NASA TECHNICAL STANDARD	**NASA-STD-8719.17**
National Aeronautics and Space Administration **Washington, DC 20546-0001**	**Approved: 2006-09-22** **Expiration Date: 2011-09-22**

NASA Requirements for Ground-Based Pressure Vessels and Pressurized Systems (PV/S)

MEASUREMENT SYSTEM IDENTIFICATION:
INCH-POUND

This page intentionally left blank.

DOCUMENT HISTORY LOG

Status	Document Revision	Approval Date	Description
Baseline		2006-09-22	Initial Release

This page intentionally left blank.

FOREWORD

This standard is published by the National Aeronautics and Space Administration (NASA) to provide uniform engineering and technical requirements for processes, procedures, practices, and methods that have been endorsed as standard for NASA programs and projects, including requirements for selection, application, and design criteria of an item.

This standard is approved for use by NASA Headquarters and NASA Centers, including Component Facilities.

This standard establishes uniform requirements for ground-based pressure vessels and/or pressurized systems used by or for NASA or within NASA jurisdiction.

Requests of information, corrections, or additions to this standard should be submitted via "Feedback" in the NASA Technical Standards System at http://standards.nasa.gov.

/s/	September, 22, 2006
Bryan O'Connor	Approval Date
Chief, Safety and Mission Assurance	

This page intentionally left blank.

TABLE OF CONTENTS

SECTION **PAGE**

LIST OF TABLES

NASA Requirements for Ground-Based Pressure Vessels and Pressurized Systems (PV/S)

1. SCOPE

1.1 Purpose

The purpose of this document is to ensure the structural integrity of PV/S through implementation of the minimum requirements for ground-based PV/S in accordance with this document, NASA Policy Directive (NPD) 8710.5, NASA Safety Policy for Pressure Vessels and Pressurized Systems, NASA Procedural Requirements (NPR) 8715.3, NASA General Safety Program Requirements, applicable Federal Regulations, and national consensus codes and standards (NCS).

1.2 Applicability

This standard applies to NASA Headquarters and NASA Centers, including Component Facilities, and to the Jet Propulsion Laboratory and to other contractors to the extent specified in their contracts.

This standard applies to all ground based equipment designed for, or operating at, positive or negative gauge pressure that is not specifically excluded in Section 4.2. It applies to NASA-owned or -operated, temporary or permanent ground-based PV/S and to non-NASA-owned contractor or tenant ground-based PV/S operated on NASA property if that PV/S is determined by the Pressure Systems Manager (PSM) to pose a risk to NASA personnel, facilities, or equipment. It specifically includes, subject to Section 4.2, systems often referred to as "low pressure" such as building and facility services equipment (e.g., shop air), laboratory systems, and vacuum systems.

When conflicts exist between this document and NCS, this document shall take precedence, except in those cases where the NCS is invoked by applicable Government regulation.

Requirements in addition to, and that do not conflict with, those listed herein may be appropriate for inclusion in Center-specific PV/S policies and procedures to address unique applications and situations not covered by this document. As provided for in NPD 8710.5, it is the PSM's responsibility to assure that such additional requirements are developed and included in the Center's certification process.

2. REFERENCES

2.1 Government Documents

42 U.S.C. 2473(c)(1), section 203(c)(1) of the National Aeronautics and Space Act of 1958, as amended.

Department of Labor (DOL), Occupational Safety and Health Administration (OSHA), 29 CFR Part 1910, Occupational Safety and Health Standards.

DOL, OSHA, 29 CFR Part 1960, Basic Program Elements for Federal Employees.

Department of Transportation (DOT) 49 CFR.

MIL-G-18977, Gauge, Pressure, Dial Indicating.

NPD 8710.5, NASA Safety Policy for Pressure Vessels and Pressurized Systems.

NPR 1441.1, NASA Records Retention Schedule.

NPR 8000.4, Risk Management Procedural Requirements.

NPR 8715.3, NASA General Safety Program Requirements.

2.2 Non-Government Documents

American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code (B&PVC).

ASME B31 series Piping Codes.

ASME PTC 25-2001, Pressure Relief Devices.

ASME B40.100, Pressure Gauges and Gauge Attachments.

Compressed Gas Association (CGA) E-4, Standard for Gas Pressure Regulators.

CGA P-1, Safe Handling of Compressed Gas in Containers.

National Board of Boiler and Pressure Vessel Inspectors, ANSI/NB-23, National Board Inspection Code.

UL-404, Gauges, Indicating Pressure, for Compressed Gas Service.

2.3 Other References (not necessarily cited in the body of the document)

See Table 6 in paragraph 5.

3. ACRONYMS AND DEFINITIONS

3.1 Acronyms

API	American Petroleum Institute
ASME	American Society of Mechanical Engineers
BWR	Boiling Water Reactor
CGA	Compressed Gas Association
COTS	Commercial Off the Shelf
DOT	Department of Transportation
FS	Factor of Safety
HVAC	Heating, Ventilating, and Air Conditioning
IGSCC	Intergranular Stress Corrosion Cracking
ISI	Inservice Inspection
MAWP	Maximum Allowable Working Pressure
MDMT	Minimum Design Metal Temperature
NB	The National Board of Boiler and Pressure Vessel Inspectors
NBIC	National Board Inspection Code, NB-23
NCS	National Consensus Codes and Standards
NDE	Nondestructive Examination
NPD	NASA Policy Directive
NPR	NASA Procedural Requirements
NPS	Nominal Pipe Size
OSMA	NASA Headquarters Office of Safety and Mission Assurance
PRD	Pressure Relief Device to include PSV, rupture disc, or other device
Psig	Pounds per Square Inch Gauge
PSM	Pressure Systems Manager
PSV	Pressure Safety Valve
PV/S	Pressure Vessels and Pressurized Systems
RAC	Risk Assessment Code
STE	Special Test Equipment
UL	Underwriters Laboratories Incorporated

3.2 Definitions

Certification: The official approval process for ensuring and documenting the integrity of PV/S.

Code PV/S: Pressure vessels and pressurized systems that are designed, fabricated, installed, Code stamped, and maintained in strict conformance with the

requirements of the national consensus code or standard (NCS) specified as applicable by the PSM.

Configuration Management: The identification, control, accounting, and verification of requirements and implementation documentation for formal orderly control of the PV/S configuration.

Commercial Off the Shelf (COTS): Commercial items that require no unique Government modification or maintenance over the life cycle of the product to meet the needs of the procuring agency. A commercial item is one customarily used for non-Governmental purposes that has been or will be sold, leased, or licensed (or offered for sale, lease, or license) in quantity to the general public. An item that includes modifications customarily available in the commercial marketplace or minor modifications made to meet NASA requirements is still a commercial item.

Deviation: As defined in NPR 8715.3, NASA General Safety Program Requirements.

DOT Service: Those uses of PV/S covered by the regulations contained in 49 CFR 100 – 185, Pipeline and Hazardous Materials Safety Administration.

Excluded PV/S: A PV/S that is not required to meet the certification (or recertification) requirements of NPD 8710.5, NASA Safety Policy for Pressure Vessels and Pressurized Systems, and need not be included in the PV/S configuration management system. Excluded PV/S are subject to all applicable laws, regulations, safety requirements, NASA requirements, and appropriate NCS and must be maintained in accordance with applicable NCS.

Existing PV/S: PV/S shall be considered to be "Existing PV/S" if installed no later than 6 months from the date of original issue of this document.

Flight PV/S: An assembly of components under pressure, including vessels, piping, valves, relief devices, pumps, expansion joints, gages, etc., that are fabricated in accordance with program requirements specifically for use in aircraft or spacecraft.

Flexible Hose: A non-rigid piping component excluding bellows expansion joints.

Factor of Safety (FS): Unless otherwise noted, this refers to the material design factor of safety on structural failure and is equal to the lesser of the material strength divided by the material stress under anticipated loading or the actual buckling load divided by the anticipated buckling load.

Ground-based PV/S: All PV/S, including PV/S based on barges, ships, or other transport vehicles, not specifically excluded in 4.2. Flight weight PV/S used for their intended purpose aboard active air or space craft, even though on the ground, are not included in this definition, but flight weight PV/S converted to ground use are included.

Hydraulics: Hydraulic systems using commercially available hydraulic fluid. Note: Associated pneumatic storage, actuation devices, or components that are used in a hydraulic system are not considered hydraulics. Pressurized hydraulic fluid containing devices are included if the system is included.

Inservice Inspections: Those inspections, examinations, or tests specified in the inspection plan as determined in this document.

Nondestructive Examination: 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.

Non-Code PV/S: Any pressure vessel that is not stamped with the appropriate symbol and documented as complying with the original construction Code or any pressure piping system that does not meet the requirements of the appropriate fabrication code (e.g. ASME Section VIII, B31.1, B31.3), including PV/S that were fabricated from non-Code materials by non-Code processes or organizations.

Owner: The management of the organization responsible for the PV/S as defined in NPD 8710.5, NASA Safety Policy for Pressure Vessels and Pressurized Systems.

Policy Variance: Documented and approved Center policy contrary to the policy in NPD 8710.5, NASA Safety Policy for Pressure Vessels and Pressurized Systems, or this standard.

Pressure Relief Device (PRD): A device designed to open and relieve excess pressure so as to protect the PV/S on which it is installed from damage due to that pressure.

Pressure Safety Valve (PSV): A pressure relief device designed to actuate on inlet static pressure and to reclose after normal conditions have been restored. [Note: this definition is that of ASME PTC 25-2001.]

Pressure Systems Manager: The person responsible for implementation of NPD 8710.5, NASA Safety Policy for Pressure Vessels and Pressurized Systems, and this standard at a NASA facility.

Pressure Vessels and Pressurized Systems (PV/S): Pressure vessels and

pressurized systems within the scope of NPD 8710.5, NASA Safety Policy for Pressure Vessels and Pressurized Systems, and this standard.

Risk Assessment Code: A numerical expression of comparative risk determined by an evaluation of both the potential severity of a condition and the likelihood of its occurrence causing an expected consequence.

Recertification: The renewal of a previous certification with adjustments as necessary to accommodate new information, configuration or operating parameter changes, or PV/S degradation.

Technical Variance: Single or case-by-case variance from this standard.

Test Article PV/S: A PV/S object(s) being tested for the sole purpose of obtaining data (other than integrity data) on the object(s).

Test Specific PV/S: PV/S used to perform testing of a specific test article. PVS used on a permanent or repeated basis, or built up of components used repeatedly for testing different hardware or configurations are not part of this category.

Variance: As defined in NPR 8715.3.

Waiver: As defined in NPR 8715.3.

4 REQUIREMENTS

4.1 Application of NPD 8710.5

4.1.1 In addition to the detail provided in this standard, the requirements of NPD 8710.5 shall be met.

4.1.2 This document provides a greater level of detail of requirements and identifies responsible parties, consistent with NPD 8710.5.

4.2 Excluded PV/S

The following PV/S do not require certification in accordance with NPD 8710.5, NASA Safety Policy for Pressure Vessels and Pressurized Systems, and are excluded from the requirements of this standard provided they are covered under appropriate inspection and maintenance programs. Each Center's PSM has the authority to require inclusion of any excluded system at that Center due to the hazards presented by its use in a particular application.

Excluded systems are subject to the requirements of OSHA, the applicable NCS, and NASA safety requirements. Operation of Commercial Off the Shelf (COTS) systems shall be within manufacturers' placard limitations.

4.2.1 Category Exclusions

4.2.1.1 Water systems under 150 pounds per square inch gauge (psig) for which surge is not a design consideration or has been mitigated.

4.2.1.2 Water deluge systems not to exceed 250 psig for which there is no hazard to personnel in the event of failure.

4.2.1.3 Control, instrument, and shop air or inert gas piping systems with Maximum Allowable Working Pressure (MAWP) not to exceed 150 psig and line sizes not to exceed Nominal Pipe Size (NPS) 3/8. Relief valves and compressed air receiver vessels are not included in this exclusion. This exclusion does not apply to higher pressure or larger size PV/S that supply the lower pressure PV/S.

4.2.1.4 COTS hot water systems for buildings.

4.2.1.5 COTS prepackaged pressurized water and steam cleaning systems maintained and operated in strict accordance with the manufacturer's recommendations. This does not include custom fabricated/assembled systems.

4.2.1.6 Fire protection water systems for facilities.

4.2.1.7 COTS prepackaged refrigerators, freezers, and Heating, Ventilating, and Air Conditioning (HVAC) equipment.

4.2.1.8 Fire extinguishers covered by: 29 CFR Part 1910, Subpart L, "Fire Protection," including portable extinguishers, standpipe and hose systems, automatic sprinkler systems, fixed dry chemical extinguishing systems, carbon dioxide extinguishing systems, and halogenated extinguishing agent systems.

4.2.1.9 Glove boxes.

4.2.1.10 Fuel storage PV/S supplied with licensed motorized vehicles and meeting applicable Department of Transportation (DOT) regulatory requirements.

4.2.1.11 COTS prepackaged hydraulic systems.

4.2.1.12 COTS welding equipment.

4.2.1.13 COTS laboratory equipment. However, equipment that could be pressurized above its MAWP for any reason by the fluid delivery system shall have appropriate overpressure protection installed and the fluid delivery system shall be certified by the PSM in accordance with this standard. This exclusion does not apply to laboratory designed and assembled systems.

> An example is a mass spectrometer with a manufacturer's placard rating of 25 psig that receives gas from a 2000 psig DOT cylinder via a pressure regulator and plastic tubing. The mass spectrometer and DOT cylinder (see 4.2.1.19) are not subject to certification in accordance with this document although they must be safely operated in accordance with manufacturer's recommendations, and there must be a certified pressure relief device (PRD) (see 4.10.1) downstream of the cylinder's pressure regulator (see 4.10.3), and the plastic tubing must be adequately rated and restrained (see 4.10.4). The required PRD may be internal to the mass spectrometer, however such an internal PRD is subject to the requirements of 4.10.1. Consequently, a separate external (accessible) PRD is usually added to meet the requirements of this document.

4.2.1.14 Vacuum systems with volumes not greater than 100 cubic feet. However, all vacuum systems that could inadvertently be pressurized above atmospheric pressure by internal

or external sources (e.g., as a result of valve leakage on a test gas line or a pressure regulator or mass flow controller failure) shall have appropriate overpressure protection (see 4.10.1, particularly 4.10.1.12), and the fluid delivery system is included within the scope of this standard.

4.2.1.15 Vacuum piping above ground not greater than NPS 6 which is adequately supported and restrained and buried vacuum piping of any diameter. This exclusion does not apply to piping which is connected to a positive pressure source that requires relief protection above a PRD setting of 2 psig. The relief protection of all vacuum piping systems attached to positive pressure sources shall be reviewed and approved by the PSM.

4.2.1.16 Temporary non-NASA owned construction or maintenance related PV/S, provided the hazards to personnel are low and the operating contractor is contractually obligated to meet, and demonstrates compliance with, all applicable Federal, State and local safety regulations.

4.2.1.17 Atmospheric storage tanks that only are subjected to hydrostatic pressure and that comply with the applicable American Petroleum Institute (API) or Underwriter Laboratories Incorporated (UL) standards.

4.2.1.18 Self-contained pressure eye wash systems, provided overpressure protection devices are periodically tested or replaced in accordance with manufacturers' recommendations.

4.2.1.19 DOT specification containers that are periodically retested and requalified strictly in accordance with 49 CFR 180, provided that the owner's OSHA inspection requirements of 29 CFR 1910.101 are met. This exclusion does not apply, however, to other attached components or laboratory equipment or other systems using or being charged from these containers.

4.2.1.20 Natural gas distribution systems.

4.2.1.21 Flight weight PV/S used for their intended flight related purpose aboard air or space craft even when that craft is on the ground. This exclusion does not apply to flight weight PV/S that have been converted for ground use outside of their flight related function.

4.2.2 Assessed Hazard Exclusion

4.2.2.1 The PSM shall have the authority to exclude other PV/S from the Center's certification program if a risk and hazard assessment that is performed in accordance with NPR 8715.3, NASA General Safety Program Requirements and paragraph 4.9 of this standard demonstrates that all of the following conditions are met:

4.2.2.1.1 There is negligible operational risk or hazard to personnel under any foreseeable failure.

4.2.2.1.2 A technical variance is approved to document the scope and conditions of the exclusion.

4.2.2.1.3 All other applicable NASA safety requirements are met.

4.2.2.1.4 All other applicable regulatory safety requirements are met.

4.2.3 Test Articles and Test Specific PV/S Exclusions

Test article PV/S that have been formally reviewed and accepted in accordance with the requirements of NPR 8715.3, NASA General Safety Program Requirements, are excluded.

Temporary test specific PV/S (e.g., special test equipment (STE)) are excluded if risk assessment has been performed in accordance with NPR 8715.3, NASA General Safety Program Requirements, there is no risk to personnel, and risk to the facility has been accepted by the Center. Equipment is not considered to fall into this category if it consists of components used repeatedly for testing different test articles or configurations.

4.3 General Requirements

General requirements apply to all non-excluded PV/S.

4.3.1 PV/S shall meet the requirements of State and Local Boiler and Pressure Vessel Statutes unless exclusive Federal jurisdiction applies. In the event of a conflict between this document and applicable statutes or regulations, the statutes or regulations govern.

4.3.2 PV/S shall comply with applicable Federal laws and regulations (e.g., 29 CFR 1910).

4.3.3 Each NASA Center, including Component Facilities and the Jet Propulsion Laboratory, shall implement a formal PV/S certification process and provide a documentation and configuration management and control system that provides critical system information necessary for determining PV/S integrity.

4.3.4 All PV/S shall be certified, recertified, and documented in accordance with the requirements of NPD 8710.5 and this standard.

4.3.5 The original service life or remaining safe life of each PV/S shall be documented at the time of certification or recertification based on relevant failure modes, cyclic service history, rates of degradation, damage mechanisms, or other appropriate factors.

4.3.5.1 Potential damage mechanisms shall be identified and evaluated, including but not limited to fatigue, creep, and corrosion.

4.3.5.2 All conditions that cause changes in the current estimate of remaining life shall be assessed and documented, with appropriate modification to the inspection and recertification plans of record, in accordance with paragraph 4.8 of this standard.

4.3.6 Compliance with the requirements of this standard shall be documented and approved by the PSM in accordance with paragraph 4.11. When this has been achieved, the PV/S shall be designated as "Certified."

4.3.7 The MAWP, operating temperature range, and other service conditions shall be documented for each PV/S.

4.3.8 Relief valve exhausts and other vents shall incorporate appropriate means of reacting to thrust loads, including balanced thrust ("zero thrust") vent tees and structural supports as appropriate.

4.3.9 PV/S shall be pressurized only after initial certification is complete, with the exception of pressurization that may be required for initial integrity testing of the PV/S.

4.3.10 PV/S that do not meet applicable NCS, guides, and regulations shall only be certified and allowed to operate if a risk and hazard assessment has been performed, the owner acceptance of residual risk has been documented, and the Center approval has been formally documented by means of a variance in accordance with paragraphs 4.6 or 4.7 and 4.11 of this standard.

4.3.11 A periodic inspection plan shall be developed for all PV/S in accordance with paragraph 4.5 of this standard.

4.3.12 Inspection activities and integrity verification shall be performed to ensure PV/S are maintained in a state of compliance with the certification (recertification) requirements of paragraph 4.11 of this standard.

4.3.13 The PSM has the authority to interpret this standard. (This is not to be interpreted as authority to change or waive the requirements of this standard).

4.3.14 A change in the service of a PV/S shall require evaluation for applicability of the original Code for the new service, possible application of a new Code appropriate to the new service, and possible reevaluation in accordance with the applicable NCS.

4.4 Design and Construction Requirements for New PV/S

4.4.1 All new ground-based conventional (i.e., non-flight) PV/S shall be designed, fabricated, assembled, erected, inspected, examined, and tested in accordance with the appropriate national consensus standards, codes, and regulations.

4.4.2 Pressure vessels for transport of pressurized fluids

4.4.2.1 Pressure vessels used to transport fluids under pressure shall comply with the DOT regulations of 49 CFR 100-185 or ASME Section XII as applicable.

4.4.3 Pressure vessels not for transport of pressurized fluids

4.4.3.1 New pressure vessels, including heat exchangers, shall be ASME Section VIII code stamped as specified within the scope of the Division being used and registered with the National Board.

4.4.3.2 Vacuum vessels shall be ASME Section VIII code stamped and registered with the National Board except as provided in paragraphs 4.2.1.14, 4.4.3.3, and 4.4.3.4 of this standard.

4.4.3.3 For new vacuum vessels, or alterations/repairs to existing vacuum vessels, operating in high vacuum service (internal pressure less than than 10^{-3} torr) or in other cases involving only

external atmospheric pressure (i.e., no external pressure greater than 14.7 psig) where specific operational needs make ASME Section VIII or NB-23 code stamping unfeasible, all of the requirements specified elsewhere in this standard shall apply with the following exceptions (this paragraph is not to be construed to accept the purchase or use of non-code stamped vacuum vessels where there is not a specific overriding need):

4.4.3.3.1 No ASME "U" Stamp ("code stamp") or National Board Inspection Code (NBIC) "R" Stamp is required, however all documentation requirements of this standard shall be met, except:

4.4.3.3.1.1 The ASME or NBIC Data Report shall be processed in all respects as for a code stamped vessel, but it shall not be submitted to the National Board, and the Certificate of Shop Inspection shall be signed either by a National Board commissioned inspector or by the PSM.

4.4.3.3.1.2 For industry standard components such as potted connectors and "Conflat" flanges used in strict accordance with the manufacturer's ratings and recommendations, material records and analysis are not required provided sufficient information regarding material is available to perform properly any welding or brazing processes required.

Note: This does not exclude from the ASME Code analysis requirement those industry standard components that are rated by their manufacturers only for external pressure and that require relief protection above a PRD setting of 2 psig (or less, if so specified by the manufacturer). If relief protection is required, bolting or other fasteners shall be analyzed in accordance with the ASME Code or other means acceptable to the PSM to determine that they have a positive pressure rating sufficient for the credible positive pressure scenarios.

4.4.3.3.2 Intermittent welds are permitted on nozzles and reinforcing pads, however an appropriate code equivalent analysis shall be performed to verify the adequacy of the weld design.

4.4.3.3.3 Nozzle reinforcement may be achieved using configurations other than those illustrated in ASME Section VIII, however adequacy of such designs shall be demonstrated by appropriate ASME Code equivalent analysis or testing.

4.4.3.3.4 The ASME Section VIII requirement for an internal pressure test (hydrostatic or pneumatic) may be replaced with a vacuum test to 1.5 times the specified pressure differential, but not to exceed an external pressure of 14.7 psig. This exception shall not be used in those cases where proof test is used in lieu of

analysis if an overpressure of 1.5 times the maximum allowable working (differential) pressure is not attained.

4.4.3.3.5 Materials other than those specified for use in ASME Section VIII and its reference documents may be used, however their adequacy for the intended application shall be demonstrated to the satisfaction of the PSM.

4.4.3.3.6 Allowable stresses and other material properties for "non-code" materials shall be obtained following the approach and safety factors used in developing ASME Section VIII allowable stresses and other values.

4.4.3.3.7 ASME Code pressure relief capacity requirements shall be met for internal pressurization sources, but the relief device need not be UV stamped provided the set pressure is less than 15 psig.

4.4.3.3.8 If a vacuum vessel requires relief protection with PRD setting above 2 psig due to the nature of the potential pressurization source, the vessel pressure shell shall be structurally qualified in accordance with the requirements of the ASME Code, Section VIII, Div. 1.

4.4.3.3.9 If relief protection of any set pressure is required for a vacuum vessel due to attached pressure sources, bolting or other fasteners shall be analyzed in accordance with the ASME Code or other means acceptable to the PSM to determine that they have a positive pressure rating sufficient for the credible positive pressure scenarios.

4.4.3.3.10 The relief protection for all vacuum vessels attached to any positive pressure source shall be reviewed and approved by the PSM.

4.4.3.4 The foregoing exceptions to the requirements of this standard and of the ASME and NBIC Codes notwithstanding, and not reducing the effect of any other requirement of this standard or of the ASME or NBIC Codes, specific note is made of the following requirements:

4.4.3.4.1 Vacuum vessels shall be fabricated, repaired, or altered only by manufacturers having either an ASME "Code Stamp" (ASME "U" Authorization) or NBIC "R" Stamp, or that have been audited and determined by the PSM to have an equivalent quality assurance manual and process, including implementation.

4.4.3.4.2 The PV/S manufacturing or alteration shall be in strict accordance with the quality assurance manual of the manufacturing organization.

4.4.3.4.3 The PSM shall review and approve designs and design analysis prior to start of PV/S construction.

4.4.3.4.4 All welding shall be:

4.4.3.4.4.1 Performed in accordance with procedures qualified in accordance with the ASME Boiler and Pressure Vessel Code, Section IX, including all essential variables for the joint in question.

4.4.3.4.4.2 Performed by welders qualified and current in accordance with the ASME Boiler and Pressure Vessel Code, Section IX, on such weld procedures.

4.4.3.4.5 Post weld heat treatment shall be performed as required and in accordance with the ASME Code.

4.4.3.4.6 Except as provided in 4.4.3.3.1.2, impact and other testing shall be performed as required and in accordance with the ASME Code.

4.4.3.4.7 Inspections shall be performed by inspectors trained and certified in use of the techniques being applied, in accordance with the requirements of the ASME Boiler and Pressure Vessel Code, Section V.

4.4.4 Boilers and Boiler Piping (See also Table 6)

4.4.4.1 Power boilers shall be ASME Section I code stamped and registered with the National Board.

4.4.4.2 Power boiler piping shall meet ASME B31.1, Power Piping.

4.4.4.3 Power boiler external piping shall be ASME code stamped.

4.4.4.4 Heating boilers shall be ASME Section IV code stamped and registered with the National Board.

4.4.5 Non-Boiler Piping Systems

4.4.5.1 Process piping shall meet the requirements of ASME B31.3, Process Piping.

4.4.5.2 Other piping shall meet the requirements of the most applicable ASME B31 series Code.

4.5 PV/S Integrity Assessment of Existing Code PV/S

4.5.1 Existing Code PV/S shall be documented as meeting the requirements of the original construction Code by means of record collection and physical measurements and condition assessment. Original Code information shall be retained.

4.5.2 Existing Code stamped vessels that do not meet original ASME Code requirements shall either be repaired in an ASME Code-compliant manner (see paragraph 4.5.4 of this standard) and brought into conformance, re-rated to a lower pressure, recertified as non-Code PV/S in accordance with paragraph 4.7 of this standard, or removed from service.

4.5.3 Code PV/S shall only be altered or repaired in accordance with the requirements of the applicable NCS.

4.5.4 ASME Code stamped items shall only be repaired or altered by National Board (NB-23) certified organizations (for example "R" and "VR" stamp holders) in strict conformance with their approved quality manual.

Comment: Government or contractor organizations that do not have an "R" or "VR" stamp do not meet the requirement.

4.5.5 Re-rating of ASME Code vessels, if required, shall be in accordance with applicable NCS.

4.5.6 Code PV/S for which current Code requirements have changed from the original fabrication Code shall be reassessed and re-rated as necessary to assure an acceptable risk level.

Note: For example, the 1988 changes to fracture toughness rules for prevention of brittle fracture could significantly increase the assessed risk of continued operation at the original design limits. Thus, a 4 inch thick vessel fabricated from A-212 Grade B (Firebox) material is now known to have an allowable minimum design material temperature (MDMT) of 118 degrees F. The vessel nameplate likely shows an MDMT of –20 degrees F. If the vessel normally receives ambient compressed gas at 60 degrees F, the vessel would require risk reassessment and likely additional hazard mitigation to assure continued safe operation.

4.5.7 The PSM has the authority to determine when or which Code requirements changes require reassessment of particular PV/S.

4.5.8 Pressure vessels designed for the transport of pressurized fluids but that are in permanent or semi-permanent installations shall meet the requirements in section 4.10.6 of this standard.

4.5.9 Code PV/S that have been re-designated as non-Code shall be clearly and visibly marked to indicate the non-Code status.

4.5.10 For existing PV/S that have not undergone a full initial integrity assessment in accordance with section 4.8 of this standard, operation shall only be permitted following approval of a technical variance waiver in accordance with Section 4.9.4. The following paragraphs provide guidance on typical evaluations to be performed for waiver documentation through an abbreviated integrity and risk assessment review in order to obtain a reasonable level of confidence that the system to be placed in operation does not involve an excessive level of risk.

4.5.10.1 Evaluate major energy and toxic material sources supplying and/or affecting the system.

4.5.10.2 Perform typical and worst case wall thickness calculations, including both stress and stability.

4.5.10.3 Perform typical nozzle reinforcement calculations.

4.5.10.4 Perform analysis of typical high stress areas such as nozzles, supports, or other significant discontinuities.

4.5.10.5 Verify material thickness and other aspects of configuration to ensure applicability of analysis.

4.5.10.6 Make conservative assumptions as to material characteristics if actual material is not known.

4.5.10.7 Consider heat treatment state for materials and operations where this may be a factor.

4.5.10.8 Perform visual inspections of overall PVS condition, including such items as system configuration, critical weld configuration, condition and quality, corrosion, erosion, or other system deterioration.

4.5.10.9 Perform volumetric inspections of critical welds or welds most likely to experience degradation, with quantity and location subject to the approval of the PSM.

4.5.10.10 Evaluate pressure relief capacity versus needs.

4.5.10.11 Identify most likely failure modes, including fatigue, and most likely locations for those failures to occur.

4.5.10.12 Consider service history with regard to relevant failure modes, including cyclic service history, and most likely locations for accumulated service related damage.

4.5.10.13 Evaluate and document the risk for the PV/S.

4.5.10.14 Develop a plan and schedule for the full inspection and recertification of the PV/S, based on a ranking of risks and associated analyses, inspections, and mitigations, with schedule determined so as to minimize the overall risk.

4.5.11 If the full recertification process in accordance with section 4.11 of this standard of existing PV/S operating under a section 4.5.10 waiver is not completed by the end of a five year period beginning on the original issue date of this standard, the PV/S shall be removed from service.

4.6 Technical Variance Requirements for New Non-Code PV/S

Note: This section does not endorse the purchase of new non-Code PV/S, but offers guidance for those rare cases where new PV/S are essential to mission success but cannot reasonably meet all of the requirements of the appropriate NCS.

4.6.1 Technical variance approval and risk acceptance shall be obtained prior to initial operation of the non-Code PV/S.

4.6.2 New non-Code PV/S shall be certified in accordance with paragraph 4.11 of this standard.

4.6.3 To the extent possible, Code design and construction techniques shall be utilized on non-Code PV/S, in particular through the use of:

4.6.3.1 Code material; i.e., material whose specifications and grades are approved for use by the Code that would otherwise apply to construction.

4.6.3.2 Components, (i.e., valves, fittings, elbows, etc.) that are certified to standards approved for use by the Code that would otherwise apply.

4.6.3.3 Code-certified welding processes, personnel, and "U" authorized shops that meet all applicable ASME quality assurance and certification requirements for Code construction.

Note: NASA fabrication shops that do not possess an ASME "U" authorization, regardless of individual personal training, qualifications, and certifications, shall not be considered equivalent to Code certified shops and hence shall only perform non-Code welding.

4.6.3.4 Assurance of material design factors of safety (FS) of no less than a Code PV/S.

4.7 Existing Non-Code PV/S (Legacy)

4.7.1 Non-Code PV/S shall be documented and evaluated to the extent possible as meeting the requirements of the most applicable NCS.

4.7.2 Non-Code PV/S shall only be altered or repaired in accordance with the requirements of the most applicable NCS to the extent possible. See 4.4.3.3 for alterations to existing vacuum vessels.

Example: A non-Code stamped PV/S that has a parallel in ASME Code construction shall be repaired or altered by National Board (NB-23) certified organizations in strict conformance with their approved quality manual except for Code stamping.

4.7.3 Assessment of non-Code PV/S that have a parallel in an NCS shall include assessing new changes in Code requirements that have updates from the edition used for original evaluation. The PSM has the authority to determine when or which Code requirements changes require reassessment of particular PV/S.

4.7.4 The design and operational limits of existing non-Code PV/S shall be determined based on the Factor of Safety (FS) in a manner consistent with the most applicable NCS from the time of construction.

Note: For ASME Section VIII, Div. 1 vessels, design tensile stress FS = 3.5 on ultimate stress since issuance of the 7/1999 Addenda to the 1998 Code, 4.0 from 8/1951 Addenda to the 1950 Code through the 7/1999 Addenda to the 1998 Code, and 5.0 prior to 8/1951 (except for a brief period during World War II based on Code Case 968).

4.7.5 All existing non-Code PV/S shall have a risk assessment performed and be processed in accordance with NPD 8710.5 and this standard.

4.7.6 When the risk associated with operation of any PV/S is unacceptable, the risk shall be mitigated in accordance with the risk reduction protocol in paragraph 1.7.1 of NPR 8715.3, NASA General Safety Program Requirements, or the PV/S shall be removed from service.

4.7.7 Code PV/S that have been re-designated as non-Code shall be clearly and visibly marked to indicate the non-Code status.

4.7.8 DOT specification vessels in permanent or semi-permanent installations that do not strictly comply with 49 CFR 100-185 shall be designated and certified as non-Code PV/S. See section 4.10.6 for additional specific requirements for DOT vessels.

4.7.9 The provisions of 4.5.10 and 4.5.11 apply to existing non-Code PV/S that must be placed in service prior to certification or recertification in accordance with section 4.11of this standard.

4.8 PV/S Integrity Assessment, Remaining Life, and Inspection Requirements

4.8.1 PV/S Integrity Assessment

4.8.1.1 Integrity assessment of each PV/S shall be performed and documented at the time of certification or recertification.

4.8.1.2 Integrity assessment shall be consistent with the methodologies identified in the appropriate post-construction NCS.

4.8.1.3 The PV/S integrity assessment shall include an inspection plan that addresses credible damage mechanisms for the specific PV/S.

4.8.1.4 Verification of integrity of each in-service PV/S shall be documented at each periodic inspection interval as specified in the inspection plan in compliance with the appropriate NCS.

4.8.1.5 If at any time a PV/S is not fit for the intended service, the PV/S shall be immediately removed from service and the certification of the PV/S shall be revoked.

Comment: Integrity verification is achieved by meeting the requirements of this NASA standard and appropriate reference documents such as ANSI/NB-23. The period of re-inspection for each PV/S is to be based on maintaining a continuous state of compliance with these requirements.

4.8.2 Remaining Life Assessment Requirements

4.8.2.1 The original service life or remaining safe life of each PV/S shall be documented at the time of certification or recertification through a detailed integrity assessment based on nondestructive examination (NDE) and inspection results, relevant damage mechanisms, cyclic service history, rates of degradation, and other appropriate factors.

4.8.2.2 The engineering assessment for remaining life shall be consistent with methodologies of appropriate post-construction NCS.

4.8.2.3 The rate of service related or environmentally induced wall thinning of PV/S shall be documented by means of periodic thickness inspection, with appropriate adjustments made to the estimated remaining life, inspection plan, and recertification plan.

4.8.2.4 When PV/S service life is limited by fatigue considerations, NCS-based fatigue or fracture life assessment shall form the basis for specified cyclic life.

4.8.2.5 When NCS fatigue analysis is performed on PV/S that are not fully compliant with the NCS from which the technique is derived (e.g., when ASME Sect. VIII, Div. 2, fatigue analysis is performed on an ASME Sect. VIII, Div. 1, or non-Code vessel), an appropriate additional FS shall be applied to the allowable cyclic life based on the risk and hazard assessment.

> Note: The fatigue life assessment methodology of ASME Section VIII, Div. 2, may be used to estimate fatigue life of Div. 1 vessels or non-Code vessels provided the allowable stress values from Div. 1 are substituted for Sm and appropriate consideration is given to the additional requirements imposed on Div 2 material, fabrication and inspection. Greater FS on cyclic life must be incorporated as uncertainty and unknowns increase. Similarly, the fracture assessment methodology of Div. 3 may be used to assess non-Div. 3 vessels provided additional consideration is given to uncertainties in stress intensity factors and fracture toughness for material that was not fully documented at the time of fabrication in accordance with Div. 3 requirements, which is typically the case for old PV/S.

4.8.2.6 Cyclic life usage shall be obtained from history files or logs or conservatively estimated and documented at the time of each periodic cyclic service inspection, with appropriate adjustments made to the estimated remaining cyclic life in the recertification plan.

4.8.2.7 Unless specifically documented in the original design, the certified remaining life of any PV/S shall not exceed 40 years, and the recertification period shall be in accordance with Paragraph 4.11of this standard.

4.8.2.8 Service life extension analysis shall include, but is not limited to, consideration of the following:

4.8.2.8.1 Relevant characteristics of the PV/S as determined by the application of appropriate NDE and/or testing.

4.8.2.8.2 The fidelity of the NDE methods employed to locate relevant flaws.

4.8.2.8.3 Brittle fracture failure mode when actual service temperature may be less than the MDMT of the PV/S material using post-1988 ASME Boiler & Pressure

Vessel or Piping Code rules for fracture toughness (e.g., UCS-66 rules in Section VIII, Div. 1).

4.8.2.8.4 If leak before break failure mode forms the basis of life extension, leak detection requirements shall be implemented and documented in the PV/S risk assessment.

4.8.3 Inspection Requirements

4.8.3.1 Inspection intervals for all relevant damage mechanisms shall be specified in the inspection plan consistent with intervals recommended in the applicable NCS and this standard.

4.8.3.2 The NDE inspection frequency for fatigue-limited PV/S shall be no more than one half the Code allowable cyclic fatigue life, which is established either by postulating a minimum detectable flaw size using appropriate NDE method(s) to determine remaining life cycles up to reaching critical flaw size or by using the cumulative cyclic usage factor and S/N diagram approach of ASME Boiler and Pressure Vessel Code, Section VIII, Div. 2, or other applicable NCS.

4.8.3.3 Inservice inspections shall be performed to obtain sufficient data to ensure that unanticipated forms or rates of degradation, service changes, or other factors have not changed the remaining life.

4.8.3.4 Records of inspection shall be maintained appropriately.

4.8.3.5 Personnel performing inspections and tests shall be appropriately qualified and certified as applicable in accordance with the appropriate NCS.

4.8.3.6 Baseline thickness shall be verified for all PV/S subject to wall thinning as the limiting damage mechanism prior to initial operation or certification.

4.8.3.7 Inservice corrosion rate thickness inspections shall be determined by the PV/S integrity assessment.

4.8.3.8 PV/S whose service life is limited by fatigue or brittle fracture shall have fatigue inspections performed no later than when the PV/S has experienced one-half of the specified number of permissible load cycles.

4.8.3.9 Inspection intervals shall be reviewed and adjusted throughout the life of a PV/S to incorporate safety related Code changes, unanticipated rates of degradation, or other relevant factors.

4.9 System Safety and Risk Assessment Requirements

4.9.1 Tailored System Safety Requirements for PV/S

4.9.1.1 The system safety activity requirements of Chapter 2 of NPR 8715.3, NASA General Safety Program Requirements, shall be tailored to the PV/S program.

4.9.1.2 Risks shall be identified and documented for all PV/S within the scope of this standard, the risk status shall be updated during the certification/recertification process, and new risks shall be identified as appropriate throughout the life of a PV/S.

4.9.1.3 Risks shall be assessed and Risk Assessment Code (RAC) determined for all PV/S in accordance with paragraph 4.9.2 of this standard.

4.9.1.4 The PSM has authority to specify the method and detail of risk analyses appropriate for each PV/S, consistent with the requirements of paragraph 4.9.2 of this standard.

4.9.1.5 Planning of risk mitigation activities and residual risk analysis shall be performed and documented in the initial PV/S certification or subsequent recertification to reduce or eliminate risks, and residual risks greater than the thresholds identified in paragraph 4.9.1.6 of this standard shall be accepted to the appropriate level as specified in paragraph 4.9.4 and NPD 8710.5.

4.9.1.6 The assessed risk of in-service PV/S shall be no greater than RAC 3 after mitigation unless that risk is specifically approved and accepted in accordance with paragraph 4.9.4 of this standard.

4.9.1.7 PV/S risks shall be mitigated in accordance with the risk reduction protocol in paragraph 1.7.1 of NPR 8715.3, NASA General Safety Program Requirements.

4.9.1.8 Measures that reduce the risk classification shall be documented and tracked throughout the life of each PV/S.

4.9.1.9 The PSM has authority to modify risk mitigation requirements or de-certify and remove from service any PV/S that is not safe to operate.

4.9.1.10 The PSM shall serve as the System Safety Manager with respect to PV/S in accordance with paragraph 2.8.2 of NPR 8715.3 for PV/S.

4.9.1.11 System safety documentation shall be as specified throughout this standard and shall be maintained within the PV/S configuration management system at each Center.

4.9.1.12 The PSM shall identify each PV/S change that potentially affects the baseline risk assessment throughout the life of the PV/S and take appropriate actions to analyze, plan, track, and control the risks associated with each change.

4.9.2 <u>RAC Determination</u>

4.9.2.1 The level of risk shall be evaluated based on the likelihood of mishap and on the severity of the consequence.

4.9.2.2 The risk shall be categorized in accordance with Tables 1, 2, and 3.

4.9.2.3 The RAC is a numerical expression of comparative risk determined by an evaluation of both the potential severity of a condition and the likelihood of its occurrence causing an expected consequence. RACs are assigned a number from 1 to 7 in a risk matrix. The PSM may approve alternative risk determination methods.

Table 1. RAC Determination					
	A Frequent	B Probable	C Occasional	D Remote	E Improbable
I Catastrophic	**1**	**1**	**2**	**3**	**4**
II Critical	**1**	**2**	**3**	**4**	**5**
III Moderate	**2**	**3**	**4**	**5**	**6**
IV Negligible	**3**	**4**	**5**	**6**	**7**

4.9.2.4 Severity is an assessment of the worst potential consequence, defined by degree of injury or property damage, which could occur.

4.9.2.5 The severity classifications are defined in Table 2.

Table 2. Severity Determination Table					
Class	Class Description	Equipment Loss[1] ($K)	Downtime[1]	Data Integrity[1]	Environmental Effect[1]
I Catastrophic	A condition that may cause death or permanently disabling injury, facility destruction on the ground, or loss of crew, major systems, or vehicle during the mission.	**> $1,000**	**> 4 months**	**Data Not recovered**	**> 5 years or >$1M to correct**
II Critical	A condition that may cause severe injury or occupational illness or major property damage to facilities, systems, equipment, or flight hardware.	**$1,000 to $250**	**4 months to 2 weeks**	**Repeat program**	**1-5 years or $250 - $1M to correct**
III Moderate	A condition that may cause minor injury or occupational illness or minor property damage to facilities, systems, equipment, or flight hardware.	**$250 to $25**	**2 weeks to 1 day**	**Repeat test period**	**< 1 yr or $25K - $250K to correct**
IV Negligible	A condition that could cause the need for minor first aid treatment though would not adversely affect personal safety or health. A condition that subjects facilities, equipment, or flight hardware to more than normal wear and tear.	**$25 to $1**	**< 1 day**	**Repeat test point**	**Minor or < $25K to correct**

[1]The values and ranges are considered default values and ranges and may be adjusted based on actual data.

4.9.2.6 Probability is the likelihood that an identified hazard will result in a mishap, based on an assessment of such factors as location, exposure in terms of cycles or hours of operation, and affected population

4.9.2.7 Examples of calculation of the probability estimation are shown in paragraph 4.9.3.5 of this standard.

Table 3. Probability Determination Table			
Level	Description	Qualitative	Definition
A (Frequent)	**Frequent**	**Likely to occur immediately**	**$X > 10^{-1}$**
B (Probable)	**Probable**	**Probably will occur in time**	**$10^{-1} \geq X > 10^{-2}$**
C (Occasional)	**Occasional**	**May occur in time**	**$10^{-2} \geq X > 10^{-3}$**
D (Remote)	**Remote**	**Unlikely to occur**	**$10^{-3} \geq X > 10^{-6}$**
E (Improbable)	**Improbable**	**Improbable to occur**	**$10^{-6} \geq X$**

4.9.3 Default Equipment Failure Probability Estimates

4.9.3.1 The equipment failure probability estimates of Table 4 shall be applied only to certified PV/S.

4.9.3.2 Without further information on a specific PV/S complying with the certification requirements of this standard, the default values of Table 4 shall be used as the equipment failure probability in the RAC determination of paragraph 4.9.2.

4.9.3.3 The PSM has authority to modify the failure probabilities, without processing a variance for specific systems covered by Table 4, provided one of the following is met: (1) failure data exists that is more relevant to the particular PV/S, (2) analysis is performed and documented consistent with the principals of risk management found in NPR 8000.4, Risk Management Procedural Requirements, (3) informed and conservative engineering judgment based on information relevant to the particular facts and condition of the PV/S in question is exercised and documented.

4.9.3.4 PV/S failure probabilities shall be combined with exposure in terms of hours or cycles of operation and affected population in determining the likelihood that a failure will result in a mishap and the overall RAC.

4.9.3.5 The values in Table 4 represent the probability of failure, not the likelihood of consequence.

Example 1: Small bore piping system with personnel exposure 2 hours/24 hour work day, 5 day work week; PV/S pressurized 24 hours/7 days a week.

State Assumptions:

Equipment Failure Probability from Table 4. Item number 11:

1×10^{-3} (catastrophic failures)/(PV-year)

Total hours pressurized per year:

52 weeks/year *7 days/week *24 hours/day = 8736 hours.

Exposure hours per year:

52 weeks/year *5 days/week *2 hours/day = 520 hours

Exposure Fraction:

Exposure hours per year/Total hours pressurized per year

520 hours/8736 hours = 5.9×10^{-2}

Likelihood of Consequence to Personnel (ignores risk to equipment/facility):

Equipment Failure Probability x Exposure Fraction:

$1 \times 10^{-3} \times 5.9 \times 10^{-2} = 6 \times 10^{-5}$

This value (6×10^{-5}) would then be used to determine the probability level (i.e., A, B, C, D, or E) from Table 3 by comparison of the value to the definition column and selecting the appropriate level. For this example the level would be D, "Remote".

This level is used in the RAC matrix (Table 1) with the severity determination of Table 2 to determine the RAC for the PV/S.

Example 2: Small bore piping system PV/S pressurized 24 hours/7 days a week with no personnel exposure (personnel are shielded or remote from hazard).

State Assumptions:

Equipment Failure Probability from Table 4. Item number 11:

1×10^{-3} (catastrophic failures)/(PV-year)

Total hours pressurized per year:

52 weeks/year *7 days/week *24 hours/day = 8736 hours.

Exposure hours per year:

52 weeks/year *5 days/week * 0 hours/day = 0 hours

Exposure Fraction:

Exposure hours per year/Total hours pressurized per year

0 hours/8736 hours = 0

Likelihood of Consequence to Personnel (ignores risk to equipment/facility):

Equipment Failure Probability x Exposure Fraction:

$1x10^{-3} * 0 = 0$

Probability Level: E, "Improbable"

4.9.3.6 For PV/S whose design life is limited by fatigue or brittle fracture failure mode, and whose life has been extended through the application of NDE, in order to consider the potential for NDE to miss existing crack-like flaws the probability of failure shall be increased by a minimum of one level from Table 4 (i.e., an original level E (10^{-6}) becomes a level D (10^{-3} to 10^{-6}).

4.9.3.7 Severity Class assessment shall include consideration of the worst credible consequence due to residual risk for all failure modes.

4.9.3.8 Where Table 4 requires that a specific failure assessment be performed, that assessment shall consider the particular facts and condition of the PV/S in question and be based on either: (1) analysis consistent with the principles of risk management found in NPR 8000.4, Risk Management Procedural Requirements, or (2) informed and conservative engineering judgment that is approved and documented by the PSM.

4.9.3.9 Failure probabilities of PV/S not included in Table 4 (e.g., plastic pipe systems) shall be specified by the PSM based on one of the following: (1) qualitative or quantitative data relevant to the PV/S in question, (2) analyses performed consistent with the principles of risk management found in NPR 8000.4, Risk Management Procedural Requirements, or (3) informed and conservative engineering judgment that is documented.

Table 4 – Tentative Catastrophic PV/S Failure Rates per Year (Median Values) for Certified PV/S

Item	PV/S Component Type	Equipment Failure Probabilities				
		$>10^{-1}$	10^{-1} to $> 10^{-2}$	10^{-2} to $>10^{-3}$	10^{-3} to $> 10^{-6}$	$\geq 10^{-6}$
	Steel Pressure Vessels:	(catastrophic failures) / (PV-yr)				
1	Code vessels fabricated to 1988 ASME or later and pre-1988 Code vessels operating above the post-1988 MDMT that comply with the certification requirements of this document					10^{-6}
2	Code vessels fabricated to pre-1988 ASME and operating lower than post-1988 MDMT with validated fracture life assessment				$>10^{-6}$	
3	Code vessels derated due to safety requirements, Code equivalent FS retained				$>10^{-6}$	
4	Code vessels with FS less than original Code (e.g., due to degradation or fluid service changes)	$>10^{-6}$, Case-by-Case Assessment required				
5	DOT container in static service, maintained under 49 CFR 180 with acceptable VT inspection					10^{-6}
6	Inactive DOT container more than 20 years beyond last 49 CFR 180 stamped retest date				$>10^{-6}$	
7	DOT container not maintained per 49 CFR 180. See notes for this item re: dual categories	FS ≤4 – Case–by-Case assessment required			$>10^{-6}$ (FS≥4)	
8	Non-Code vessels fabricated as equivalent to ASME (operation colder than vs. meets post 1988 rules)	>E-3 (colder than post 1988 MDMT) – case-by-case assessment required			$>10^{-6}$ (meets post-1988)	
9	Non-Code vessels/non-Code equivalent – *	$>10^{-6}$, Case–by-Case assessment required				
	Steel Piping System:	(catastrophic failures / Piping System-yr)				
10	Small bore (NPS 4" and under) piping system (no double containment, sensors/alarms, etc.) – Small system (less than 75 ft. of pipe)				10^{-3}	
11	Small bore (NPS 4" and under) piping system (no double containment, sensors/alarms, etc.) – Large system (more than 75 ft. of pipe)			$>10^{-3}$		

Item	PV/S Component Type	Equipment Failure Probabilities $>10^{-1}$	10^{-1} to $> 10^{-2}$	10^{-2} to $>10^{-3}$	10^{-3} to $> 10^{-6}$	$\geq 10^{-6}$
	Steel Pressure Vessels:	**(catastrophic failures) / (PV-yr)**				
12	**Large bore piping system (> NPS 4', non-intergranular stress corrosion cracking (IGSCC)) – Small system (less than 75 ft. of pipe)**				**10^{-4} (10^{-5} if 6.2.11.3 failures do not apply)**	
13	**Large bore piping system (> NPS 4', non-IGSCC) – Large system (more than 75 ft. of pipe) with failure modes that include thermal fatigue, fluid dynamic loads, or erosion/corrosion wall thinning as described in 6.2.11.2**			**$>10^{-3}$**	**10-4 (if 6.2.11.3 failures do not apply)**	
14	**Degraded or non-Code piping systems**	**Case-by-Case assessment required**				

NOTES:

1. Failure mode is assumed to be catastrophic rupture of the pressure boundary with leak before rupture, which is the dominant failure mode of the data in the listed references.
2. Failure rates are considered constant throughout the service life. Such a "no-aging" constraint requires that inspections be performed and leaks are corrected.

4.9.4 Variance

4.9.4.1 Copies of all variances shall be sent to NASA Headquarters Office of Safety and Mission Assurance.

4.9.4.2 The rationale and acceptance of variances must be objectively reviewed, evaluated, and documented.

NOTE

NASA does not have approval authority for variances to Federal, State, or local regulations (e.g., OSHA, Cal OSHA), nor to consensus standards that are required by Federal regulations (e.g., ANSI, American Conference of Governmental Industrial Hygienists (ACGIH)) that apply to NASA. Any variance 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.

4.9.4.3 Policy Variances

4.9.4.3.1 A policy variance shall be used when a Center policy varies from NPD 8710.5 or when Center policy varies from any "shall" statement in this standard.

4.9.4.3.2 Policy variances shall be approved in accordance with NPR 8715.3, NASA General Safety Program Requirements.

4.9.4.4 Technical Variances

4.9.4.4.1 A technical variance shall be used to address case-by-case variations from requirements of this standard.

4.9.4.4.2 Technical variances shall be prepared in accordance with NPD 8710.5.

4.9.4.4.3 Technical variances shall be reviewed and approved in accordance with Table 5, Technical Variance Approval Process.

Table 5

Technical Variance Approval Process

	RAC 1 & 2	RAC 3+
Headquarters notification	X	X
Center Director Approval	X	
Safety and Mission Assurance Director Approval	X	X
PSM	X	X
Program Manager/Owner	X	X

4.10 Requirements for Specific Components

4.10.1 PRDs

4.10.1.1 The location, design, operating parameters, last test date, and due date for re-closable PRDs on each in-service PV/S shall be documented in the PV/S configuration management system.

Note: Redundant PRDs used only for operational pressure control below the MAWP of the PV/S are not subject to this requirement, provided the system is otherwise protected in accordance with the requirements of the applicable NCS.

4.10.1.2 Nonreclosable PRDs shall meet the requirements of paragraph 4.10.1.1 of this standard with the exception of test date and due date.

4.10.1.3 Overpressure protection for PV/S shall be in accordance with the applicable NCS.

4.10.1.4 Overpressure protection devices for PV/S rated less than 15 psig shall have adequate relief capacity and set pressure tolerance.

4.10.1.5 The accuracy of the pressure set point of pressure safety valves (PSVs) shall be periodically retested, or the PSVs shall be replaced. Unless the provisions of paragraph 4.10.1.7 of this standard apply, the following retest intervals shall be used, consistent with the guidance of NB-23, Part RB:

4.10.1.5.1 Steam Systems – Annually

4.10.1.5.2 Gas systems above 200 psi MAWP – 3 years

4.10.1.5.3 PSVs in combination with rupture disks – 5 years

4.10.1.5.4 Category M, corrosive, flammable, or toxic fluid systems – 2 years (Note: This paragraph is not directly from NB-23.)

4.10.1.5.5 All others – in accordance with Center procedures, but no more than 5 years.

4.10.1.6 Rupture disks need not be replaced periodically provided their vent spaces are inspected and confirmed unrestricted (e.g., free of debris) at the intervals listed above for PSVs.

Note: Because the normal failure of rupture disc is to fail below rated burst pressure, if it has been determined that such a failure will not result in an increased risk, manufacturer's recommended replacement periods may be increased.

4.10.1.7 As objective evidence is collected on the operation of a specific PSV in a specific service, the PSV periodic retest may be extended, but to a total of no more than five years, or reduced.

4.10.1.8 Adjustments and repairs to Code stamped PSVs shall comply with the applicable NCS.

4.10.1.9 Adjustments and repairs to non-Code PSVs shall comply with the applicable NCS to the extent possible.

4.10.1.10 Pressure regulators shall not be used to provide overpressure protection to a PV/S.

4.10.1.11 Pressure safety relief valves shall only be used in accordance with the applicable ASME code of construction.

4.10.1.12 PV/S with an MAWP of less than 15 psig including vacuum systems charged from internal or external gas sources shall have appropriate PRD protection. Code stamped PRDs are generally not available with ratings less than 15 psig. Therefore these low-pressure PV/S may be protected with non-Code/non-conventional PRDs such as check valves with known cracking pressures or lift disks whose relieving pressure depends solely on the weight of the disk. Such non-conventional PRDs are subject to all other applicable requirements of this section, including periodic retesting.

4.10.2 Safety-Related Switches and Pressure Indicating Devices

4.10.2.1 When pressure-indicating devices or pressure or temperature switches exist on a pressure system to provide safety and hazard information to personnel, critical operational information to operators or control systems, or to document compliance with Code test pressures, they shall be considered safety-related devices and shall meet the requirements listed below.

4.10.2.1.1 The location and last test date of all safety-related pressure-indicating devices and pressure or temperature switches shall be documented in the PV/S configuration management system.

4.10.2.1.2 Safety-related pressure-indicating devices shall meet an appropriate NCS, such as ASME B40.100, UL-404, or MIL-G-18997.

4.10.2.1.3 The accuracy of all safety-related pressure indicators shall be periodically verified by means of a Center-approved procedure at an interval no less frequent than that required for PRDs on the same system.

4.10.2.1.4 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.

4.10.2.1.5 If a catastrophic failure of a gauge can cause personnel injury the pressure gauge shall be equipped with a relief case.

4.10.3 Pressure Regulators

4.10.3.1 Pressure regulators used to control pressure of gases supplied from compressed gas cylinders or portable tanks shall comply with OSHA regulations in 29 CFR 1910, particularly section 101, and by citation, CGA P-1 (in particular paragraphs 3.3.8 and 3.3.9).

4.10.3.2 PV/S downstream of pressure regulators shall either be certified for the MAWP of the pressure source, or appropriate PRDs to accommodate a full open regulator failure shall be included in the PV/S installation to preclude the possibility of the downstream pressure exceeding the MAWP or placard rating of the lowest rated component, except as provided in paragraph 4.10.3.3 of this standard.

4.10.3.3 When the PSM concurs that the use of PRDs is not feasible downstream of a regulator (such as due to venting or purity constraints), and if there are no pressure vessels downstream of the regulator, a pressure regulator certified in accordance with CGA Standard E-4 may be used in lieu of a certified PRD (since it precludes the possibility of downstream pressurization to a demonstrated high degree of reliability), provided its full-open discharge pressure does not exceed the placard rating of the lowest rated downstream element or component, and provided the regulator has been inspected and maintained in accordance with CGA E-4 and pressure tested within the past five years.

4.10.4 Flexible Hoses

4.10.4.1 Flexible hoses that may subject personnel to a whipping hazard in the event of end connection failure shall have their ends restrained.

4.10.4.2 Flexible hoses whose rupture would cause unacceptable hazard to personnel shall have sufficient intermediate restraint at appropriate intervals along their lengths to mitigate the hazard.

4.10.4.3 Flexible hoses shall be assembled as directed by the manufacturer's requirements and tested in accordance with the applicable NCS.

4.10.4.4 Flexible hoses whose rupture would cause unacceptable hazard to personnel or risk to mission shall be retested at the flexible hose MAWP no less frequently than every 5 years.

4.10.4.5 Flexible hoses shall not be used in PV/S in lieu of rigid piping or tubing unless the use of rigid piping or tubing has been determined to be impractical (such as where vibration isolation, motion allowance, or component flexibility requires their use).

4.10.4.6 A flexible hose that is permanently installed by welding or brazing shall be included as part of the PV/S inspection and testing requirements, and the retest requirement of paragraph 4.10.4.4 does not apply.

4.10.5 View Ports in PV/S (including sight glasses and liquid level indicators)

4.10.5.1 View ports shall be treated as hazardous, and hazard mitigation steps shall be employed to ensure the safety of personnel from brittle failures.

4.10.5.2 For materials in the brittle range, the Code equivalent FS on breaking strength for view ports shall be 10, or as recommended by the manufacturer subject to approval by the PSM.

4.10.5.3 A view port shall be initially pressure tested in accordance with the applicable NCS for the PV/S in which it is installed.

4.10.5.4 Fluid compatibility shall be considered during view port testing.

4.10.5.5 The initial pressure test shall be performed with the view port installed in the PV/S or in a fixture duplicating the installed loads.

4.10.5.6 View ports shall have an engineering assessment performed (including view port cycle life and ambient noise effects) to determine the appropriate inspection period.

4.10.5.7 Retesting shall be performed if required by the engineering assessment in paragraph 4.10.5.6 of this standard.

4.10.5.8 View ports or windows on PV/S shall be inspected visually annually for cracks, scratches, or other imperfections. An engineering assessment shall be performed on the imperfections to disposition the findings.

4.10.6 DOT Containers Used as Stationary Equipment

4.10.6.1 General

4.10.6.1.1 DOT containers used as stationary equipment shall be certified as either DOT cylinders or as non-Code vessels.

Note: This standard does not address the road worthiness of the trailer.

4.10.6.1.2 DOT specification cylinders that are used in non-DOT service, such as in refillable fixed installations, shall be certified as non-Code vessels with risk assessment, acceptance, and approval via the variance process.

4.10.6.1.3 The DOT containers used in non-DOT service shall be certified based on the original DOT requalification intervals for the specific cylinder specification (reference Table 1 in 49 CFR 180.209(a) and 49 CFR 180.405)

Note: An uncertainty for consideration during certification is that not all DOT specifications are based upon ASME, ASTM, or other standard material specifications. Because of this, minimum assured material strength, toughness, and fracture properties are usually not known, although individual cylinder tensile strength can sometimes be inferred if the original DOT design thickness is known. Thus, for any grouping of cylinders, there is generally no assurance of commonality in material properties from one cylinder to the next. It is therefore difficult to perform conservative fatigue and fracture analysis for remaining life calculations. For these reasons, and because they have lower material strength FS (see

section 4.10.6.2 below), DOT cylinders cannot generally be considered ASME equivalent.

4.10.6.2 If a DOT container is used as stationary equipment, and the owner has elected to certify the DOT container as non-Code PV/S, it shall be certified (recertified) as described below.

4.10.6.2.1 ASME Equivalent Derating – The original cylinder working pressure shall be de-rated for NASA use, to increase the material FS to be FS =4 (or other appropriate FS applicable to the time and material of construction). The extent of derating shall be based on equivalent stress ratio between DOT and ASME.

Example: For 3AA containers, the MAWP is 62% of the service rating stamped on a cylinder, calculated as follows. The test pressure maximum hoop stress is 67% of ultimate for 3AA cylinders (reference 49 CFR 178.37(f)(2)). The test pressure is also 5/3 the service rating (reference 49 CFR 178.37(i)(4)), which means that the stamped service pressure results in hoop stress of (3/5)(.67) = 0.4 times the ultimate stress (i.e., 2.5 normal safety factor on ultimate strength). In order for the hoop stress not to exceed 0.25 times the ultimate stress (FS = 4), the service pressure must not exceed 62% of the rated new service pressure (MAWP) [(0.62)(0.4)=0.25]. Deratings for other containers are determined by applying similar data from 49 CFR 178, Subpart C.

4.10.6.2.2 Consideration shall be given to the service temperature and the potential change in material properties.

4.10.7 Vessels Originally **Not** Designed for, but being used for Mobile Applications

4.10.7.1 This paragraph applies to PV/S that were not originally designed to meet DOT requirements and are used to transport material under pressure.

4.10.7.2 This type of PV/S shall not be used to transport material on public thoroughfares or water ways.

4.10.7.3 An engineering evaluation shall be performed to document that the fixed vessel design meets the static and dynamic load requirements associated with transport and use as a mobile vessel.

4.10.7.4 This type of PV/S shall be evaluated as “non-Code PV/S” per paragraph 4.7 of this standard.

4.10.8 Laboratory systems and equipment shall meet the requirements of this standard, except as noted for DOT cylinders in 4.2.1.19, vendor COTS equipment in 4.2.1.13, and vacuum systems in 4.2.1.14. Specific component requirements are provided for gas pressure regulators in 4.10.3 and 4.10.1.10, and for flexible hoses in 4.10.4.

4.11 Certification and Recertification Process

4.11.1 Required Inspections and Assessments

4.11.1.1 Prior to certification or recertification a comprehensive integrity assessment shall be performed in accordance with paragraph 4.8.1of this standard.

4.11.1.2 Prior to certification or recertification initial service life and remaining life shall be determined in accordance with paragraph 4.8.2 of this standard.

4.11.1.3 Prior to certification or recertification a periodic inspection plan shall be developed or updated in accordance with paragraph 4.8.3 of this standard and all appropriate inspections completed.

4.11.1.4 Prior to certification or recertification a risk assessment shall be performed or updated in accordance with the requirements of paragraph 4.9 of this standard.

4.11.1.5 Prior to certification or recertification all components that require periodic inspection or testing shall be current as required in paragraph 4.10 of this standard.

4.11.2 Certification and Recertification, Triggers

4.11.2.1 Disregard of maintenance or inspection shall be cause for revocation of the certification at the discretion of the PSM.

4.11.2.2 PV/S shall be certified before entering service.

4.11.2.3 PV/S shall be recertified on or before one-half the documented initial service life or one half the recertified remaining life.

4.11.2.4 Recertification shall be performed when the PV/S service changes (e.g., commodity, design parameters, location, and orientation).

4.11.2.5 Recertification shall be performed if any repair, alterations, or modifications are made to the PV/S.

4.11.2.6 Recertification shall be performed as directed by the PSM in the case of NCS changes that reduce the estimated remaining life or increase the known risk of continued operation. (An example of this is the incorporation of fracture toughness requirements for MDMT in UCS-66 in 1988.) (Refer to paragraphs 4.5.6 and 4.5.7 of this standard.)

4.11.2.7 Recertification shall be performed if any unanticipated service degradation is identified that reduces estimated service life, changes probability of failure or failure modes, or changes the risk assessment.

4.11.3 Documentation Requirements

4.11.3.1 Certification and recertification status and limitations, including any applicable variances, shall be documented in the PV/S configuration management system and made available to the owner organizations.

4.11.3.2 Documents and data that establish certification (or recertification) status and limitations shall be maintained and retrievable in the PV/S configuration management system in accordance with NPR 1441.1, NASA Records Retention Schedule.

4.11.3.3 Formal notification of certification or recertification, including all applicable constraints and schedules, shall be made by the PSM to the owning organization and documented in the configuration management system.

4.11.4 Overdue Components Certification Status

4.11.4.1 If component tests specified in paragraph 4.10 of this standard are not completed within the prescribed interval, the PV/S certification shall be revoked.

4.11.4.2 A variance is required to extend the period of an overdue item past the interval prescribed in paragraph 4.10 of this standard.

4.12 Design, Operation, and Maintenance Requirements

4.12.1 The owner shall operate PV/S within the certification parameters.

4.12.2 The owner shall maintain change and modification records of PV/S.

Note: This may be used to identify problem components or PV/S trends.

4.12.3 The owner shall provide to the PSM the data required to maintain certification status.

4.12.4 The owner shall promptly report to the PSM any PV/S incidents or anomalies and shall perform corrective actions as required by the PSM.

4.12.5 The owner shall have certified and qualified personnel operating the system.

4.12.6 The owner shall collect operational data as required to support certification/recertification of PV/S and provide the data to the PSM as required to facilitate certification/recertification.

Note: Some areas of concern are cyclic operation, corrosion, erosion, and creep.

4.12.7 The owner shall operate and maintain boilers in accordance with recommendations of the boiler manufacturer, including water quality. In some cases, due to operational, environmental, or other parameters, maintenance procedures in addition to the manufacturer's recommendations may be necessary.

4.12.8 The owner shall maintain PV/S and their components in accordance with the manufacturer's recommendations or with a suitable maintenance plan to ensure continued compliance with the certification/recertification. In some cases, due to operational, environmental, or other parameters, maintenance procedures in addition to the manufacturer's recommendations may be necessary.

4.12.9 The owner shall not operate PV/S unless certified, except for inspection, examination, and testing as required by the NCS or the inspection plan.

4.12.10 The owner shall maintain weld filler rod and braze material as recommended by the manufacturer.

5 OTHER REFERENCES

The following table is provided for guidance as to applicable codes, standards, and laws. Actual applicability is to be determined by the PSM.

Table 6 - Application of National Consensus Codes, Standards, and Laws to PV/S[12]

PV/S	Designed, Fabricated, Inspected, Tested, and Installed	Operated and Maintained	Repair, Alteration, Inservice Inspection
Unfired Pressure Vessel	ASME B&PVC Section VIII,		**API 510 , 572, 579, 580, 581 ANSI/NBIC NB-23**
Process Piping	ASME B31.3		**API 570, 576, 574, 579, 580, 581 ANSI/NBIC NB-23**
Power Boiler	ASME B&PVC Section I	ASME B&PV Section VII	**ANSI/NBIC NB-23,**
Heating Boiler	ASME B&PVC Section IV	ASME B&PV Section VI	**ANSI/NBIC NB-23**
Power Piping	ASME B31.1		**ANSI/NBIC NB-23**
DOT Cylinders and Cargo Tanks	49 CFR, 29 CFR 1910.101 CGA C-6, C-8, P-1, S-1.1, S-1.2	49 CFR CGA C-6, C-8, P-1, S-1.1, S-1.2	**49 CFR, 29 CFR 1910.101** **CGA C-6, C-8, P-1, S-1.1, S-1.2**
Low Pressure Fixed Storage	29 CFR 1910.106, API 620		**API 510, 572, 579, 580, 581** **STI – SP001**
Liquid Oxygen Systems	NFPA 50, 53 , 55, ASTM G88, ASTM MNL 36, and 29 CFR *1910.104*	ASTM MNL 36, and 29 CFR *1910.104*	**ASTM MNL 36, and 29 CFR 1910.104**
Gaseous Oxygen Systems	NFPA 50, 53, 55, ASTM G88, ASTM MNL 36, and 29 CFR *1910.104*	ASTM MNL 36, and 29 CFR *1910.104*	**ASTM MNL 36, and 29 CFR 1910.104**
Liquid Hydrogen Systems	CGA G-5.4, NFPA 50B, 55, ANSI/AIAA G-095-2004, and 29 CFR 1910.103., NASA/TM-2003-212059, ISO TC 197/SC N	NFPA 50B, 55, NASA NSS 1740.16, ANSI/AIAA G-095-2004	
Refrigeration Piping	ASME B31.5		

[1] 29 CFR 1910.6 contains a list of all referenced standards and the paragraph of application
[2] 49 CFR 171.7 contains a list of all material incorporated by reference and the paragraph of application

PV/S	Designed, Fabricated, Inspected, Tested, and Installed	Operated and Maintained	Repair, Alteration, Inservice Inspection
Gaseous Hydrogen Systems	CGA G-5.4, NFPA 50A, 55, ANSI/AIAA G-095-2004, and 29 CFR 1910.103, NASA/TM-2003-212059, ISO TC 197/SC N	NFPA 55 (50B), ANSI/AIAA G-095-2004 NASA/TM-2003-212059, ISO TC 197/SC N	
Acetylene Cylinders	29 CFR 1910.102 (CGA G-1) & 1910.253	29 CFR 1910.102 (CGA G-1) & 1910.253	
Compressed Air Receivers	29 CFR 1910.169, ASME B&PVC VIII	29 CFR 1910.169	29 CFR 1910.169
Flammable Liquids	29 CFR 1910.106, 49 CFR 171-180, NFPA 30		
Liquified Petroleum Gases	29 CRF 1910.110, 110(b)(10) – Safety Devices, DOT 49 CFR 178, ASME B&PV VII, NFPA 58	29 CRF 1910.110, NFPA-58	
Anhydrous Ammonia	29 CFR 1910.111, ASME B&PV VIII, DOT	29 CFR 1910-111	
Oxygen Welding	29 CRF 1910.253, ANSI B57.1 (CGA V-1), NFPA-51	29 CFR 1910.253, NFPA-51	
DOT Cylinders	49 CFR 100-180, 29 CFR 1910.101, (CGA S-1.1, S-1.2, S-1.3)	29 CFR 1910.101, (CGA P-1, S-1.1, S-1.2)	29 CFR 1910.101, (CGA C-6, C-8) and ANSI/NB-23
Tanks (fixed)	29 CFR 1910.106 (API-12A, -12B, -12D, -12F, -620, -650, -2000), ASME B&PVC VIII, UL-58, -80, -142), AWWA D-100., UFGS 13209.N		API 510, 572, 579, 580, 581, 653
Building Services and Piping	ASME B31.9		

PV/S	Designed, Fabricated, Inspected, Tested, and Installed	Operated and Maintained	Repair, Alteration, Inservice Inspection
Risk Based Inspection			API 580, API 581, API -570, API -510

6 Basis for Table 4 Values

6.1 Reference Documents

Bush, Spencer H., "Statistics of Pressure Vessel and Piping Failures," *Journal of Pressure Vessel Technology*, August 1988, Vol. 110, pp 225 – 233.

Bush, Spencer H, *Pressure Vessel Reliability*, presented at the Transactions of the ASME, February 1975.

Bush, Spencer H, *The Impact of Inservice Inspection on the Reliability of Pressure Vessels and Piping,* presented at the ASME 2nd National Congress on Pressure Vessels and Piping, San Francisco, CA, 1975.

Brown, Sundararajan & Short, *Pipe Risk Analysis: A Case Study*, ASME PVP-Vol 285, Codes and Standards for Quality Engineering, 1994.

6.2 Basis for Table 4 Values

The following is a discussion of the basis for the Table 4, Tentative Catastrophic PV/S Failure Rates per Year (Median Values) for Certified PV/S. It provides an explanation of how the data from a literature search was translated into default values for failure rates. It is intended to provide understanding of the data to permit proper usage and to allow for appropriate modification if there is a better basis for a particular PV/S.

6.2.1 Item 1: Post-1988 ASME Code Vessels

6.2.1.1 ASME Code vessels manufactured post-1988 or older ASME vessels having original design MDMT equal to MDMT under post-1988 UCS-66 rules shall have an assigned failure rate of $1x10^{-6}$ per year or less. The $1x10^{-6}$ failure rate is based on statistics provided in each of the references listed above, under the assumption that the NASA vessels receive periodic inspection using multiple methods of surface and volumetric NDE each of which has a reasonable likelihood of detecting significant flaws or defects that could result in catastrophic failure if left undetected for the life of the vessel.

6.2.1.2 One acknowledged problem with the referenced data is that none of the failure data sufficiently specifies the types of failures that occurred, although it is clear that many reported failures involve non-catastrophic events. Distinction is made between disruptive and non-disruptive failures, but all disruptive failures are not catastrophic failures that result in significant injury or property damage. The NASA requirement is to identify the worst-case probability and consequence. Thus, leaks are generally not worst-case unless leak-before-break is the specified worst-case failure mode. In the literature cited, it is generally not possible to distinguish worst-case failures from less severe failures. Also, data presented in the referenced literature include much foreign data for vessels built to non-ASME standards over unknown time spans. Thus, the data are not directly relatable to ASME vessels, particularly those fabricated to current standards.

6.2.1.3 Also, there is very limited information on how the failure rates have changed over time, although where such data exists, the rate appears to have declined as the present is approached, with improvements being arguably related to Code, NDE, and manufacturing improvements.

6.2.1.4 Table 6 summarizes actual event (raw) "catastrophic" or "disruptive" failure rate data provided in S. H. Bush, "Statistics of Pressure Vessel and Piping Failures." The 99% confidence data are also provided in Spencer H. Bush, "Pressure Vessel Reliability," but are not included in this assessment, which focuses on actual failures. The applicability of these industrial statistical data to NASA pressure vessels has not been qualified at this time and is presented only as the basis for the engineering judgment exercised in developing Table 1.

Table 7. - Summary Catastrophic Failure Rate Data

Source	**Period**	**Rate (per vessel-year**
US Large Vessels, NB	**Through 1979**	**26.0×10^{-6}**
UK, Phillips & Warwick	**1962 – 1978**	**40.0×10^{-6}**
F.R.G, IRS-TUV	**1959 – 1964**	**18.3×10^{-6}**
F.R.G, IRS-TUV	**1965 – 1970**	**5.6×10^{-6}**
F.R.G, IRS-TUV	**1971 – 1976**	**2.1×10^{-6}**
(F.R.G, IRS-TUV – all)	***1959 – 1976***	**6.1×10^{-6}**
US EEI-TVA		**0**
US EEI		**0**
F.R.G. – Kellerman et. Al.		**0**
UK, Smith & Warwick		**16.0×10^{-6}**
US – ABBMA		**0**
Oberender		**6.2×10^{-6}**

6.2.1.5 The data from Germany indicate the decreasing rate over time, presumably as manufacturing practices and NDE methods for in-service inspection improved. This could also be due in part to existing defects being corrected from leak testing.

6.2.1.6 From Spencer H. Bush, "Pressure Vessel Reliability," which originally analyzed in greater detail the summary data presented in S. H. Bush, "Statistics of Pressure Vessel and Piping Failures," there is detailed discussion of how the 99% confidence level ranges are established when, in fact, there were no catastrophic failures in the U.S. population studied. Of significance to this assessment are the following statements.

6.2.1.7 "The expected probability may be significantly lower since the derived probability range is inferred from service data available, coupled with the observation of no occurrence of a disruptive failure event, and the use of a 99% confidence interval to determine the statistically inferred number of occurrences of disruptive failures."

6.2.1.8 With regard to foreign data, many of the "failures" cited, because of their nature and locations, were probably generated during the fabrication stage and remained virtually unchanged until detected during a periodic inspection; they did not directly interfere with functional use….Better terminology describing this data might be "defect statistics" rather than "failure statistics."

6.2.1.9 On the value of periodic inspections, "Attempts to quantify the reduction in disruptive failure probabilities as a function of level of inspection are limited to studies on nuclear reactors …. O'Neill and Jordan … considered the combined effects of acoustic emission, ultrasonic testing, visual examination, and leak detection in reducing failure probability. They concluded the combined effects reduced failure probability by a factor of 10 to 100. Cave and Holmes … cited a factor of about 100 between failure probability for no inspection versus full inspection and a factor of 10 for partial inspection, based primarily on the studies of Kellermann [9]." However, these documents do not formally establish the bases for these quantitative reductions in failure probabilities

6.2.1.10 In "The Impact of Inservice Inspection on the Reliability of Pressure Vessels and Piping," Bush states "O'Neil and Jordan … attempted to quantify failure probability in terms of the probability of gross vessel rupture occurring between service inspections by a formula weighting the various inspections…[based on various NDE and manufacturing factors failing to detect or prevent failure – ed.]" They calculated the probability of catastrophic failure to be $0.8\mathbf{x10^{-6}}$ per vessel-year using the same U.S. failure data.

6.2.1.11 Conclusion - Based on this information, NASA's ASME Code vessels with post-1988 MDMT design, subjected to recertification and periodic inspection in accordance with this standard may be assumed to experience a failure rate of $1\mathbf{x10^{-6}}$ per vessel year, or Level E in NPR 8715.3, NASA General Safety Program Requirements.

6.2.2 Item 2: Pre-1988 ASME Vessels with Invalid Current MDMT

6.2.2.1 With the 1988 UCS-66 rule change for MDMT determination, it became apparent that many thick wall pre-1988 ASME vessels operate below the actual transition temperature of the metal and would have an MDMT under post-1988 rules significantly higher than indicated on their "U" stamp nameplate. Such vessels would have a brittle fracture failure mode that was not recognized in original design, which could potentially be the worst-case failure mode.

6.2.2.2 If pre-1988 vessels operate at temperature below their post-1988 MDMT, but have had service life determined using the Code fracture mechanics technique, are recertified at no more than ½ the calculated fracture life, and have comprehensive NDE applicable to finding relevant cracks as the basis for recertification, then it is reasonable to assume that the failure rate will be greater than standard code compliant vessels, but not excessively so. Therefore, the assigned failure rate is one category greater than Item 1, or Category D.

6.2.3 Item 3: Derated Vessels – Retained Code FS

6.2.3.1 If vessels originally constructed to Code experience service related degradation (e.g., wall thinning) negating their original Code certification, and pressure or temperature derating must be implemented to regain their original code FS, then it is assumed that the probability of failure will be one category more frequent than for standard code compliant vessels. This assumes some active degradation mechanism that may cause additional undetected damage, or may accelerate before further mitigation.

6.2.4 Item 4: Code Vessels with less-than Code FS

6.2.4.1 If Code vessels have suffered degradation such as wall thinning, but are continuing to operate at their original ratings, they are operating with a FS less than required by Code. Depending on the nature and extent of the degradation and the actual FS experienced, the failure probability will increase a little or a lot. In these cases, a specific failure analysis will be

required. In no case may the failure rate be assumed to be less than Category D, and it may be substantially more frequent.

6.2.5 Item 5: DOT Containers with current 49 CFR 180 certification

6.2.5.1 It is assumed that DOT gas cylinders that are in acceptable condition per OSHA/CGA visual inspection criteria and are maintained under 49 CFR 180 and that are not transported or refilled by NASA will have failure rates equivalent to current ASME Code vessels. Data available on the DOT/RSPA website (http://hazmat.dot.gov/pubs/inc/data/2005/2005frm.htm), which includes all fluid releases, clearly shows that there are many failures annually, but determining what data is relevant to NASA is difficult. In 2005 (through November) for example, 9330 hazardous materials incidents were reported (11,808 in 2004), but only 13 involved "burst or rupture" failures due to "deterioration or aging" of containers. Since the total population of packages is unknown, or how many were compressed gases, it is unknown what the relevant failure rate is. Also, these failures occurred during some phase of transportation or periodic retesting rather than spontaneously in the field. The only deaths due to failure of non-bulk containers in the DOT database were those associated with the Value Jet crash in 1996 (failed oxygen generation cylinders).

6.2.5.2 The population size that resulted in the above noted 9330 incidents for 2005 is unknown, but it represents the total number of components regulated by the DOT. Also, the incidents included in the raw data include such things as finding undocumented pressure containers being shipped on aircraft (no failure involved). If no more than 1 in 1000 pressure cylinders are involved in the reported incidents (i.e., an incident rate of .001 for the total population, which seems very conservative), then the catastrophic failure rate (13 burst failures) for the population would be $1\mathbf{x10^{-6}}$. Therefore, an assigned failure rate of $1\mathbf{x10^{-6}}$ for in-service static DOT containers is judged to be suitable for this standard.

6.2.6 Item 6: Inactive DOT Cylinders more that 20 years since last Retest

6.2.6.1 Pressurized DOT cylinders in storage that are more than 20 years since their last 49 CFR 180 retest are generally more likely to have been subjected to corrosion due to environmental factors. Such cylinders may be reasonably assumed to have a higher risk of failure than recently maintained cylinders and are assigned Level D probability unless they are demonstrated to be corrosion free and are stored indoors.

6.2.7 Item 7: DOT Containers not maintained per 49 CFR 180

6.2.7.1 DOT Containers have substantially lower FS than required by ASME (typically 3 or less). If they are not periodically retested per part 49 CFR 180, they become non-Code vessels. Regardless of their derated pressures or extent of NDE for recertification, NASA requires that their risk of failure be assumed at least one level more frequent than for those that continually comply with part 49 CFR 180. Based on the condition of the particular containers and service applied, the risk could be substantially higher, and must be evaluated by the PSM. This, the minimum failure risk level is listed as two values. If such containers are derated to equivalent ASME MAWP with FS $\geq$ 4, then the probability level may be assumed no less frequent than category D. If service pressure is rated any higher than the equivalent ASME MAWP (i.e., FS < 4), then the probability level can be no less frequent than Level C, and a case-by-case assessment is needed.

6.2.8 Item 8: Non-Code Vessels equivalent to ASME

6.2.8.1 NASA's fundamental assumption about non-Code pressure vessels is that they are less safe than Code compliant vessels. If new non-Code vessels are designed and fabricated in a manner fully equivalent with current ASME Code and the only non-compliant feature is a missing U-stamp, but all aspects of the vessel and its production met Code equivalent QA and QC standards, and the FS no less than current Section VIII, Div. 1 (FS = 3.5 since 1998), and using post-1988 material fracture toughness rules, then the failure probability may be assumed to be only one level more frequent (i.e., D) than for fully compliant Code vessels. For new non-Code vessels where the only non-compliance is a missing U-stamp, and meeting all of the following requirements, the failure probability may be assumed to be only one category more frequent (i.e., D) than for fully compliant Code vessels: (1) designed and fabricated in a manner fully equivalent with current ASME Code, (2) all welds and processes met Code equivalent QA and QC standards, (3) the FS is no less than current Section VIII, Div. 1 (FS=3.5 since 1998), and (4) using post-1988 fracture toughness rules.

6.2.8.2 Non-Code vessels designed and fabricated as Code equivalent using pre-1988 toughness rules but which are limited to operate above the post-1988 MDMT may also be assumed to be Level D.

6.2.8.3 Non-Code vessels designed and fabricated as Code equivalent using pre-1988 toughness rules but which operate below their post-1988 MDMT shall be assumed to have failure Level no less than C, although in most cases a specific assessment will be required.

6.2.9 Item 9: Non-Code Vessels/Non-Code Equivalent

6.2.9.1 Non-Code vessels that do not meet Code equivalent standards are assumed to have inherently greater risk of failure and present greater hazard to personnel than Code or Code equivalent vessels. In most cases specific analysis and hazard mitigation features will be required, although designs with substantial excess margins of safety may be assumed to be no less frequent than Level D.

6.2.10 Item 10 and 11: Small Bore Piping Systems (less than NPS 4)

6.2.10.1 Based on the information presented in "Statistics of Pressure Vessel and Piping Failures" by Spencer Bush in 1988, the incidence of disruptive failures of small bore piping systems is substantially greater than for large bore systems, with vibration fatigue and lack of attention playing significant roles in those failures. He also points out that many failures are not reported in small lines, particularly in instrument lines and secondary systems. Therefore, the reported statistics are likely not conservative.

6.2.10.2 In addition, although the failure rates are reported for nuclear plants, much of the data are based on industrial piping considered relevant to nuclear. The data are also reported on two bases – per reactor (system) year and per year per foot of pipe. The recommended median failure probability per system per year is $1x10^{-3}$, while the per-year-foot rate is $1.3x10^{-5}$. Since the probability is dependent on quantity of piping, and since Table 4 is based on annual probabilities, entries for both small piping systems (less than 75 linear ft. of small bore pipe) and large piping systems (more than 75 linear ft.) are shown as Level D and Level C respectively.

6.2.10.3 Brown, Sundararajan & Short, "Pipe Risk Analysis: A Case Study," discusses a risk analysis based on a small bore failure rate probability of $8.87\mathbf{x10^{-3}}$ (large system, Level C per Table 1) obtained from Gulf Oil data for a reference 70 weld, ½ inch carbon steel, 673 ft. long system. Risk reduction strategies that were studied to reduce the failure probability include

improved Inservice Inspection (ISI) (factor of 10 improvement for large bore, less for small bore – assumed to be 5) and double containment with sensors and alarms, which reduced failure probability to $1.2x10^{-5}$.

6.2.11 Item 12 and 13: Large Bore Piping Systems (equal to or greater than NPS 4)

6.2.11.1 Bush, "Statistics of Pressure Vessel and Piping Failures," also reports large bore piping failure statistics in terms of nuclear piping reliability, but also based on industrial piping experience. It is notable that Intergranular Stress Corrosion Cracking (IGSCC) near weldments in austenitic stainless steel in BWR nuclear plants causes an order of magnitude increase in catastrophic failure probability vs. systems where IGSCC is not a significant failure mode. Table 4 excludes consideration of IGSCC induced failure, but if specific NASA large bore piping systems are susceptible to IGSCC, the failure rate must be increased by one order of magnitude.

6.2.11.2 Significant failure modes in large bore piping are thermal fatigue in feed water piping, fluid dynamic loads (water hammer, jets), and wall thinning (erosion, wet steam erosion-cavitation, single phase erosion-corrosion/flow accelerated corrosion). The recommended median rupture failure probability is $1\mathbf{x10^{-4}}$ per system year, while the per-ft-year rate is reported as $1.3\mathbf{x10^{-5}}$. Therefore, as for small bore systems, entries are shown for both small and large quantity systems,

6.2.11.3 Brown, Sundararajan & Short, "Pipe Risk Analysis: A Case Study," also discusses an NPS 8 pipe identical otherwise to the NPS ½ system discussed above in Item 6.2.10. For the 673 ft reference pipe system, the nominal failure probability for fluid releases per year due to weld failure was deduced to be $2\mathbf{x10^{-3}}$. This could be reduced by a factor of 10 through use of enhanced ISI, and by an additional factor of 2 by the use of stainless steel rather than carbon steel, with a resulting failure probability of $1\mathbf{x10^{-4}}$ per year. Thus, large bore piping systems with substantial footage require enhanced ISI as a minimum to fall within the Level D range for NASA assessment.

6.2.12 Item 14: Degraded and Non-Code Piping Systems

6.2.12.1 The above listed failure rates presume systems that obtain industry standard maintenance and inspection. If piping systems are operated with known significant deficiencies due to service or environmentally induced degradation or due to design inadequacies, their failure rates must be assumed to be more frequent than for Code compliant piping fit for service. Generic probability assignment on such systems would be difficult to perform due to the age of components and system uncertainties. Therefore, a case-by-case assessment is required for such systems.

7 INDEX