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At point B, the system pressure has increased to above the vapor pressure of the outgassing source; therefore, the straight line between Points B and C represents system leakage. Only the straight line section of the curve should be used for determining leak rates. The curve between points A and B should be ignored.

EXAMPLE: Leak rate determined from figure 5

$$\text{Leak rate} = \frac{(200 - 100) \text{ microns} \times 1 \text{ liter}}{(10 - 2) \text{ hours}} = 12.5 \frac{\text{micron liters}}{\text{hours}}$$

$$\frac{12.5 \text{ micron liters}}{\text{hours}} \times \frac{1000 \text{ cm}^3}{\text{liter}} \times \frac{1 \text{ atmosphere}}{760,000 \text{ microns}} = 0.0164 \frac{\text{atmosphere cm}^3}{\text{hour}}$$

Figure D.5.—Typical plot of system pressure.

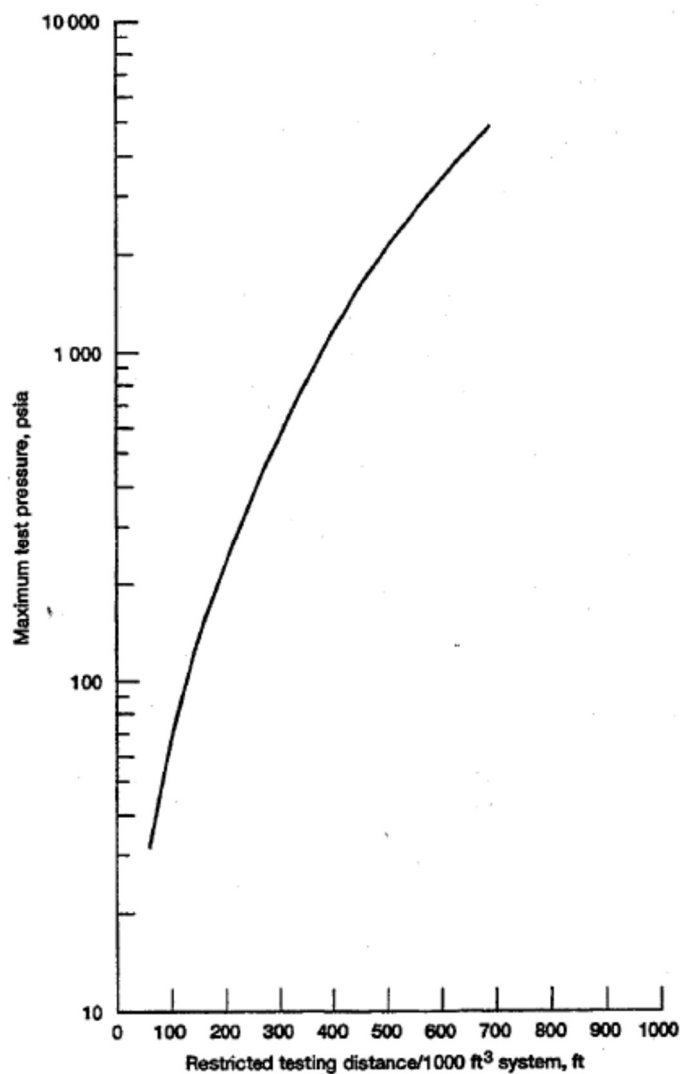


Figure D.6.—Restricted distance for pneumatic pressure testing.