

ASME PVHO-1–2016
(Revision of ASME PVHO-1–2012)

Safety Standard for Pressure Vessels for Human Occupancy

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**The American Society of
Mechanical Engineers**

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**The American Society of
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FOREWORD

Early in 1971, an ad hoc committee was formed by action of the ASME Codes and Standards Policy Board to develop design rules for pressure vessels for human occupancy. The importance of this task was soon recognized, and the ASME Safety Code Committee on Pressure Vessels for Human Occupancy (PVHO) was established in 1974 to continue the work of the ad hoc committee. Initially, this committee was to confine its activity to the pressure boundary of such systems. It was to reference existing ASME Boiler and Pressure Vessel Code (BPVC) sections, insofar as practicable, adapting them for application to pressure vessels for human occupancy. The common practice hitherto had been to design such chambers in accordance with Section VIII, Division 1 of the ASME BPVC; however, a number of important considerations were not covered in those rules. Among these were requirements for viewports and the in-service use of pressure relief valves, and special material toughness requirements. This Standard provides the necessary rules to supplement that section, and also Section VIII, Division 2 of the BPVC. The user is expected to be familiar with the principles and application of the Code sections.

BPVC criteria furnish the baseline for design. In PVHO-1, design temperature is limited to 0°F to 150°F (–18°C to 66°C). Supporting structure and lifting loads are given special attention. Certain design details permitted by Section VIII are excluded. A major addition is the inclusion of design rules for acrylic viewports (Section 2). The formulation of rules for these vital and critical appurtenances was one of the reasons for establishing the PVHO Committee. Finally, all chambers designed for external pressure are required to be subjected to an external pressure hydrostatic test or pneumatic test.

The 2007 edition was completely rewritten and reformatted from the 2002 edition. Section 1, General Requirements, is intended to be used for all PVHOs, regardless of use. The rules for external pressure design were expanded to include unstiffened and ring-stiffened cylinders, in addition to spheres. Other additions included sections pertaining to application-specific PVHOs. Sections were included for medical hyperbaric systems, diving systems, submersibles, and quality assurance. The piping section was expanded. Where possible, Mandatory Appendices were incorporated into the body of the document. All Forms were revised to reflect the document (PVHO-1), an abbreviation denoting the corresponding section (e.g., General Requirements is GR), and the form number within that Section. An example is PVHO-1 Form GR-1.

The 2012 edition included expansions made to the General Requirements, Viewports, and Diving Systems Sections.

The 2016 edition includes additional expansions made to the General Requirements, Viewports, Medical Hyperbaric Systems, and Diving Systems Sections. It includes a new Nonmandatory Appendix for preparing PVHO performance-based Cases for flexible chambers. There is continuing work being accomplished by the Subcommittees in the areas of PVHOs using nonstandard materials, including nonmetallic PVHOs. A companion document (PVHO-2) that covers in-service guidelines for PVHOs has been published.

The 2016 edition of PVHO-1 was approved and adopted by the American National Standards Institute as meeting the criteria as an American National Standard on January 20, 2016. Previous editions were published in 1977, 1981, 1984, 1987, 1993, 1997, 2002, 2007, and 2012.

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The Committee welcomes proposals for revisions to this Standard. Such proposals should be as specific as possible, citing the paragraph number(s), the proposed wording, and a detailed description of the reasons for the proposal, including any pertinent documentation.

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The request for an interpretation should be clear and unambiguous. It is further recommended that the inquirer submit his/her request in the following format:

Subject: Cite the applicable paragraph number(s) and the topic of the inquiry.
Edition: Cite the applicable edition of the Standard for which the interpretation is being requested.
Question: Phrase the question as a request for an interpretation of a specific requirement suitable for general understanding and use, not as a request for an approval of a proprietary design or situation. The inquirer may also include any plans or drawings that are necessary to explain the question; however, they should not contain proprietary names or information.

Requests that are not in this format may be rewritten in the appropriate format by the Committee prior to being answered, which may inadvertently change the intent of the original request.

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Requests for PVHO Cases shall provide the following:

- (a) *Statement of Need.* Provide a brief explanation of the need for the revision(s) or addition(s).
- (b) *Background Information.* Provide background information to support the revision(s) or addition(s) including any data or changes in technology that form the basis for the request that will allow the Committee to adequately evaluate the proposed revision(s) or addition(s). Sketches, tables, figures, and graphs should be submitted as appropriate. When applicable, identify any pertinent paragraphs in the Standard that would be affected by the revision(s) or addition(s) and paragraphs in the Standard that reference the paragraphs that are to be revised or added.

Furthermore, the proposed Case should be written as a question and a reply in the same format as existing Cases. Requests for PVHO Cases should also indicate the applicable edition to which the proposed Case applies.

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ASME PVHO-1-2016

SUMMARY OF CHANGES

Following approval by the PVHO Committee and ASME, and after public review, ASME PVHO-1-2016 was approved by the American National Standards Institute on January 20, 2016.

ASME PVHO-1-2016 contains editorial changes, revisions, and corrections identified by a margin note, **(16)**, placed next to the affected areas.

<i>Page</i>	<i>Location</i>	<i>Change</i>
1	1-1	Revised
2	1-6	Subparagraphs (a), (b), (f) revised
3	1-7.6	Subparagraph (g) revised
4	1-7.13	Title revised
	1-7.13.1	Revised
10–11	1-7.13.4	Subparagraph (d)(3) figure number corrected
13	1-7.13.6	(1) Title revised (2) First paragraph added (3) Subparagraph (a) revised
	1-7.15	Revised
22	2-2.4.1	Subparagraph (a) revised
26	Fig. 2-2.5.1-1	Revised
27	Fig. 2-2.5.1-2	Revised
28	Fig. 2-2.5.1-3	Revised
39	Fig. 2-2.5.1-13	Revised
40	Fig. 2-2.5.1-14	Revised
41	Fig. 2-2.5.1-15	Revised
49	Fig. 2-2.10.1-5	R_m changed to R_n
51	Fig. 2-2.10.1-7	β changed to ϵ
52	Fig. 2-2.10.1-8	β changed to ϵ
53, 56	2-2.11.11	Added, and following paragraphs redesignated
54	Fig. 2-2.11.10-1	Revised
57	Fig. 2-2.11.11-1	Added
62	Table 2-2.14.13-2	Signs added under Specified Values columns
70	2-3.7	Subparagraph (c)(1) revised
83–84	2-10.5	Revised

<i>Page</i>	<i>Location</i>	<i>Change</i>
86–87	4-1.2	(1) Subparagraph 4-1.2.2(c) deleted (2) Subparagraph 4-1.2.2(d) redesignated as 4-1.2.3, and original 4-1.2.3 redesignated as 4-1.2.4
	4-1.2.4	Revised
	4-1.2.5	Added
99	5-1.1	Revised
100	5-5.5.1	Revised
	5-5.6	Added, and following paragraphs redesignated
102	6-1.5	Reference to Nonmandatory Appendix F updated
106–111	6-4.4	Added
	6-4.5	Added
	Fig. 6-4.5.2.2-1	Added
	Fig. 6-4.5.2.2-2	Added
	6-4.6	Added
	6-6	Added
114	7-3.1.3	Reference to para. 4-2.4.5 corrected
121–125	Mandatory Appendix II	(1) Definitions of <i>clump weight</i> , <i>design pressure</i> , <i>drop weight</i> , <i>examination</i> , <i>guide wire(s)</i> , <i>inspection</i> , <i>material specification</i> , <i>operating pressure</i> , <i>testing</i> added (2) Definition of <i>hyperbaric stretcher</i> revised
136	Table D-7.1-1	Redesignated
138, 153	Nonmandatory Appendix E	Added, and former Nonmandatory Appendix E redesignated as Nonmandatory Appendix F

SPECIAL NOTE:

The Cases to PVHO-1 follow the last page of this Edition. However, they are not part of the Standard itself.

ASME PVHO-1 2016

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SAFETY STANDARD FOR PRESSURE VESSELS FOR HUMAN OCCUPANCY

Section 1 General Requirements

(16) 1-1 INTRODUCTION

This Standard defines the requirements that are applicable to all Pressure Vessels for Human Occupancy (PVHOs) fabricated to this Standard (Sections 1 through 4) and shall be used in conjunction with specific requirements in other Sections (Sections 5 through 7, as applicable) and Mandatory Appendices of this Standard. In the event of conflict between Sections 1 through 4 and other Sections (5 through 7), the application-specific requirements from Sections 5 through 7 shall govern.

PVHOs shall be designed, fabricated, inspected, tested, marked, and stamped in accordance with the requirements of this Standard and of the ASME Boiler and Pressure Vessel Code (the Code), Section VIII, Division 1 or Division 2, unless otherwise permitted within this Standard.

In-service requirements for PVHOs are found in ASME PVHO-2.

1-2 SCOPE

1-2.1 Application

This Standard applies to all pressure vessels that enclose a human within their pressure boundary while under internal or external pressure exceeding a differential pressure of 2 psi (15 kPa). PVHOs include, but are not limited to, submersibles, diving bells, and personnel transfer capsules, as well as decompression, recompression, hypobaric, and hyperbaric PVHOs.

1-2.2 Geometry

The scope of this Standard in relation to the geometry is the pressure boundary as defined in the User's Design Specification and shall include, but not be limited to, the following:

- (a) shells of revolution
- (b) openings and their reinforcements
- (c) nozzles and other connections
- (d) flat heads
- (e) quick-actuating closures

- (f) vessel penetrations
- (g) attachments and supports
- (h) access openings
- (i) viewports
- (j) pressure relief devices
- (k) pressure-retaining covers for vessel openings

1-2.3 Limitations

The pressure boundary of the PVHO shall be as follows:

- (a) welding end connection for the first circumferential joint for welded connections
- (b) the first threaded joint for screwed connections
- (c) the face of the first flange for bolted, flanged connections
- (d) the first sealing surface for proprietary connections or fittings

1-3 EXCLUSIONS

The following types of vessels are excluded from this Standard:

- (a) nuclear reactor containments
- (b) pressurized airplane cabins
- (c) aerospace vehicle cabins
- (d) caissons

1-4 USER REQUIREMENTS

It is the responsibility of the user, or an agent acting for the user who intends that a PVHO be designed, fabricated, inspected, tested, marked, stamped, and certified to be in compliance with this Standard, to provide or cause to be provided for such PVHO, a User's Design Specification. The User's Design Specification shall set forth the intended operating conditions of the PVHO to provide the basis for design. It shall identify the external environment to which the PVHO will be exposed, the intended function of the PVHO, mechanical loads imposed on the PVHO, specific installation requirements, and applicable codes and standards.

1-5 MANUFACTURER'S DATA REPORT

The manufacturer or a designated agent shall make design calculations and prepare a Manufacturer's Data Report stating that the design, as shown on the design drawings, complies with this Standard and the User's Design Specification.

A Registered Professional Engineer, or the equivalent in other countries, shall certify that the Manufacturer's Data Report is in compliance with this Standard and the User's Design Specification.

(16) 1-6 MATERIALS

All PVHO materials shall meet the requirements of this Standard.

Pressure vessel metallic material shall meet the specified Division of Section VIII of the Code. Nonstandard materials shall be qualified for use as defined in Nonmandatory Appendix D. The following materials shall not be used for pressure parts: SA-36, SA-283, SA-515, and cast and ductile iron.

Ferrous materials for PVHOs shall also comply with the following requirements:

(a) Except as provided for in paras. (b), (c), (d), or (e) below, drop-weight tests in accordance with ASTM E208 shall be made on all wrought and cast ferrous materials. For plates, one drop-weight test (two specimens) shall be made for each plate in the as-heat-treated condition. For product forms other than plate, one drop-weight test (two specimens) shall be made for each heat in any one treatment lot. The sampling procedure for each form of material shall comply with the requirements of the specifications listed in the Code in either Section VIII, Division 1, Table UG-84.3 or Section VIII, Division 2, para. 3.10.4, as applicable. The test shall be conducted at a temperature 30°F (17°C) lower than the minimum temperature for seamless and postweld heat-treated vessels, and 50°F (28°C) lower for as-welded vessels. The two specimens shall both exhibit no break performance.

(b) When, due to the material thickness or configuration, drop-weight specimens cannot be obtained, Charpy V-notch tests shall be conducted. The Charpy V-notch test of each material shall comply with the requirements of the applicable material specification or, when none is given, shall comply in all respects with the requirements of the applicable product form specifications listed in Section VIII, Division 1, Table UG-84.3 or Section VIII, Division 2, para. 3.10.4, as applicable. For either case, the test temperature shall not be higher than that specified in para. (a) above.

(c) As an alternative to the requirements of para. (a) above, those materials listed in Table A1.15 of Section II, Part A, SA-20 of the Code may be accepted on the basis of Charpy V-notch testing. Testing shall be in accordance with the procedures contained in the specified Division of Section VIII of the Code, except that the acceptance

criteria for plate shall be from each plate as heat treated. The test temperature shall not be higher than that specified in para. (a) above regardless of the temperature shown in Table A1.15 of SA-20.

(d) Ferrous materials that are 0.625 in. (16 mm) or less in thickness are exempt from the additional toughness tests of paras. (a) through (c) above provided these materials are either of the following:

(1) normalized, fully killed, and made in accordance with fine grain practice

(2) fully killed, made in accordance with fine grain practice with a grain size of 5 or finer and an operating temperature of 50°F (10°C) or higher

(e) The additional toughness tests of paras. (a) through (c) above may be waived for the 300 series stainless steels.

(f) When the material has a specified minimum yield strength exceeding 60 ksi (414 MPa), weld metal and heat-affected zone impact properties for weld procedure qualifications and weld production tests shall also meet the requirements of the specified Division of Section VIII of the Code at a test temperature 30°F (17°C) lower than the design temperature, regardless of the value of the minimum design metal temperature.

PVHOs constructed of ferrous materials that are exposed to the corrosive effects of marine environments shall have provisions made for the desired life by a suitable increase in the thickness of the material over that required by the design procedures, or by using some other suitable method of protection.

1-7 DESIGN AND FABRICATION REQUIREMENTS

1-7.1 Joint Design

The design and fabrication shall be in accordance with the specified Division of Section VIII of the Code and the following requirements common to all PVHOs, unless otherwise permitted within this Standard:

(a) All joints of Categories A through C shall be Type No. 1 of Table UW-12 for Section VIII, Division 1 vessels or shall be weld joint Type 1 of Table 4.2.2 and meet the requirements of para. 6.2.4.1 for Section VIII, Division 2 vessels.

(b) All joints of Category D shall be full-penetration welds extending through the entire thickness of the vessel or nozzle wall and shall be Type No. 1 or Type No. 7 of Table UW-12 for Section VIII, Division 1 vessels or shall be weld joint Type 1 or Type 7 of Table 4.2.2 for Section VIII, Division 2 vessels. Backing strips shall be removed.

(c) Intermediate heads may be designed in accordance with Fig. UW-13.1(e) for Section VIII, Division 1 vessels only when the following conditions are met:

(1) The allowable stress used in the calculations for the intermediate head and for the shell that the intermediate head is attached to shall be 70% or less of the

allowable stress found in Section II, Part D of the Code. This reduced allowed stress shall apply to the shell only for a distance measured parallel along the shell of 2.5 times the square root of the shell mean radius times the shell thickness from the centerline of the butt weld to either side [reference Fig. UW-13.1(e) of the Code].

(2) The flange of the intermediate head shall be at least $1\frac{1}{2}$ in. (38 mm) long and shall be welded to the shell with a minimum fillet weld of $t_h/2$ or $\frac{1}{4}$ in. (6.4 mm), whichever is less.

(3) The butt weld shall be 20% or less of the allowable stress value for the vessel material [reference UW-13(c)(2)].

(4) In addition to the strength requirements of section 1-7.1, stiffener rings or other attachments exposed to a corrosive environment shall be seal welded by welds that are continuous on all sides.

1-7.2 Welding

Pressure vessel welding shall be performed in accordance with Section IX of the ASME Code.

1-7.3 Nondestructive Testing

All nondestructive testing shall conform to Section V of the ASME Code.

(a) All Type No. 1 butt welds shall be 100% radiographed. All Type No. 7 corner welds shall be 100% ultrasonically examined. Both the above radiographic and ultrasonic inspections shall be performed in accordance with the specified Division of Section VIII of the Code.

(b) PVHO vessels that incorporate an intermediate head per para. 1-7.1(c) shall be inspected as follows:

(1) The butt weld joint shall be 100% radiographed and 100% ultrasonic examined per the requirements of Section VIII, Division 1 or Division 2.

(2) The butt weld, fillet weld, and/or seal weld shall be examined after hydrostatic test in accordance with para. (d) below.

(c) The reverse side of the root pass of double welded joints shall be sound. This shall be shown by magnetic particle (MT) or liquid penetrant (PT) examination. If necessary, chipping, grinding, or melting-out may be required to ensure sound metal. Weld metal shall then be applied from the reverse side.

(d) After hydrostatic tests, all pressure-retaining welds and/or seal welds shall be examined in accordance with the requirements for either MT examination (Section V, Article 7 of the Code) or PT testing (Section V, Article 6 of the Code). The acceptance criteria shall be those of the applicable requirements of the specified Division of Section VIII of the Code.

1-7.4 Electrical Outfitting

All electrical penetrators through the pressure boundary shall be suitable for the environment in which they

will operate in order to minimize the risk of fire, explosion, electric shock, emission of toxic fumes to personnel, and galvanic action on the pressure boundary.

Electrical penetrators and equipment shall not be damaged by pressurization and depressurization of the PVHO to operating pressures.

1-7.5 Viewports

Viewports shall conform to Section 2 of this Standard.

1-7.6 Penetrations

Penetrations of the pressure boundary shall comply with the following:

(a) Penetrators shall be constructed of material suitable for the intended service and compatible with the vessel shell material.

(b) Penetrators shall be either of standard piping components or of a port and insert construction. See Nonmandatory Appendix B, Figs. B-2-1 and B-3-1.

(c) Where a penetrator is of the port and insert construction, the insert shall be constructed of ASME PVHO material.

(d) Sealing surfaces of elastomer sealed penetrators shall be protected from corrosion effects.

(e) Penetrators incorporating piping or commercial components shall be rated by the manufacturer to be suitable for the intended design pressure and temperature and meet the testing requirements of para. 1-7.8 of this Standard.

(f) Penetrators and inserts shall be tested in accordance with para. 1-7.8.

Portions of the insert that become part of the pressure boundary shall be tested to the same pressure required for the PVHO. Portions of the insert that are subject to greater pressure than the pressure boundary shall be tested in accordance with the requirements of Section 4.

(g) Except as permitted in 1-7.6(e) above, penetrations of the pressure boundary including piping, windows, manways, and service locks shall conform to the reinforcement requirements of the ASME Code, Section VIII, Division 1 or Division 2. Plate material used as reinforcement shall meet the requirements of Mandatory Appendix 20 of the Code for Division 1 or Section 3.9 of the Code for Division 2.

1-7.7 Inspection

All PVHOs and processes used in their manufacture shall be inspected in accordance with the manufacturer's quality assurance system in accordance with Section 3 of this Standard.

1-7.8 Testing

All PVHOs and pressure-retaining components of PVHOs shall demonstrate structural integrity through testing as follows:

(a) All internally pressurized vessels shall be tested according to the applicable section of this Standard and/or the specified Division of Section VIII of the Code.

(16)

(b) Unless otherwise stated in this Standard, all externally pressurized vessels, regardless of the design rules used, shall be subjected to an external pressure test to a differential pressure not less than 1.25 times the maximum allowable working pressure (MAWP). The test pressure shall be maintained for not less than 1 hr. The differential test pressure may be achieved by a combination of internal and external test pressures.

1-7.9 Documentation

The manufacturer (PVHO) shall provide the owner/user or his designated agent a copy of the Manufacturer's Data Report [PVHO-1 Form GR-1 (PVHO-1 Form GR-1S)] and Forms U-1 and U-2 (Division 1) or Forms A-1 and A-2 (Division 2), as applicable, for PVHOs built to Section VIII of the Code. The manufacturer (PVHO) shall retain a copy of the Manufacturer's Data Report (PVHO-1 Form GR-1), applicable Section VIII forms, and all viewport-supporting documents per Section 2 of this Standard on file for at least 10 yr from the date of manufacture. Nondestructive testing documentation shall meet the requirements of Section V of the ASME Code. In addition to the aforementioned documentation, the manufacturer (PVHO) shall furnish the following documentation to the user or his designated agent:

- (a) instructions critical to the maintenance of the PVHO
- (b) instructions critical to the operation of the PVHO and subsystems (operating procedures)
- (c) coating/painting information
- (d) photocopy or equivalent of the PVHO data plate
- (e) list of standards used
- (f) seal and gasket sizes and materials
- (g) User's Design Specification
- (h) evidence of successful completion of test(s) required in para. 1-7.8
- (i) system schematics (life support, hydraulics, electrical, communications, etc.)
- (j) system descriptions (life support, hydraulics, electrical, communications, etc.)
- (k) assembly drawings
- (l) equipment documentation (technical manuals, catalog cuts, etc.)

1-7.10 Piping

Unless otherwise permitted within this Standard, piping shall conform to the requirements of Section 4 of this Standard.

1-7.11 Opening Reinforcements

All opening reinforcements shall be integral with the nozzle and/or shell. Reinforcement pads are not permitted.

1-7.12 Brazed or Riveted Construction

Brazed or riveted construction is prohibited on the pressure boundary.

1-7.13 Alternative Design Rules for External Pressure Vessels (16)

1-7.13.1 General. This section provides alternative rules to those given in Section VIII, Division 1 or Division 2 for determining allowable compressive stresses and associated allowable external pressure for unstiffened and ring-stiffened circular cylinders, and the minimum required thickness for unstiffened spheres and spherical and ellipsoidal heads. The use of these alternative rules may result in a pressure vessel design that is lighter weight than that using the rules of Section VIII, Division 1 or Division 2. When used, this section shall be made applicable to the entire vessel. (16)

The hull design shall consider all load conditions in addition to external pressure loadings. These loading conditions shall include, but are not limited to, those specified in Section VIII, Division 1 or Division 2.

The cylinder geometry is illustrated in Fig. 1-7.13.1-1 and the stiffener geometries in Fig. 1-7.13.1-2. The effective sections for ring stiffeners are shown in Fig. 1-7.13.1-3.

Use of these rules requires the shell section to be axisymmetric. Except for local reinforcement, these rules are based on a uniform thickness of the shell section. Where locally thickened shell sections exist, the thinnest uniform thickness in the adjacent shell section shall be used.

The reinforcement for openings in vessels that do not exceed 10% of the cylinder or head diameter or 80% of the ring spacing into which the opening is placed may be designed in accordance with the requirements of para. UG-37(d)(1) or para. 4.5.17 of the Code for openings in cylindrical shells and paras. 4.5.10 and 4.5.11 of the Code, as applicable, for openings in spherical and formed heads. The required thickness shall be determined in accordance with para. 1-7.13.4. The factor, F , used in UG-37(c) shall be 1.0. Openings in shells that exceed these limitations require a special design based on a finite element analysis of the opening and surrounding shell and stiffeners. The required thickness of the reinforcement shall be sufficient to reduce the von Mises stress at the edge of the reinforcement to the von Mises stress in a region distant from the reinforcement. This distant region is typically at unpenetrated regions of a spherical shell, unstiffened cylindrical shell, or mid-bay in stiffened cylinders. If the von Mises stress at the edge of the reinforcement exceeds that at the distant region, the allowable external pressure shall be decreased by the ratio of the distant region stress to reinforcement edge stress.

PVHO-1 Form GR-1 Manufacturer's Data Report for Pressure Vessels for Human Occupancy
As Required by ASME PVHO-1

1. Design criteria _____
2. Manufactured and certified by _____
3. Manufactured for _____
4. Location of installation _____
5. Type _____ (drawing no.) _____ (manufacturer's serial no.) _____ (year built)
6. The chemical and physical properties of all parts meet the requirements of material specifications of ASME PVHO-1 _____ (year) and Addenda to _____ (date) and Case nos. _____. In addition, the design, construction, and workmanship conform to ASME Section VIII, Division _____ (1 or 2), _____ (year) and Addenda to _____ (date) and Code Case nos. _____.
7. Constructed for maximum allowable working pressure of _____ psi (internal) and/or _____ psi (external), at a maximum temperature of _____ °F and/or minimum temperature of _____ °F, and hydrostatic test pressure of _____ psi (internal) and/or _____ psi (external).
8. Service: Fatigue analysis required _____ (yes or no) _____ (describe service)
9. Windows: Certification Reports, properly identified and signed by the window fabricator, are attached for the following items:

No.	Location	Type	Diameter or Size	Nominal Thickness	How Attached

10. Manufacturer's Data Report/Partial Data Reports, completed in accordance with the ASME BPV Code, Section VIII, Division _____ (1 or 2) and properly identified and signed by Commissioned Inspectors, are attached for the following items (use PVHO-1 Form GR-1S for additional items, if necessary):

Data Report	Remarks (Name of Part, Manufacturer's Name, and Identifying Stamp)

CERTIFICATION OF DESIGN

User's Design Specification on file at _____

Manufacturer's Design Report on file at _____

User's Design Specification certified by _____ P.E. State _____ Reg. no. _____

Manufacturer's Design Report certified by _____ P.E. State _____ Reg. no. _____

CERTIFICATION OF COMPLIANCE

We certify that the statements made in this report are correct and that all details of material, construction, and workmanship of this vessel conform to the ASME Safety Standard for Pressure Vessels for Human Occupancy (PVHO-1).

ASME Certificate of Authorization _____ (U or U2), Certificate no. _____ Exp. date _____

Date _____, 20 _____ Company name _____ (PVHO manufacturer) Signed _____ (representative)

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Fig. 1-7.13.1-1 Geometry of Cylinders

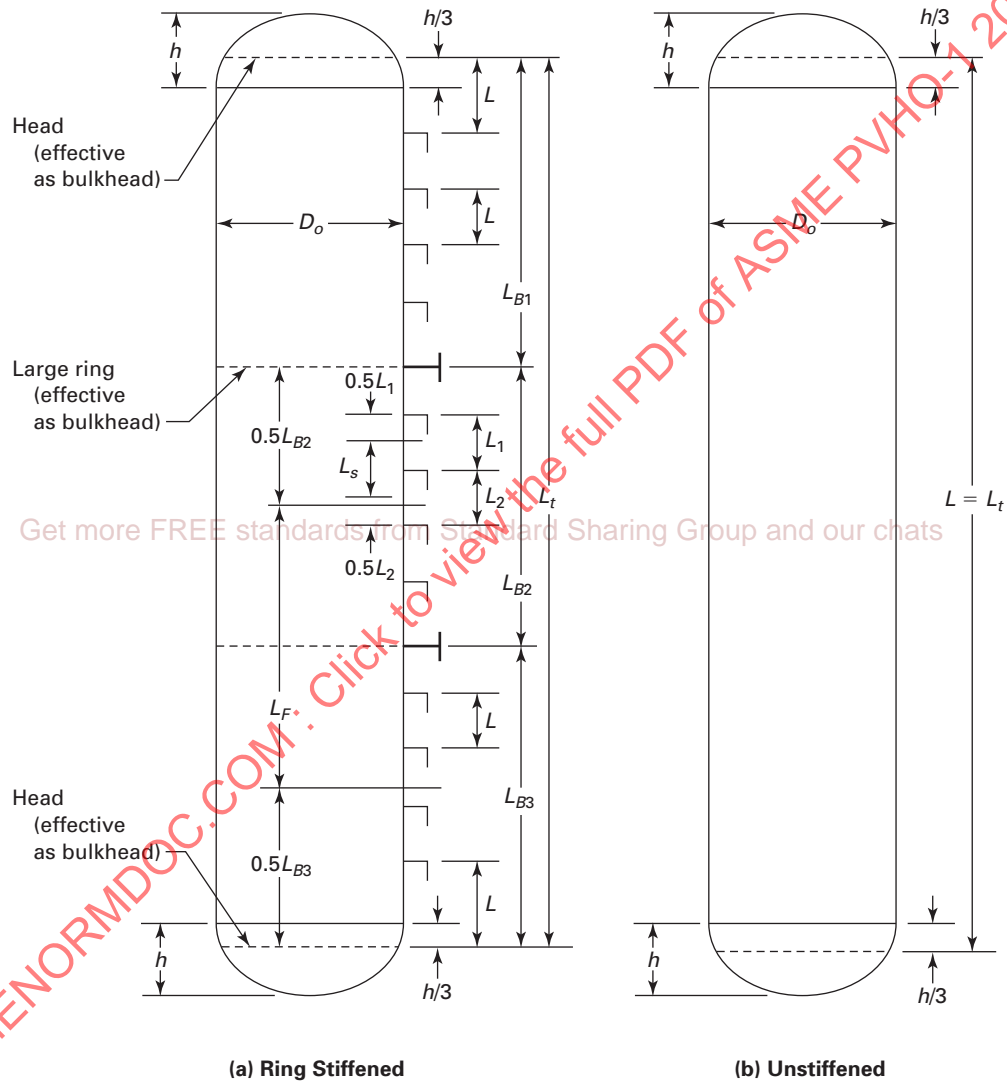


Fig. 1-7.13.1-2 Stiffener Geometry

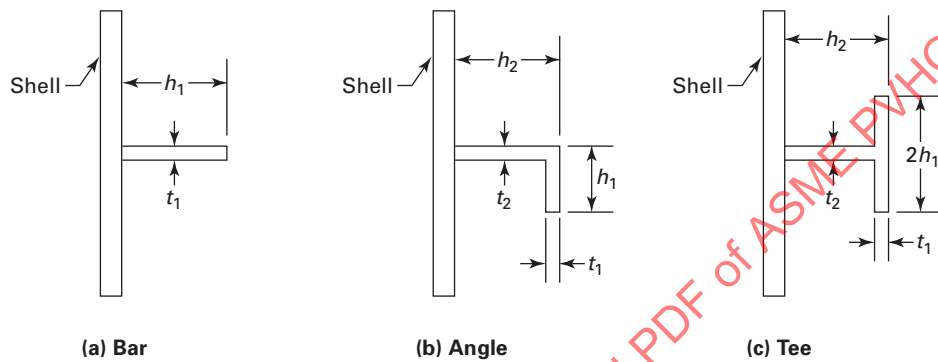
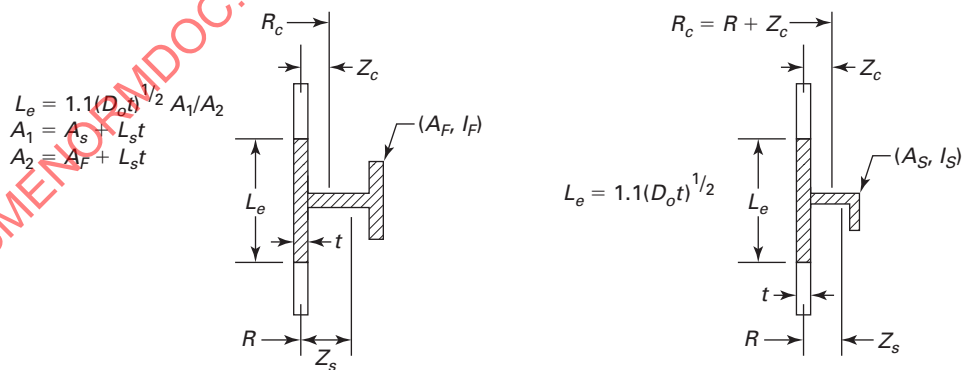


Fig. 1-7.13.1-3 Sections Through Rings



For stiffened cylinders, special consideration shall be given to ends of members (shell sections) as follows: the von Mises stress at midbay at the end segment shall not exceed 105% of the midbay stress away from the effects of the end.

Special consideration shall also be given to areas of load application where stress distribution may be non-linear and localized stresses may exceed those predicted by linear theory. When the localized stresses extend over a distance equal to one-half the buckling mode (approximately $1.2\sqrt{D_o t}$), the localized stresses should be considered as a uniform stress around the full circumference. Additional stiffening may be required.

All calculations shall be performed using all dimensions in the corroded condition.

1-7.13.2 Nomenclature

- A_1 = cross-sectional area of small ring plus shell area equal to $L_s t$, in.²
- A_2 = cross-sectional area of large ring plus shell area equal to $L_s t$, in.²
- A_F = cross-sectional area of a large ring stiffener that acts as a bulkhead, in.²
- A_S = cross-sectional area of a ring stiffener, in.²
- C = a factor used to determine minimum shell thickness and length of the template used in checking local shell deviations
- c = distance from neutral axis of cross section to point under consideration, in.
- D_o = outside diameter of cylinder, in.
- E = modulus of elasticity of material at design temperature, determined from the applicable material chart in Subpart 2 of Section II, Part D, ksi. The applicable material chart is given in Tables 1A and 1B, Tables 2A and 2B, or Tables 5A and 5B, Subpart 1, Section II, Part D. Use linear interpolation for intermediate temperatures.
- e = maximum plus or minus deviation from a true circular form, in.
- e_x = local deviation from a straight line measured along a meridian over a gauge length, L_x , in.
- F_{ha} = allowable hoop compressive membrane stress of a cylinder or formed head under external pressure alone, ksi
- F_{he} = elastic hoop compressive membrane failure stress of a cylinder or formed head under external pressure alone, ksi
- F_{hef} = average value of the hoop buckling stresses, F_{he} , over length L_F , where F_{he} is determined from para. 1-7.13.4(c), ksi
- FS = stress reduction factor or design factor
- F_y = yield strength of material at design metal temperature from applicable table in Subpart 1 of Section II, Part D, ksi
- h_1 = the full width of a flat bar stiffener or out-standing leg of an angle stiffener or one-half of the full width of the flange of a tee stiffener, in.
- h_2 = the full depth of a tee section or full width of an angle leg, in.
- I = moment of inertia of full cross section
= $\pi R^3 t$, in.⁴
- I_F = moment of inertia of large ring that acts as a bulkhead about its centroidal axis, in.⁴
- I_s = moment of inertia of ring stiffener about its centroidal axis, in.⁴
- I'_s = moment of inertia of ring stiffener plus effective length of shell about centroidal axis of combined section, in.⁴
= $I_s + A_s Z_s^2 [L_e t / (A_s + L_e t)] + L_e t^3 / 12$
- $L, L_1, L_2, L_3, L...$ = design length of unstiffened vessel section between lines of support, in. A line of support is
(a) a circumferential line on a head (excluding conical heads) at one-third the depth of the head from the head tangent line as shown in Fig. 1-7.13.1-1
(b) a stiffening ring that meets the requirements for I'_s in para. 1-7.13.4(d)
- $L_B, L_{B1}, L_{B2}, L_{B...}$ = length of cylinder between bulkheads or large rings designed to act as bulkheads, in.
- L_c = chord length of template used to measure deviation from nominal circularity, in.
- L_e = effective length of shell, in. (see Fig. 1-7.13.1-3). For small ring, $L_e = 1.1(D_o t)^{1/2}$. For large ring acting as a bulkhead, $L_e = 1.1(D_o t)^{1/2}(A_1/A_2)$.
- L_F = one-half of the sum of the distances, L_B , from the centerline of a large ring to the next large ring or head line of support on either side of the large ring, in. (see Fig. 1-7.13.1-1)
- L_s = one-half of the sum of the distances from the centerline of a stiffening ring to the next line of support on either side of the ring, measured parallel to the axis of the cylinder, in. A line of support is described in the definition for L (see Fig. 1-7.13.1-1), in.
- L_t = overall length of vessel as shown in Fig. 1-7.13.1-1, in.
- L_x = gauge length measured along meridian of cylinder, in.
- $M_L = L_F / \sqrt{R_o t}$
- $M_x = L / \sqrt{R_o t}$
- P = external design pressure, ksi
- P_a = allowable external pressure in the absence of other loads, ksi
- PT = external test pressure, equal to $1.25P$, ksi
- R = radius to centerline of shell, in.

- R_c = radius to centroid of combined ring stiffener and effective length of shell, in.
 $= R + Z_c$
 R_o = radius to outside of shell, in.
 t = thickness of shell, less corrosion allowance, in.
 t_1 = thickness of the bar, leg of angle, or flange of tee of stiffener, in.
 t_2 = thickness of the web or angle leg of stiffener, in.
 Z_c = radial distance from centerline of shell to centroid of combined section of ring and effective length of shell, in.
 $= A_s Z_s / (A_s + L_e t)$
 Z_s = radial distance from centerline of shell to centroid of ring stiffener (positive for outside rings), in.

1-7.13.3 Materials

(a) *Allowable Materials.* Pressure vessels subjected to external pressure may be fabricated from steel materials, with exceptions as noted, listed in Tables UCS-23, UHA-23, and UHT-23 of Section VIII, Division 1 or Tables 3.A.1 through 3.A.3 of Section VIII, Division 2 of the Code. Materials not acceptable for use for pressure parts are identified in subsection 1-6. General requirements for materials are listed in subsection 1-6.

(b) *Postweld Heat Treat Requirements.* The fabricated vessel shall be postweld heat treated (PWHT) in accordance with the requirements of Section VIII, Parts UCS, UHA, and UHT for a Division 1 design or paras. 6.4 and 6.6 of the Code for a Division 2 design. In addition, spherical shells and spherical segment heads shall be PWHT regardless of thickness. The PWHT shall be done prior to the external pressure test.

(16) 1-7.13.4 Stiffened and Unstiffened Cylinders

(a) *Limitations.* For PVHOs not conforming to the following limitations, the external pressure design shall be as required by the specified Division of Section VIII of the Code.

(1) The minimum outside diameter to thickness ratio (D_o/t) is restricted to 1,000.

(2) The maximum shell thickness, including corrosion allowance, shall not exceed 2 in. (50 mm).

(3) The minimum shell thickness, excluding corrosion allowance, shall not be less than $\frac{3}{8}$ in. (10 mm).

(b) *Stress Reduction Factors.* The allowable stress is determined by applying a stress reduction factor, FS , to the predicted elastic buckling stress (F_{ic}). The required values of FS are 2.0 when the buckling stress is elastic and $\frac{5}{3}$ when the buckling stress equals yield stress at design temperature. A linear variation is used between these limits. The equations for FS are as follows:

$$\begin{aligned}
 FS &= 2.0 \text{ if } F_{ic} \leq 0.55 F_y \\
 &= 2.407 - 0.741 F_{ic}/F_y \text{ if } 0.55 F_y < F_{ic} < F_y \\
 &= 1.667 \text{ if } F_{ic} \geq F_y
 \end{aligned}$$

Note that F_{ic} is the predicted buckling stress that is calculated using $FS = 1$ in the allowable stress equations in para. (c) below.

(c) *Allowable Stress and External Pressure for Cylindrical Shells.* The allowable external pressure in the absence of other loads (P_a) calculated using these rules shall be greater than or equal to the external design pressure (P), i.e., $P_a \geq P$.

The allowable external pressure for stiffened and unstiffened cylindrical shells is given by the following equations:

$$P_a = \text{minimum of } P_1 \text{ and } P_2$$

where

$$\begin{aligned}
 P_1 &= 2F_{ha}(t/D_o) \\
 P_2 &= 1.067F_y(t/D_o)
 \end{aligned}$$

The allowable external pressure is based upon a circumferential compressive stress that is the lesser of F_{ha} and $\frac{2}{3}F_y$ at hydrostatic test pressure of 1.25P

where

$$\begin{aligned}
 F_{ha} &= F_y/FS \text{ if } F_{he}/F_y \geq 2.439 \\
 &= (0.7 F_y/FS) (F_{he}/F_y)^{0.4} \text{ if } 0.552 < F_{he}/F_y < 2.439 \\
 &= F_{he}/FS \text{ if } F_{he}/F_y \leq 0.552
 \end{aligned}$$

and where

$$\begin{aligned}
 C_h &= 0.55(t/D_o) \text{ if } M_x \geq 2(D_o/t)^{0.94} \\
 &= 1.12 M_x^{-1.058} \text{ if } 13 < M_x < 2(D_o/t)^{0.94} \\
 &= 0.92 / (M_x - 0.579) \text{ if } 1.5 < M_x \leq 13 \\
 &= 1.0 \text{ if } M_x \leq 1.5 \\
 F_{he} &= 1.6C_h E(t/D_o)
 \end{aligned}$$

(d) *Sizing of Stiffener Rings*

(1) *Small Rings*

$$I_s' \geq 1.5F_{he} L_s R_c^2 t / E(n^2 - 1)$$

where F_{he} is stress determined from para. (c) above with $M_x = M_s$

$$n^2 = 2D_o^{3/2} / 3L_B t^{1/2}$$

Use $n = 2$ for $n^2 < 4$ and $n = 10$ for $n^2 > 100$.

(2) *Large Ring Acting as a Bulkhead*

$$I_s' \geq F_{hef} L_F R_c^2 t / 2E$$

where F_{hef} is F_{he} , which is the stress determined from para. (c) above with $M_x = M_L$. The terms I_s , A_s , and Z_s in the equation for I_s' are those associated with the large ring geometry, such as I_F and A_F .

(3) *Stiffener Geometry Requirements.* Stiffener geometry requirements are as follows. See Fig. 1-7.13.1-2 for stiffener geometry and definition of terms.

(-a) Flat bar stiffener, flange of a tee stiffener, and outstanding leg of an angle stiffener

$$h_1/t_1 \leq 0.375 (E/F_y)^{1/2}$$

(-b) Web of a tee stiffener or leg of an angle stiffener attached to the shell

$$h_2 / t_2 \leq 1.0 (E/F_y)^{1/2}$$

(e) *Tolerances for Cylindrical Shells Subjected to External Pressure.* Cylindrical shells shall meet the tolerances as specified herein. These tolerance requirements replace some portions of those specified in para. UG-80(b) or para. 4.4.4 of the Code. In place of the maximum deviation requirements specified in UG-80(b)(2) or para. 4.4.4.1(b) of the Code, the following requirements apply:

(1) The maximum plus or minus deviation from a true circular form, e , shall not exceed the value given by the following equation:

$$e = 0.0165t (M_x + 3.25)^{1.069}$$

Note that e need not be less than $0.2t$ and shall not exceed the lesser of $0.0242R$ or $2t$.

(2) Measurements to determine e shall be made from a segmental circular template having the design outside radius and placed on the outside of the shell. The chord length, L_c , is given by the following equation:

$$L_c = 2R \sin (\pi/2n)$$

where

$$\begin{aligned} n &= c [\sqrt{(R/t)} / (L/R)]^d \\ c &= 2.28(R/t)^{0.54} \leq 2.80 \\ d &= 0.38(R/t)^{0.044} \leq 0.485 \end{aligned}$$

and

$$2 \leq n \leq 1.41 \sqrt{(R/t)}$$

(3) All requirements of UG-80(a) or para. 4.3.2.1 of the Code are applicable. The requirements of UG-80(b)(3), (6) through (8), and (10) or paras. 4.4.4.1(c) and (e) through (h) of the Code remain applicable.

(4) The local deviation from a straight line, e_x , measured along a meridian over a gauge length, L_x , shall not exceed the maximum permissible deviation, e_x , given below.

$$\begin{aligned} e_x &= 0.002R \\ L_x &= 4\sqrt{(Rt)} \text{ but not greater than } L \text{ for cylinders} \\ &= 25t \text{ across circumferential welds} \end{aligned}$$

$L_x < 95\%$ of the meridional distance between circumferential welds

1-7.13.5 Minimum Required Thickness for Unstiffened Spheres and Formed Heads

(a) *Limitations.* The allowable pressure for spheres and spherical segments is derived using the following iterative procedure. This procedure applies to spheres and hemispherical formed heads directly.

An adjustment is made for 2:1 ellipsoidal heads. These rules do not apply to other shaped ellipsoidal or to torispherical heads. For PVHOs not conforming to these and the following limitations, the external pressure design shall be as required by the specified Division of Section VIII of the Code.

(1) The maximum outside radius, R_o , shall not exceed 60 in. (1 500 mm).

(2) The maximum shell thickness, including corrosion allowance, shall not exceed 2 in. (50 mm).

(3) The minimum shell thickness, excluding corrosion allowance, shall not be less than $\frac{3}{8}$ in. (10 mm).

(b) *2:1 Ellipsoidal Heads.* For 2:1 ellipsoidal heads, use the procedure specified in para. (c) below using

$$R_o = 0.9D_o$$

(c) *Minimum Thickness.* The minimum required thickness for the spherical shell or formed head exclusive of corrosion allowance shall be determined by the following procedure:

Step 1: Calculate the value of C from the following two equations:

$$C = \text{the larger of } C_1 \text{ or } C_2$$

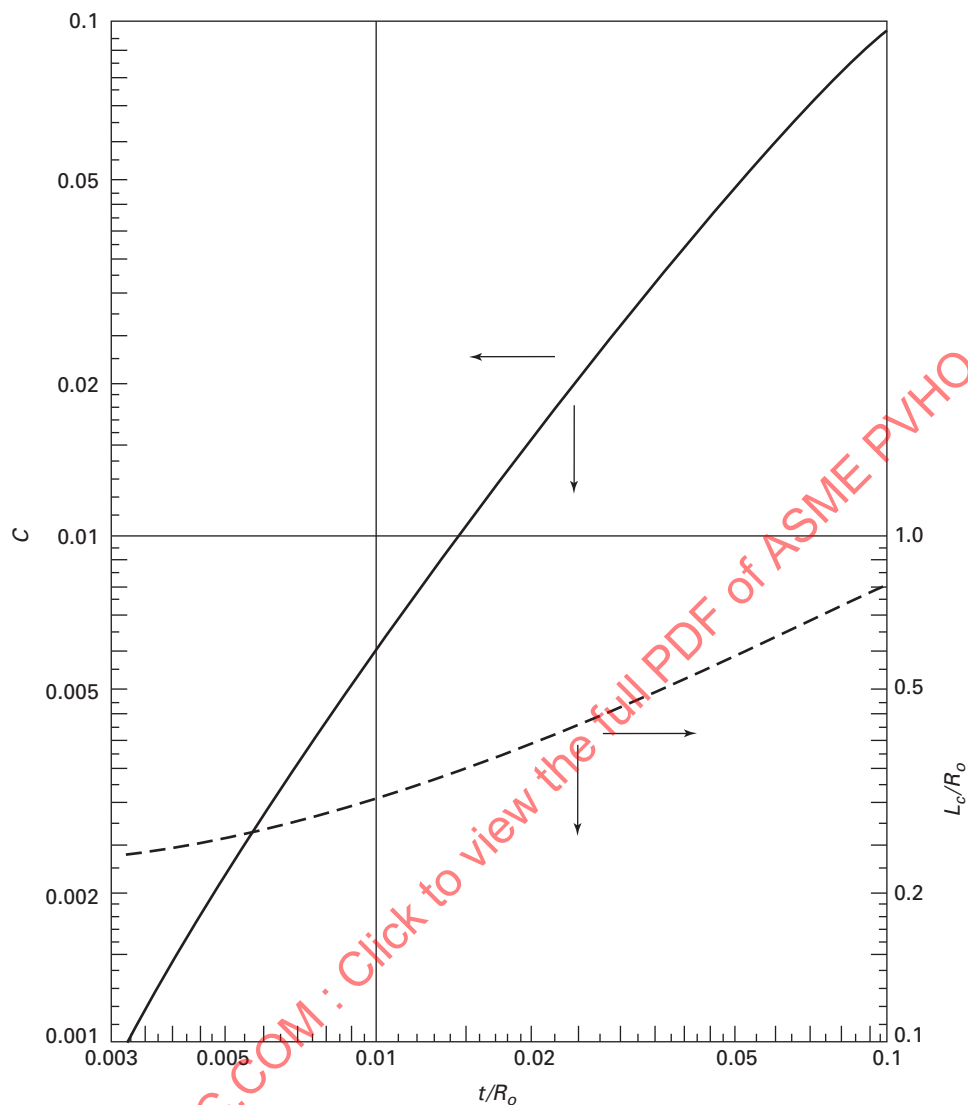
$$C_1 = \frac{0.75PT}{F_y}$$

$$C_2 = \sqrt{\frac{1.79PT}{E}}$$

Step 2: Enter the left ordinate of Fig. 1-7.13.5-1 with the value of C calculated in Step 1. Move horizontally to an intersection with the solid curve. Extrapolation beyond the upper or lower limit of the curve is prohibited. When values of C fall outside the limits of Fig. 1-7.13.5-1, the design shall follow the rules of Section VIII, UG-28(d) for Division 1 or para. 4.4.7 of the Code for Division 2.

Step 3: From the intersection obtained in Step 2, move vertically down and read the required minimum ratio of thickness to outside radius, t/R_o . This required minimum ratio applies to the spherical shell for the chosen material yield strength, elastic modulus, and test pressure.

Step 4: Determine the minimum required thickness, t , for the given outside radius, R_o . The value of t shall be neither less than $\frac{3}{8}$ in. (10 mm)

Fig. 1-7.13.5-1 Values of t/R_o and L_c/R_o 

nor greater than 2 in. (50 mm). If the maximum thickness of the spherical shell including corrosion allowance exceeds 2 in. (50 mm), the rules of Section VIII, UG-28(d) (Division 1) or para. 4.4 of the Code (Division 2) shall apply.

(d) Tolerances for Spherical Shells and Spherical Segments Subjected to External Pressure

(1) *Out-of-Roundness.* The difference between the maximum and minimum inside diameters at any cross section shall not exceed 1% of the nominal inside diameter at the cross section under consideration. The diameters may be measured on the inside or outside of the sphere. If measured on the outside, the diameters shall be corrected for the plate thickness at the cross section under consideration. When the cross section passes through an opening, the permissible difference in the

inside diameters just given may be increased by 2% of the inside diameter of the opening.

(2) *Local Shell Tolerances.* The maximum plus or minus deviations from true spherical form, measured radially on the outside or inside of the vessel, shall not exceed 0.5% of the nominal outside radius of the spherical shell and shall not be abrupt. Measurements shall be made from a segmental template having the design inside or outside radius (depending on where the measurements are taken) and a chord length, L_c , equal to the arc length determined as follows:

Using the required minimum ratio of thickness to the outside radius, t/R_o obtained in Step 3, move vertically upward on Fig. 1-7.13.5-1 to the intersection of the dashed line. Move horizontally to the right from the dashed line and determine the ratio of critical arc length

to outside radius, L_c/R_o . The chord length, L_c , is obtained by multiplying this ratio by the outside radius, R_o .

(16) **1-7.13.6 Pressure Testing for Alternative Design Rules.** All vessels designed in accordance with section 1-7.13 shall be tested using the following methods:

(a) *Test Pressure.* The pressure vessel shall be subjected to an external hydrostatic pressure test that subjects every part of the vessel to an external pressure, PT , not less than $1.25P$ to be marked on the vessel. The test pressure shall be maintained for no less than 1 hr.

(b) *Post-Test Measurements.* Measurements for determining the deviations specified in paras. 1-7.13.4(e) and 1-7.13.5(d) shall be taken after the external pressure hydrostatic test.

Any deviations exceeding the limits of paras. 1-7.13.4(e) and 1-7.13.5(d) shall be corrected, and the external pressure test shall be repeated.

(c) *Strain Gauging.* As part of the hydrostatic test, strain gauges shall be applied to the pressure hull. Gauges shall be applied at hard spots, discontinuities, high-stress regions, and other locations deemed appropriate. Appropriate strain gauge types (single gauge or biaxial/triaxial strain gauge rosettes) shall be used at each location. A drawing(s) shall be created indicating the locations of the gauges on the pressure hull. At the conclusion of the test, a hydrostatic test report shall be created. This report shall include strain gauge locations, strain gauge type at each location, the criteria used to select the strain gauge locations, and the measured stress results. The test report shall also include a comparison of calculated and measured stresses, and an evaluation of any significant differences between these stresses. The strain gauge plan and copies of the test report shall be provided to the user and any authorities having jurisdiction.

1-7.14 Hatch Design

Hatches that do not use bolts for attachment may be designed in accordance with the requirements of Section VIII, Division 1, Mandatory Appendix 1-6(g) of the Code with the following conditions:

(a) The circular centerline of the spherically dished head shall pass through the centroid of the flange.

(b) The connection of the dished head to the flange shall include fillet(s) of radius not less than 10 mm.

(c) If an O-ring seal is specified, it shall be located at the mean radius of the flange.

(d) Hatch construction shall be from materials that meet ASME PVHO requirements.

(e) If the hatch is convex to pressure, the minimum thickness of the head shall be the greater of that determined in Division 1, Mandatory Appendix 1-6(g) of the Code and that calculated from para. 1-7.13 of this Standard.

1-7.15 Rectangular Door Design

(16)

If rectangular openings are employed in Section VIII, Division 1 or Division 2 construction, a detailed analysis of the interaction of the entire assembly (i.e., door, door frame, adjacent shell, and relative appurtenances) shall be performed to ensure the design is adequate for the intended application. For Division 2 vessels, the analysis shall be performed in accordance with Part 5 of the Code. For Division 1 vessels, see U-2(g).

1-7.16 Supports and Attachments

Consideration shall be given to the following:

(a) The design shall consider the external local forces transmitted to the PVHO.

(b) Only those materials permitted for shells may be used for welded lifting attachments, and the material shall be compatible with that of the shell.

1-8 PRESSURE RELIEF DEVICES

Unless otherwise specified, the following requirements shall be met for pressure relief devices installed on PVHOs.

(a) The applicable requirements of Section VIII, UG-125 through UG-136 (Division 1) or Part 9 of the Code (Division 2) shall be met.

(b) A quick-operating manual shutoff valve shall be installed between the PVHO and the pressure relief valve, and shall be normally sealed open with a frangible seal as permitted in Section VIII, UG-135(e) and Nonmandatory Appendix M of Division 1 and Annex 9.A of Division 2. The valve shall be readily accessible to the attendant monitoring the operation of the PVHO.

(c) Rupture disks shall not be used, except in series upstream of pressure relief valves to prevent gas leakage, and shall meet all other applicable requirements of the Code.

1-9 MARKING

(a) Each PVHO shall be marked with the following:

(1) designation of this Standard, PVHO-1

(2) name of the manufacturer of the pressure vessel, preceded by the words "Certified by"

(3) maximum allowable working pressure, psig (MPa gauge) (internal) and/or psig (MPa gauge) (external) at °F (°C) maximum and °F (°C) minimum

(4) manufacturer's serial number

(5) year built

(6) design criteria: PVHO-1-2016; Section(s) (e.g., 5, 6, or 7 as applicable)

(b) The marking described in para. 1-9(a) shall be on a nameplate substantially as shown in either Fig. 1-9-1 or Fig. 1-9-2, as applicable. It shall be of material suitable for the intended service and remain legible for the life of the vessel. Nameplates shall be located in a conspicuous place on the vessel.

Fig. 1-9-1 Form of Nameplate, U.S. Customary

PVHO-1	
Certified by	

(name of manufacturer)	
_____ psi internal	_____ psi external
(maximum allowable working pressures)	
_____ °F maximum	_____ °F minimum
(design temperature range)	
_____	_____
(manufacturer's serial no.)	(year built)

(design criteria)	

Fig. 1-9-2 Form of Nameplate, Metric

PVHO-1	
Certified by	

(name of manufacturer)	
_____ MPa internal	_____ MPa external
(maximum allowable working pressures)	
_____ °C maximum	_____ °C minimum
(design temperature range)	
_____	_____
(manufacturer's serial no.)	(year built)

(design criteria)	

(c) Nameplates shall have markings produced by casting, etching, embossing, debossing, stamping, or engraving, except that the "PVHO-1" lettering shall be stamped on the nameplate.

(1) The required marking on the nameplate shall be in characters not less than $\frac{5}{32}$ in. (4.0 mm) high, except the lettering "PVHO-1" shall not be less than $\frac{3}{8}$ in. (9.5 mm) high and shall be legible.

(2) Characters for metallic nameplates shall be either indented or raised at least 0.004 in. (0.10 mm).

(d) The nameplate may be marked before it is affixed to the vessel, in which case the manufacturer shall ensure that the nameplate with the correct marking has been applied to the proper vessel.

(e) The nameplate shall be permanently attached to the vessel or to a pad, bracket, or structure that is welded or soldered directly to the vessel. The nameplate shall be located within 30 in. (76 cm) of the vessel. Removal shall require willful destruction of the nameplate or its attachment system.

(f) In addition to the requirements of paras. (a) through (d) above, the applicable stamping requirement

of the specified division of Section VIII of the Code shall be met.

1-10 NONMETALLIC MATERIALS AND TOXICITY OFF-GAS TESTING

(a) All nonmetallic materials off-gas volatile substances that may be toxic. The rate of off-gassing increases with increasing temperature and decreases with increasing age of the material (e.g., plastics and paint).

(b) In PVHOs whose primary means of life support is by ventilation of the atmosphere and/or by mask supply from an external gas source, off-gassed volatiles are continuously removed and are normally not of consequence, such that the procedures in para. (d) below need not apply.

(c) In PVHOs where the primary means of life support is by addition of oxygen and removal of carbon dioxide (CO₂), off-gassed volatiles will accumulate. Thus, after fabrication and completion of all outfitting, the toxicity off-gas test procedures in para. (d) below are required of any such PVHO that has internal paint or contains nonmetallic materials (other than acrylic windows).

(d) Toxicity Off-Gas Testing Procedures

(1) Internally pressurized PVHOs should be pressurized to MAWP at least once and then thoroughly ventilated prior to doing the off-gas testing.

(2) Where the normal duration of PVHO occupation is less than 8 hr, the PVHO shall be sealed and maintained at maximum operating temperature for at least 8 hr, after which time atmospheric gas samples shall be obtained from inside the PVHO and analyzed. The off-gassing test shall be performed with all openings sealed and with the PVHO at 1 atm (nominal), regardless of MAWP. However, a slight pressurization of the PVHO (prior to closing or sealing) may be used to aid in obtaining gas samples.

(3) The gas sample shall be analyzed using appropriate gas chromatography/mass spectrometry (GC/MS) methods. The concentration level of volatile compounds shall not exceed the threshold limit values (TLVs) set forth in the current edition of *ACGIH Threshold Limit Values for Chemical Substances* or the OSHA permissible exposure limits (PELs) set forth in 29 CFR 1910.1000, as stipulated by the user. If any of those limits are exceeded, the PVHO shall be well ventilated with clean air, and the procedure shall be repeated until satisfactory results are obtained.

(4) The use of higher temperatures and/or longer durations to "bake out" sources of contaminants prior to testing is permitted. Care shall be taken not to exceed the design temperature of components including acrylic windows.

(5) Where normal durations of PVHO occupation exceed 8 hr, the previous procedures apply with the

Table 1-10-1 Conversion Factor, F_p (for PVHO Occupation Exceeding 8 hr)

Duration of Exposure	F_p
8 hr (or less)	1.0
12 hr	0.85
16 hr	0.75
24 hr	0.65
36 hr	0.56
48 hr	0.52
72 hr	0.46
7 days	0.37
14 days	0.32
30 days	0.28
60 days	0.26
90 days (or longer)	0.25

exception that the PVHO shall be sealed and maintained at maximum operating temperature for at least the maximum duration of exposure anticipated. The ACGIH TLVs (or OSHA PEL values) used for evaluation shall be modified by multiplying them by a value of F_p as shown in Table 1-10-1 (linear interpolation is permitted).

(6) Where normal durations of PVHO occupation exceed 24 hr, the duration of off-gas may be less, provided that the quantification and reporting limits are less than the allowable limits divided by the ratio of occupation duration divided by test duration. And the results obtained would then be extrapolated by multiplying by the same ratio of occupation duration divided by test duration. For example, in the case of "screening" [para. (10) below], if the anticipated occupation duration is 5 days, the off-gas duration may be limited to 24 hr, with the results multiplied by 5, provided that the quantification and reporting limits were less than 5 parts per million (ppm) (vs. 25 ppm allowed) for total hydrocarbons and 2 ppm (vs. 10 ppm allowed) for total halogens. However, if the extrapolated results (after multiplying by 5) exceeded 25 ppm and/or 10 ppm, respectively, then the quantity of gas sample for GC/MS analysis would need to be sufficient to provide quantification and reporting limits of 20 parts per billion (ppb) (vs. 0.1 ppm). And if that were not practical, then the time ratio used in the testing would need to be appropriately less.

(7) For PVHOs that use hydroxide absorbents (e.g., LiOH, soda lime) for the removal of carbon dioxide (CO_2), the concentrations of trichloroethylene, vinylidene chloride, methyl chloroform, and acetylene dichloride shall not exceed 0.1 ppm, regardless of their ACGIH TLV (or OSHA PEL) or duration of occupation, i.e., Table 1-10-1 does not apply to those four compounds.

(8) Where reactive compounds (e.g., ammonia, chlorine, hydrogen sulfide, sulfur dioxide) are anticipated, on-site testing for the presence of these compounds should be done using appropriate color-change

indicator tubes (e.g., Draeger, Gastec). Evaluation of the test results shall be in accordance with para. (3), (5), or (6) above, as applicable.

(9) Where potential sources of mercury vapor are anticipated, on-site testing for its presence should be done using either color-change indicator tubes with a sufficiently low detection limit or a gold-film-type analyzer. Evaluation of test results shall be in accordance with para. (3), (5), or (6), as applicable.

(10) If the total halogen concentration can be shown to be less than 10 ppm, and the total hydrocarbons (expressed as methane) can be shown to be less than 25 ppm, then the GC/MS analysis and evaluation need not be done. However, if either of those limits is exceeded, the GC/MS analysis and evaluation are required.

1-11 RISK ANALYSIS

The PVHO designer shall implement and document an established standard or procedure (such as a failure modes, effects, and criticality analysis or a safety hazards analysis) for evaluating and mitigating potential risks associated with the PVHO and associated systems. Potential hazards shall include both hardware failure and operator error. The risks identified shall be evaluated and mitigated to a level acceptable by the user or appropriate authority. Mitigation and protective measures may include design features that minimize the probability of occurrence, inspection and tests during and following fabrication, implementation of safety and/or warning devices, protective systems, and caution or warning procedures and labels. The risk analysis results shall be retained by the designer in accordance with para. 1-7.9.

Section 2 Viewports

2-1 GENERAL

2-1.1 Scope

Windows covered by this Standard include windows manufactured during original construction and windows used as replacements during the service life of the chamber.

The windows covered by this Standard are intended for use only in chambers with window service conditions defined by

- (a) maximum allowable working pressure, equal to design pressure
- (b) maximum temperature at design pressure, equal to design temperature
- (c) pressure cycles, at design pressure and temperature

2-1.2 Exclusions

The windows covered by this Standard are not intended for chambers where any of the following restrictions on design parameters are exceeded:

- (a) The operating temperature shall be within the 0°F to 150°F (−18°C to 66°C) range.
- (b) The pressurization or depressurization rate shall be less than 145 psi/sec (1 MPa/s).
- (c) The fluid (external or internal) shall be only water, seawater, air, or gases used in life-support systems.
- (d) The number of pressure cycles or the total duration of the operational life of the window shall not exceed 10,000 cycles or 40,000 hr, respectively.
- (e) The maximum operational pressure shall not exceed 20,000 psi (138 MPa).
- (f) The exposure to nuclear radiation shall not exceed 4 Mrad.
- (g) The design life of the windows shall not exceed the time limits specified in subsection 2-2.7.

2-1.3 Certification

Each window shall be individually identified by the window fabricator in accordance with para. 2-6.1.

2-1.3.1 Traceability. The window fabricator shall provide an overall window certification that shall certify that the window has been fabricated in accordance with all applicable requirements of the Standard (see PVHO-1 Form VP-1 for a representative certification form). The window certification shall provide traceability of the window throughout all processes associated with its manufacture.

2-1.3.2 Additional Requirements. In addition to the overall window certification, the following certifications shall be required for a window to be considered acceptable for use in chambers:

- (a) a design certification for each window and matching viewport assembly that shall include a summary of engineering calculations and/or a description of the experimental method and data used to verify compliance of the window design with the requirements of this Standard (see subsection 2-2 for design requirements).
- (b) a material manufacturer's certification for each lot of acrylic that shall certify that the material meets or exceeds the minimum values of physical properties specified in Table 2-3.4-1 for each lot and verify for each casting or lot (see subsection 2-3 for material certification requirements).
- (c) a material certification for each window shall certify that the material meets the minimum values specified in Table 2-3.4-2 and that these properties have been experimentally verified. Average values specified in Table 2-3.4-2 shall be reported (see subsection 2-3 for material certification requirements).
- (d) a pressure testing certification for each window that shall describe the pressure, temperature, pressurization rate, duration of sustained loading, and viewport flange or test fixture used during the pressure test (see subsection 2-7 for pressure testing requirements).

2-2 DESIGN

2-2.1 General

The manufacturer of the chamber shall be responsible for ensuring that the viewport design is adequate for the design conditions of the chamber. Particular attention shall be paid to design consideration of the window, including, but not limited to, the design pressure, the temperature at design pressure, and the cyclic life at design pressure.

2-2.2 Standard Window Geometry

2-2.2.1 Configuration. Acrylic windows in chambers must have one of the standard geometries shown in Figs. 2-2.2.1-1 through 2-2.2.1-4. Minimum acceptable thickness ratios shall comply with the requirements of Figs. 2-2.2.1-1 through 2-2.2.1-4 for the specific window geometry. (For acceptance of nonstandard window geometries, see para. 2-2.6.)

PVHO-1 Form VP-1 Fabrication Certification for Acrylic Windows

Window Drawing No. _____

Window Identification _____

Material Stock Description

Manufacturer of acrylic _____

Trade name _____

Casting shape _____ Nominal thickness _____

Lot number _____ Casting number _____

Certified for conformance to Table 2-3.4-1 by _____ Date _____

Certified for conformance to Table 2-3.4-2 by _____ Date _____

Window Description

Maximum allowable working pressure rating _____ psi _____ MPa

Maximum temperature rating _____ °F _____ °C

Window designed by _____

Joint bonding (if applicable) _____ (name of company and designer)

Manufacturer of acrylic cement _____

Trade name of cement _____

Curing means and duration _____

Average tensile strength (per ASTM D638) _____

Joint quality conforms to para. 2-3.10 (yes/no) _____

Polishing agents _____

Cleaning agent _____

Fabrication Process Data

First annealing temperature (if applicable) _____

Duration _____ Cooling rate _____

Intermediate annealing temperature (if applicable) _____

Duration _____ Cooling rate _____

Final annealing temperature (chart required) _____

Duration _____ Cooling rate _____

Dimensional checks

Actual outside diameter, D_o _____ Actual inside diameter, D_i _____Actual thickness, t_{max} and t_{min} _____ Actual included angle, α _____

Actual sphericity (maximum deviation from specified sphericity measured by a template on the concave or convex surface) _____

Conforms/deviates from specification for spot casting repairs _____

Window fabricator has tested windows _____ Yes _____ No

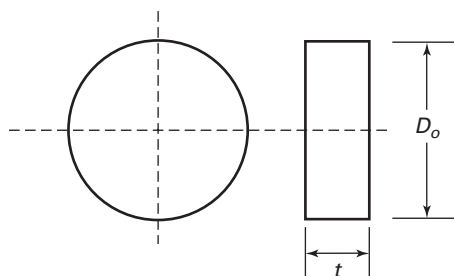
Window fabricator has completed PVHO-1 Form VP-5 _____ Yes _____ No

The window identified above has been fabricated in accordance with the material and fabrication requirements of the Safety Standard for Pressure Vessels for Human Occupancy, ASME PVHO-1-_____ Edition, and company _____ drawing number _____, revision _____, dated _____.

authorized representative of window fabricator_____
date_____
name and address of window fabricator

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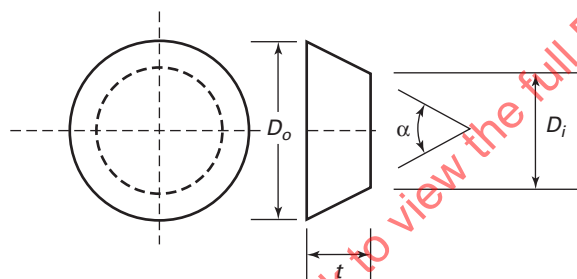
Fig. 2-2.2.1-1 Standard Window Geometries — Part 1



$$t \geq \frac{1}{2} \text{ in. (12.5 mm)}$$

$$t/D_o \geq 0.08$$

(a) Flat Disk Window

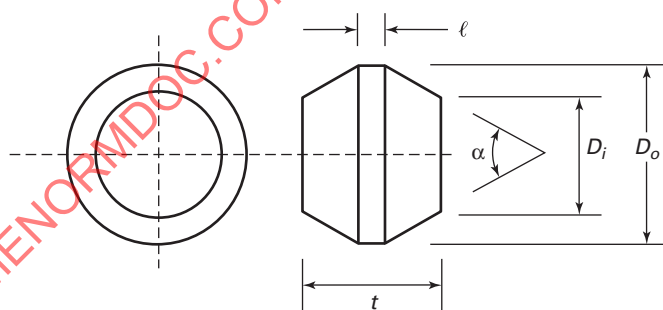


$$t \geq \frac{1}{2} \text{ in. (12.5 mm)}$$

$$t/D_i \geq 0.125$$

$$\alpha \geq 60 \text{ deg}$$

(b) Conical Frustum Window



$$t \geq \frac{1}{2} \text{ in. (12.5 mm)}$$

$$t/D_i \geq 0.250$$

$$\alpha \geq 60 \text{ deg}$$

$$\ell \leq 0.25t$$

(c) Double Beveled Disk Window

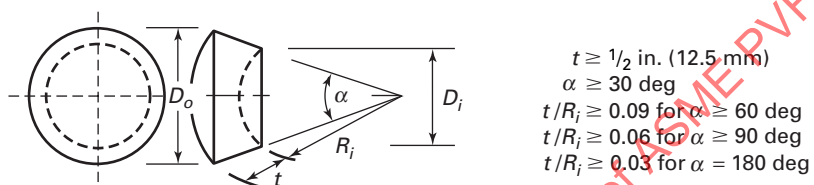
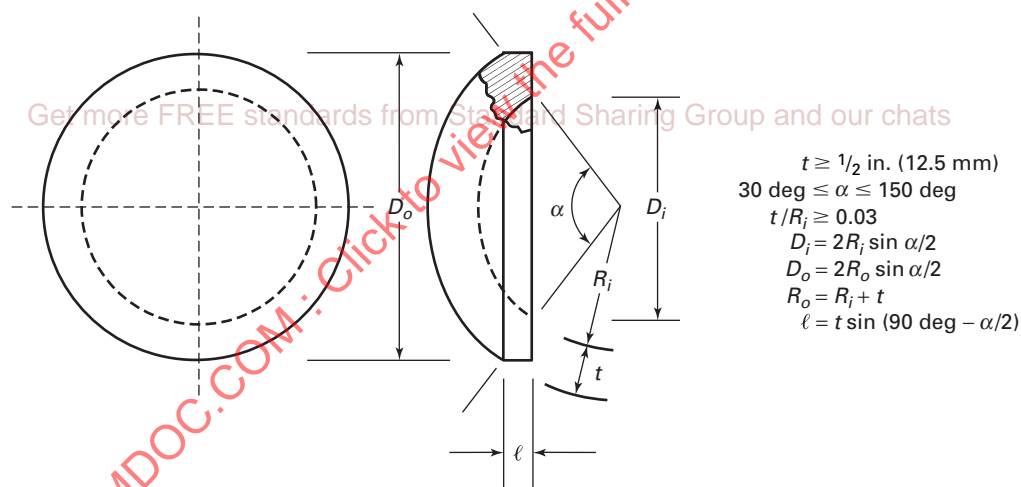
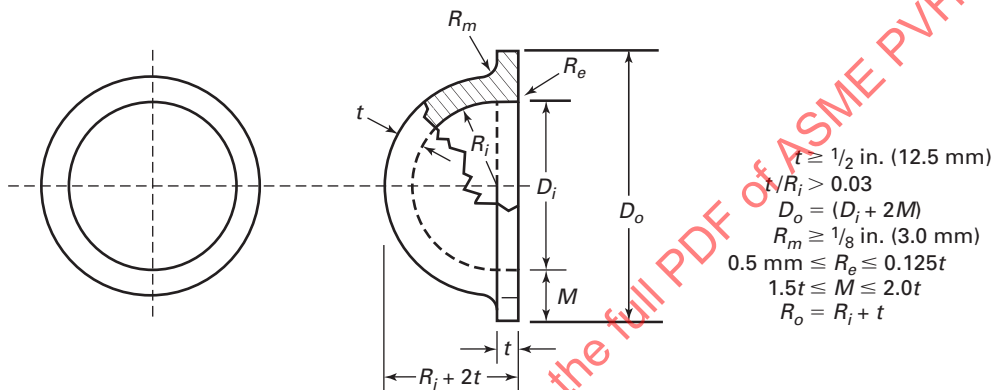
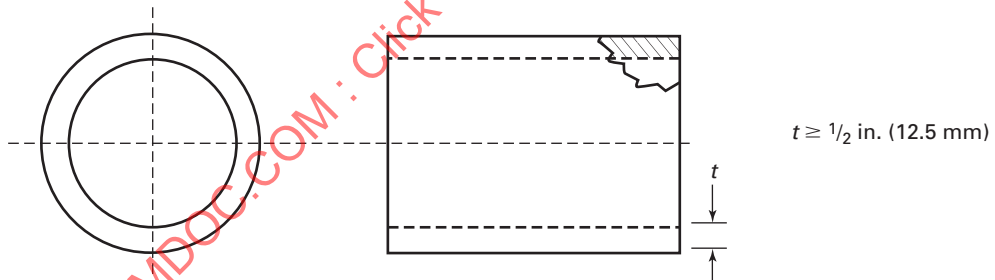
Fig. 2-2.2.1-2 Standard Window Geometries — Part 2**(a) Spherical Sector Window With Conical Edge****(b) Spherical Sector Window With Square Edge**

Fig. 2-2.2.1-3 Standard Window Geometries — Part 3

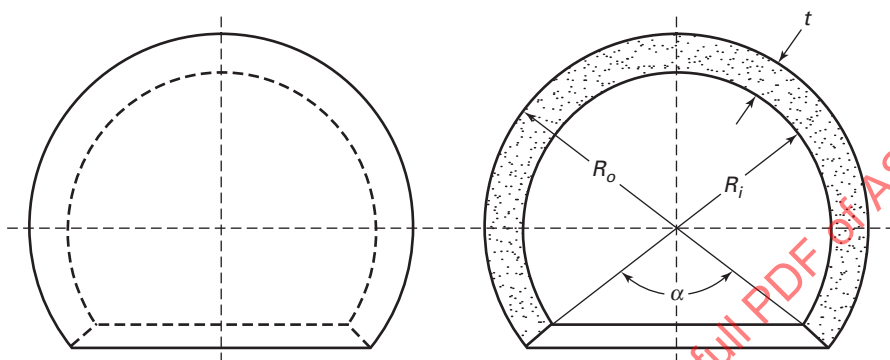


(a) Hemispherical Window With Equatorial Flange



(b) Cylindrical Window

Fig. 2-2.2.1-4 Standard Window Geometries — Part 4

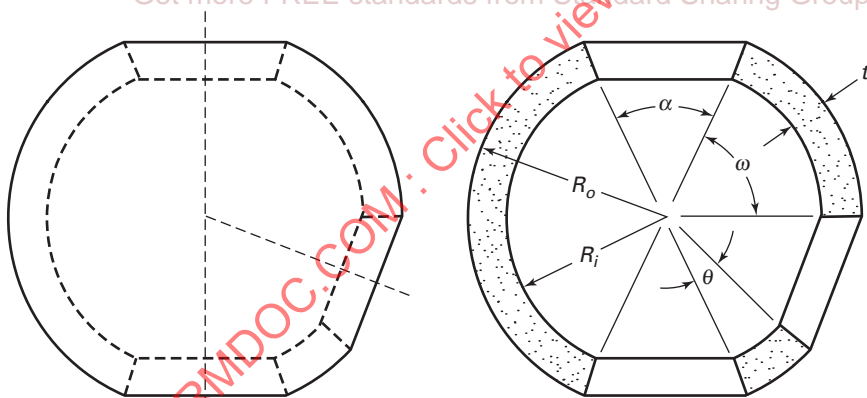


(a) Hyperhemispherical Window

$$t \geq \frac{1}{2} \text{ in. (12.5 mm)}$$

$$0.03 \leq t/R_o \leq 0.355$$

$$\alpha \leq 100 \text{ deg}$$



(b) NEMO Window

$$t \geq \frac{1}{2} \text{ in. (12.5 mm)}$$

$$0.03 \leq t/R_o \leq 0.355$$

$$\alpha \leq 50 \text{ deg}$$

$$\omega, \theta = \text{spacing between adjacent penetrations shall exceed } \alpha/2 \text{ of the larger penetrations}$$

2-2.2.2 Calculation. Calculations of the short-term critical pressure (STCP), on the basis of Figs. 2-2.2.1-1 through 2-2.2.1-4, satisfy the requirements of the design certification required by this Standard under para. 2-1.3.2(a).

2-2.2.3 Tests. It shall also be acceptable to establish the STCP by conducting a series of destructive tests on full-scale or model-scale windows performed in accordance with the procedure in para. 2-2.5.2.

2-2.3 Determination of Dimensions for Standard-Geometry Windows

2-2.3.1 0 psi to 10,000 psi. The dimensions of a standard window in the 0 psi to 10,000 psi (0 MPa to 69 MPa) design pressure range shall be based solely on the window's STCP and the approved conversion factor (CF) for the given maximum ambient temperature. Minimum STCP values of standard window geometries are given in Figs. 2-2.5.1-1 through 2-2.5.1-15. CF values for standard window geometries are given in Tables 2-2.3.1-1 through 2-2.3.1-5.

2-2.3.2 10,000 psi to 20,000 psi. The dimensions of windows in the 10,000 psi to 20,000 psi (69 MPa to 138 MPa) design pressure range shall be based solely on nondestructive tests in the form of long-term and cyclic pressurizations. Dimensions of approved windows for this design pressure range are given in Table 2-2.3.2-1. Only conical frustum windows with included angle of 90 deg or larger are qualified for this pressure range.

2-2.4 Determination of Conversion Factor by Table Method

- (16) **2-2.4.1 Temperature.** When selecting the conversion factors from Tables 2-2.3.1-1 through 2-2.3.1-5, temperature ranges shall be chosen on the basis of highest ambient sustained temperature expected during operation of the chamber at the design pressure.

(a) If the chamber interior is illuminated by externally mounted heat-generating lights shining through the windows, the 150°F (66°C) temperature range shall be mandatory in the selection of conversion factors for all windows.

(b) If the chamber is not illuminated with externally mounted lights, the temperature ranges shall be chosen on the basis of environmental temperature where the chambers reach design pressure. If the design pressure is reached when

- (1) only submerged in water, use the ambient temperature of water at that depth
- (2) only in air, use the average of the maximum ambient external and internal air temperatures
- (3) either in air or in water, use the average maximum ambient external and internal air temperatures

2-2.4.2 Pressure. When a viewport is subjected to pressurization from both sides, the conversion factor used for the window design shall be determined on the basis of the highest design pressure, regardless of whether this pressure is external or internal to the chamber.

2-2.4.3 Values of Conversion Factors. The values of CF in Tables 2-2.3.1-1 through 2-2.3.1-5, D_i/D_f in Figs. 2-2.10.1-1 and 2-2.10.1-2 and Table 2-2.3.2-1, and t/D_i in Table 2-2.3.2-1 represent minimums. The user of this Standard may exceed these values.

2-2.5 Determination of Short-Term Critical Pressure

2-2.5.1 Calculation Method. The STCP of a window accepted for service in chambers, without the use of experimental data, shall not be less than

$$\text{STCP} = \text{CF} \times P$$

where

CF = conversion factor

P = design pressure

Windows having included angles between those shown in Figs. 2-2.5.1-4 through 2-2.5.1-7 are to have a t/D_i equal to that determined for a window of the next smaller included angle as shown in the appropriate figure. (For example, a spherical sector window having an included angle of 100 deg and requiring an STCP in the 5 MPa to 50 MPa range would be designed using the 90-deg curve in Fig. 2-2.5.1-6.)

(a) For flat disk acrylic windows, shown in Fig. 2-2.2.1-1, use conversion factors from Table 2-2.3.1-1 and STCPs from Figs. 2-2.5.1-1 through 2-2.5.1-3. Short-term critical pressures may also be experimentally determined according to the procedure in para. 2-2.5.2.

(b) For conical frustum acrylic windows, shown in Fig. 2-2.2.1-1, use CFs from Table 2-2.3.1-2 and STCPs from Figs. 2-2.5.1-4 and 2-2.5.1-5. Short-term critical pressures may also be experimentally determined according to the procedure in para. 2-2.5.2. Windows of this type are accepted for service only where the pressure is applied to the base of the frustum.

(c) For double beveled disk acrylic windows, shown in Fig. 2-2.2.1-1, use CFs from Table 2-2.3.1-2 and STCPs from Figs. 2-2.5.1-4 and 2-2.5.1-5. Short-term critical pressures may also be experimentally determined according to the procedure in para. 2-2.5.2.

(d) For spherical sector acrylic windows with conical edge, shown in Fig. 2-2.2.1-2, use CFs from Table 2-2.3.1-3 and STCPs from Figs. 2-2.5.1-6 and 2-2.5.1-7. Short-term critical pressures may also be experimentally determined according to the procedure in para. 2-2.5.2. Windows of this type are accepted for service only where the hydrostatic pressure is applied to the convex face.

Table 2-2.3.1-1 Conversion Factors for Acrylic Flat Disk Windows

Operational Pressure Ranges	Temperature, °F (°C)				
	50 (10)	75 (24)	100 (38)	125 (52)	150 (66)
$N = 1$ 2,500 psi (17.2 MPa)	CF = 5	CF = 6	CF = 8	CF = 10	CF = 16
$N = 2$ 5,000 psi (34.5 MPa)	CF = 5	CF = 6	CF = 8	CF = 10	4,000 psi (27.6 MPa)
$N = 3$ 7,500 psi (51.7 MPa)	CF = 5	CF = 6	7,000 psi (48.3 MPa)		

GENERAL NOTES:

- (a) The conversion factors (CF) in this table apply only to short-term critical pressures (STCP) plotted in Figs. 2-2.5.1-1 through 2-2.5.1-3.
 (b) Dotted lines refer to intermediate pressure ranges as indicated by the adjacent pressure figures.
 (c) Interpolation between CFs is allowed.

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Table 2-2.3.1-2 Conversion Factors for Acrylic Conical Frustum Windows and Double Beveled Disk Windows

Operational Pressure Ranges	Temperature, °F (°C)				
	50 (10)	75 (24)	100 (38)	125 (52)	150 (66)
$N = 1$ 2,500 psi (17.2 MPa)	CF = 5	CF = 6	CF = 8	CF = 10	CF = 16
$N = 2$ 5,000 psi (34.5 MPa)	CF = 4	CF = 5	CF = 7	CF = 9	4,500 psi (31 MPa)
$N = 3$ 7,500 psi (51.7 MPa)	CF = 4	CF = 5			
$N = 4$ 10,000 psi (69 MPa)	CF = 4	CF = 5	8,000 psi (55.2 MPa)		

GENERAL NOTES:

- (a) The CFs in this table apply only to STCPs plotted in Figs. 2-2.5.1-4 and 2-2.5.1-5.
 (b) Dotted lines refer to intermediate pressure ranges as indicated by the adjacent pressure figures.
 (c) Interpolation between CFs is allowed.

Table 2-2.3.1-3 Conversion Factors for Acrylic Spherical Sector Windows With Conical Edge, Hyperhemispherical Windows With Conical Edge, and NEMO-Type Windows With Conical Edge

Operational Pressure Ranges	Temperature, °F (°C)				
	50 (10)	75 (24)	100 (38)	125 (52)	150 (66)
$N = 1$ 2,500 psi (17.2 MPa)	CF = 4	CF = 6	CF = 8	CF = 10	CF = 16 1,500 psi (10.3 MPa)
$N = 2$ 5,000 psi (34.5 MPa)	CF = 4	CF = 6	CF = 8	CF = 10 3,500 psi (24.1 MPa)	3,000 psi (20.7 MPa)
$N = 3$ 7,500 psi (51.7 MPa)	CF = 4				

GENERAL NOTES:

- (a) The CFs in this table apply only to STCPs plotted in Figs. 2-2.5.1-6 and 2-2.5.1-7 for spherical sector windows with conical edge and Figs. 2-2.5.1-14 and 2-2.5.1-15 for hyperhemispherical windows with conical edge and NEMO-type windows with conical penetrations.
- (b) Dotted lines refer to intermediate pressure ranges as indicated by the adjacent pressure figures.
- (c) Interpolation between CFs is allowed.

Table 2-2.3.1-4 Conversion Factors for Acrylic Spherical Sector Windows With Square Edge and Hemispherical Windows With Equatorial Flange

Operational Pressure Ranges	Temperature, °F (°C)				
	50 (10)	75 (24)	100 (38)	125 (52)	150 (66)
$N = 1$ 2,500 psi (17.2 MPa)	CF = 5	CF = 7	CF = 9	CF = 11	CF = 17 1,500 psi (10.3 MPa)
$N = 2$ 5,000 psi (34.5 MPa)	CF = 5	CF = 7	CF = 9	3,000 psi (20.6 MPa)	
$N = 3$ 7,500 psi (51.7 MPa)	CF = 5				

GENERAL NOTES:

- (a) The CFs in this table apply only to STCPs plotted in Figs. 2-2.5.1-6 and 2-2.5.1-7.
- (b) Dotted lines refer to intermediate pressure ranges as indicated by the adjacent pressure figures.
- (c) Interpolation between CFs is allowed.

Table 2-2.3.1-5 Conversion Factors for Acrylic Cylindrical Windows**Part A: Internal Pressure**

Operational Pressure Ranges	Temperature, °F (°C)				
	50 (10)	75 (24)	100 (38)	125 (52)	150 (66)
$N = 1$ 250 psi (1.7 MPa)	CF = 13	CF = 14	CF = 15	CF = 20	CF = 25

Part B: External Pressure

Operational Pressure Ranges	Temperature, °F (°C)				
	50 (10)	75 (24)	100 (38)	125 (52)	150 (66)
$N = 1$ 2,500 psi (17.2 MPa)	CF = 6	CF = 7	CF = 9	CF = 11	CF = 17

GENERAL NOTES:

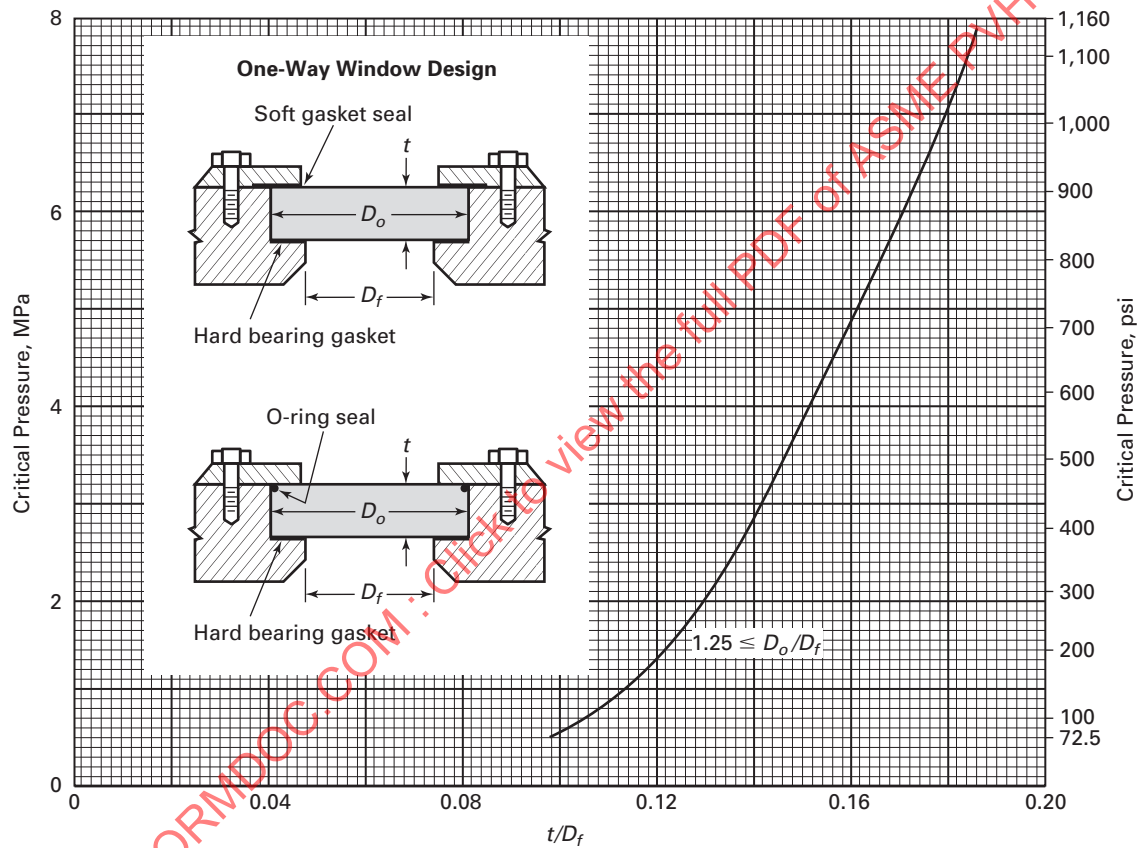
- (a) The CFs in Part A of this table apply only to STCPs plotted in Figs. 2-2.5.1-8 and 2-2.5.1-9.
- (b) The CFs in Part B of this table apply only to STCPs plotted in Figs. 2-2.5.1-10 through 2-2.5.1-13. Since the tube may fail due to yielding of material (Fig. 2-2.5.1-8) or elastic buckling (Figs. 2-2.5.1-9 through 2-2.5.1-11), both modes of failure shall be considered in selection of t/D_i ratio. The mode of failure that is chosen as the design criterion depends on which of the failure modes requires a higher t/D_i ratio for the desired STCPs. The mode of failure requiring a higher t/D_i ratio is chosen as the design criterion.
- (c) Interpolation between CFs is allowed.

Table 2-2.3.2-1 Conical Frustum Windows for Design Pressures in Excess of 10,000 psi (69 MPa)

Design Pressure		Temperature Ranges									
		$\leq 50^\circ\text{F} (10^\circ\text{C})$					$\leq 75^\circ\text{F} (24^\circ\text{C})$				
		D_i/D_f					D_i/D_f				
psi	MPa	t/D_i	60 deg	90 deg	120 deg	150 deg	t/D_i	60 deg	90 deg	120 deg	150 deg
11,000	75.86	1.0	1.13	1.17	1.23	1.69	1.1	1.13	1.17	1.23	1.69
12,000	82.76	1.1					1.2				
13,000	89.66	1.2					1.3				
14,000	96.55	1.3					1.4				
15,000	103.45	1.4					1.5				
16,000	110.34	1.5	1.20	1.26	1.53	2.48	1.6	1.20	1.26	1.53	2.48
17,000	117.24	1.6					1.7				
18,000	124.14	1.7					1.8				
19,000	131.03	1.8					1.9				
20,000	137.93	1.9					2.0				

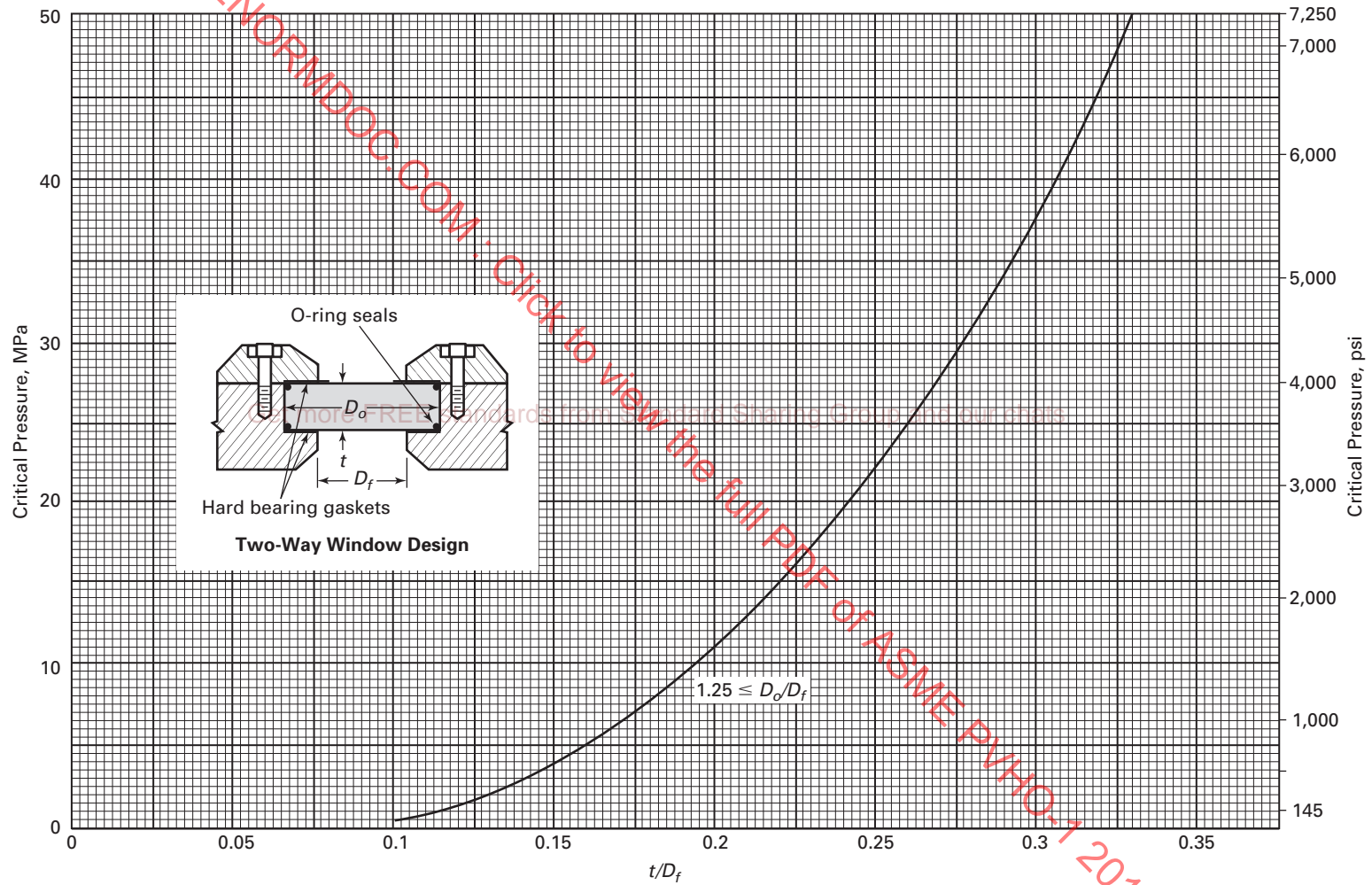
GENERAL NOTE: D_i/D_f ratio refers to the conical frustum seat specification shown in Fig. 2-2.10.1-1.

(16)

Fig. 2-2.5.1-1 Short-Term Critical Pressure of Flat Disk Acrylic Windows — Part 1

(16)

Fig. 2-2.5.1-2 Short-Term Critical Pressure of Flat Disk Acrylic Windows — Part 2



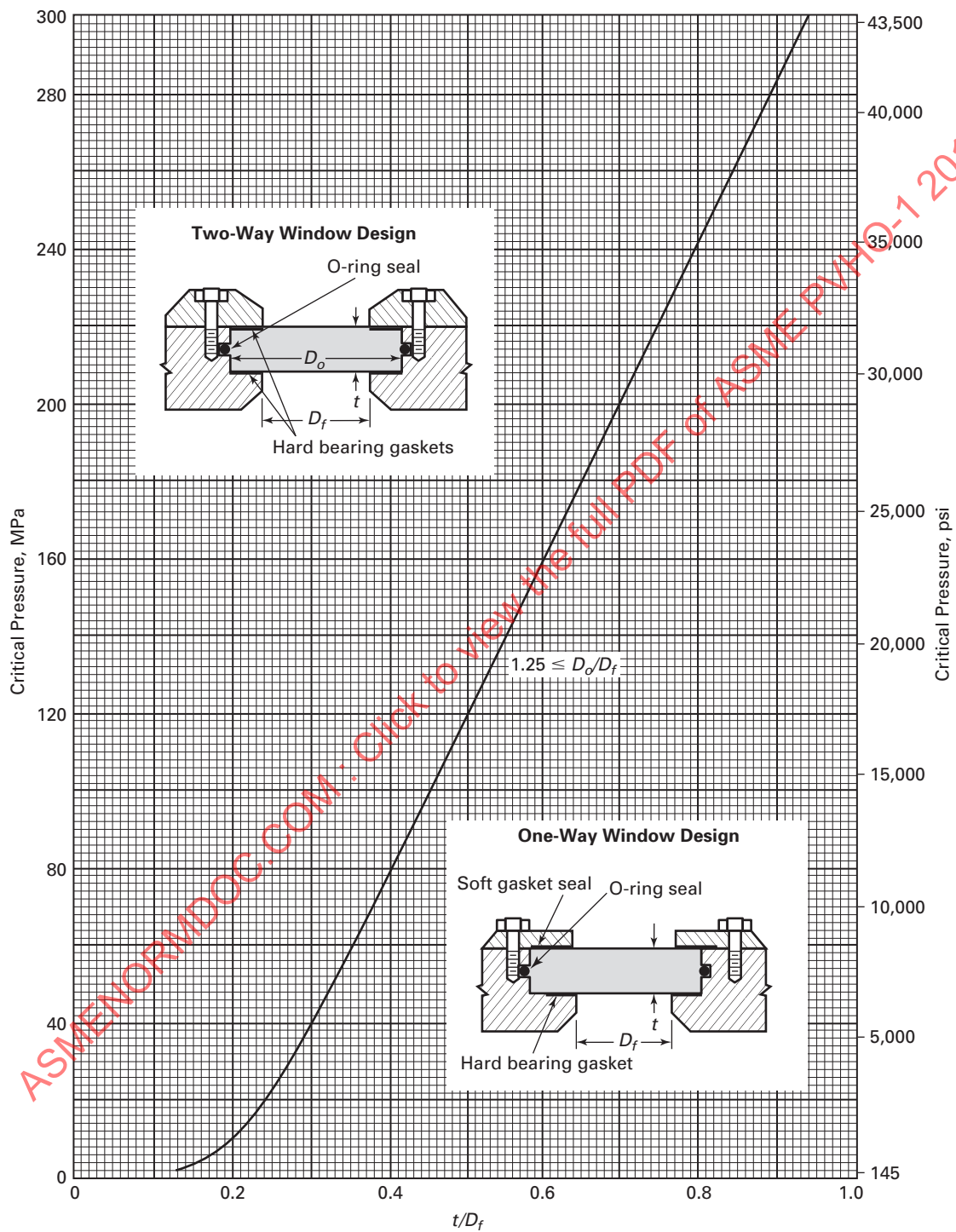
(16) **Fig. 2-2.5.1-3 Short-Term Critical Pressure of Flat Disk Acrylic Windows — Part 3**

Fig. 2-2.5.1-4 Short-Term Critical Pressure of Conical Frustum Acrylic Windows — Part 1

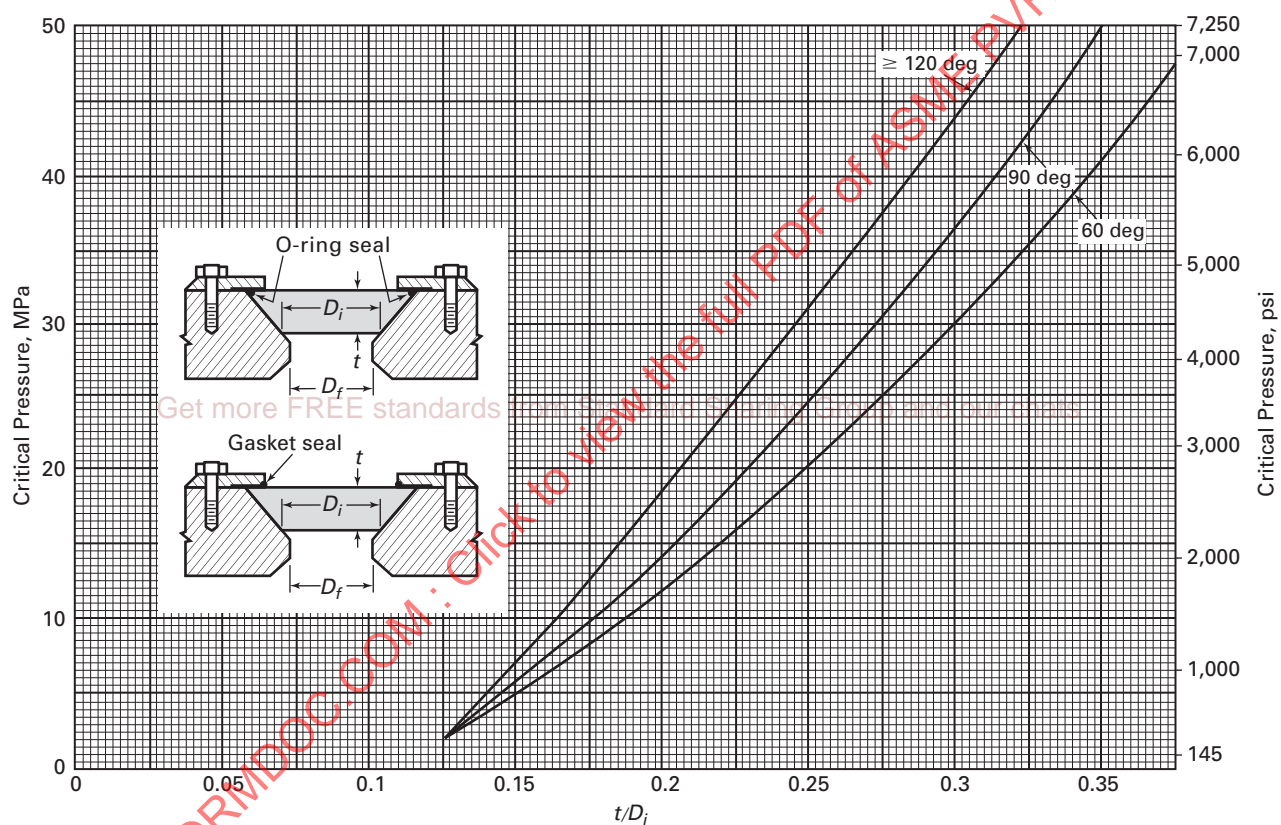


Fig. 2-2.5.1-5 Short-Term Critical Pressure of Conical Frustum Acrylic Windows — Part 2

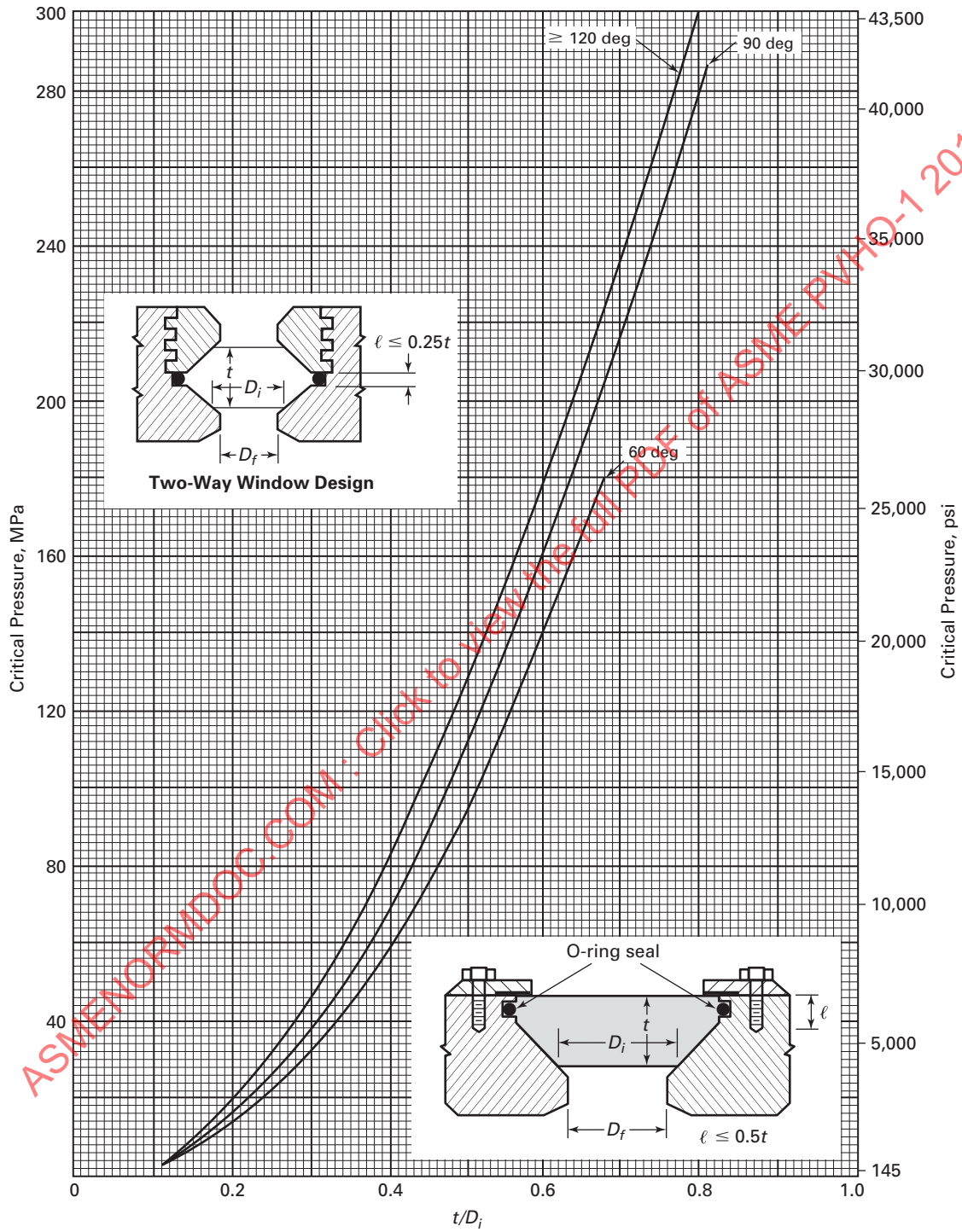


Fig. 2-2.5.1-6 Short-Term Critical Pressure of Spherical Sector Acrylic Windows — Part 1

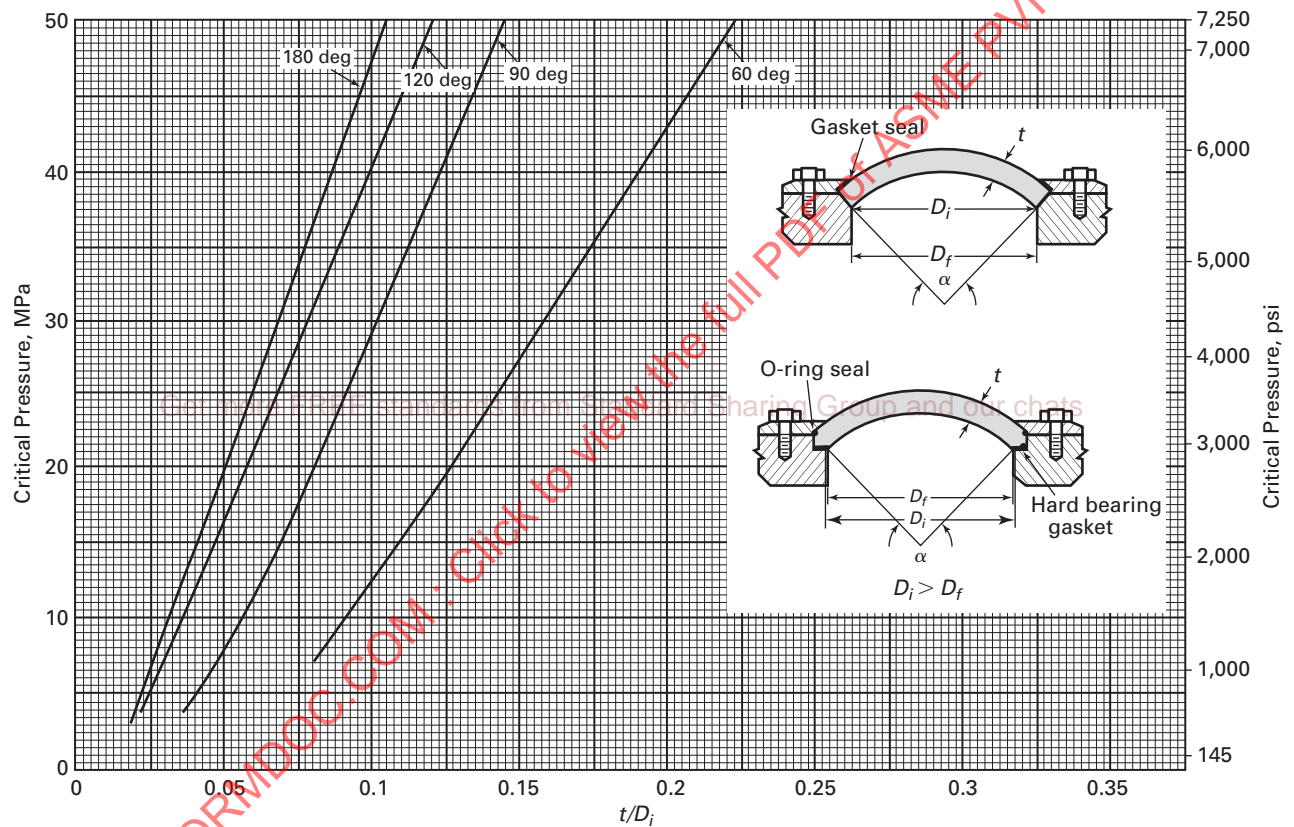
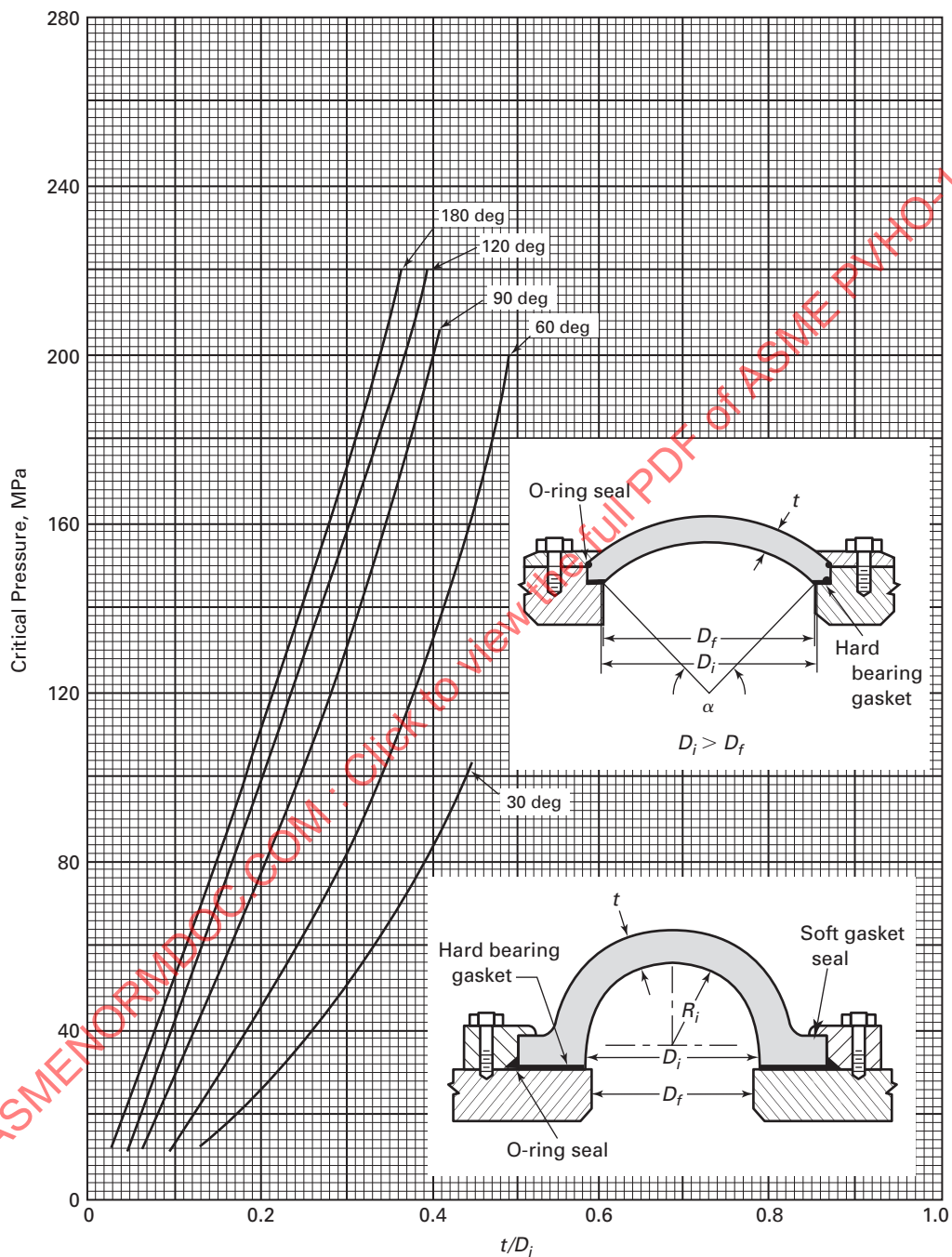


Fig. 2-2.5.1-7 Short-Term Critical Pressure of Spherical Sector Acrylic Windows — Part 2



(e) For spherical sector acrylic windows with square edge, shown in Fig. 2-2.2.1-2, use CFs from Table 2-2.3.1-4 and STCPs from Figs. 2-2.5.1-6 and 2-2.5.1-7. Short-term critical pressures may also be experimentally determined according to the procedure in para. 2-2.5.2. Windows of this type are accepted for service only where the hydrostatic pressure is applied to the convex surface.

(f) For hemispherical windows with equatorial flange, shown in Fig. 2-2.2.1-3, use CFs from Table 2-2.3.1-4 and STCPs from Figs. 2-2.5.1-6 and 2-2.5.1-7. Short-term critical pressures may also be experimentally determined according to the procedure in para. 2-2.5.2. Windows of this type are accepted for service only where the hydrostatic pressure is applied to the convex surface.

(g) For cylindrical acrylic windows, shown in Fig. 2-2.2.1-3, use CFs from Table 2-2.3.1-5 and STCPs from Figs. 2-2.5.1-8 through 2-2.5.1-13. Short-term critical pressures may also be experimentally determined according to the procedure in para. 2-2.5.2.

(h) For hyperhemispherical acrylic windows, shown in Fig. 2-2.2.1-4, use CFs from Table 2-2.2.1-3 and STCPs from Figs. 2-2.5.1-14 and 2-2.5.1-15. Short-term critical pressures may also be experimentally determined according to the procedure in para. 2-2.5.2. Windows of this type are accepted for service where the hydrostatic pressure is applied only to the convex surface, or the hydrostatic pressures are applied to either surface but the magnitude of internal design pressure does not exceed 5% of the external design pressure.

(i) For NEMO acrylic windows, shown in Fig. 2-2.2.1-4, use CFs from Table 2-2.3.1-3 and STCPs from Figs. 2-2.5.1-14 and 2-2.5.1-15. Short-term critical pressures may also be experimentally determined according to the procedure in para. 2-2.5.2. Windows of this type are accepted for service where the hydrostatic pressure is applied only to the convex surface, or the hydrostatic pressures are applied to either surface but the magnitude of the internal design pressure does not exceed 5% of the external design pressure.

2-2.5.2 Testing Method. The experimental determination of the STCP of an acrylic window shall be conducted by subjecting the window to hydrostatic pressure that is increased, from ambient, at a constant rate of approximately 650 psi/min (4.5 MPa/min). The pressurization shall take place at the ambient temperature range of 70°F to 77°F (21°C to 25°C) in a flange that satisfies the requirements of subsection 2-2.9.

The evaluation of a window design shall be conducted on a minimum of five full-scale windows or on a minimum of five model-scale windows plus one full-scale window.

(a) For tests conducted on full-scale windows, the results generated shall be considered representative only if the lowest STCP for any window is at least 75% of the mean STCP of the other four windows. In such a case, the STCP value of the window design shall be taken as the lowest critical pressure among the five tests. In the case where the lowest STCP does not meet this

criterion, the STCP value of the window design shall be equal to the single lowest STCP among the five windows multiplied by a factor of 0.75.

(b) For tests conducted on model-scale windows, the results shall be considered acceptable only if the STCP of the full-scale window is equal to or above the single lowest STCP among the five model-scale windows. In case the STCP of the single full-scale window does not meet this criterion, four more full-scale windows shall be tested, and the STCP value of the window design shall be calculated according to para. (a) above, solely on the basis of the full-scale window tests.

2-2.6 Nonstandard Window Geometries and Standard Window Geometries With Lower Conversion Factors

2-2.6.1 Case Submittal Procedure. Acrylic windows of nonstandard geometry, or of standard geometry but with nonstandard lower CFs, may be submitted for consideration as a Case for adoption by the ASME Pressure Vessels for Human Occupancy Committee and possible subsequent incorporation into the Standard as another standard geometry or standard CF for windows meeting the design parameters of subsection 2-2.

(a) Prior to submission for review, the window design shall be experimentally verified according to para. 2-2.6.3, and the window design, testing procedure, test results, and any other pertinent analytical or experimental data shall be summarized in a clear, concise, and legible technical report.

(b) One copy of the report shall accompany the submission for consideration by the Committee. Submission of the report to the Committee places its content into the public domain for review and comment by the public.

2-2.6.2 Use in Standard PVHOs. Windows with nonstandard geometries, or with standard geometries and lower CFs, may be incorporated into chambers for human occupancy provided their material properties and structural performance satisfy the mandatory short-term, long-term, and cyclic proof pressure requirements of this Standard.

2-2.6.3 Testing Criteria. Windows with nonstandard geometries, or with standard geometries and lower CFs, shall meet the following mandatory requirements:

(a) *short-term proof pressure (STPP):* 4 times the design pressure, sustained continuously for a minimum of 30 min without catastrophic failure at design temperature environment under short-term pressurization

(b) *long-term proof pressure (LTPP):* design pressure sustained continuously for 80,000 hr in design temperature environment without catastrophic failure

(c) *crack-free cyclic proof pressure (CPP):* design pressure sustained intermittently during 1,000 pressure cycles of 8 hr each in design temperature environment without cracking

Fig. 2-2.5.1-8 Short-Term Critical Pressure of Cylindrical Acrylic Windows Pressurized Internally — Part 1

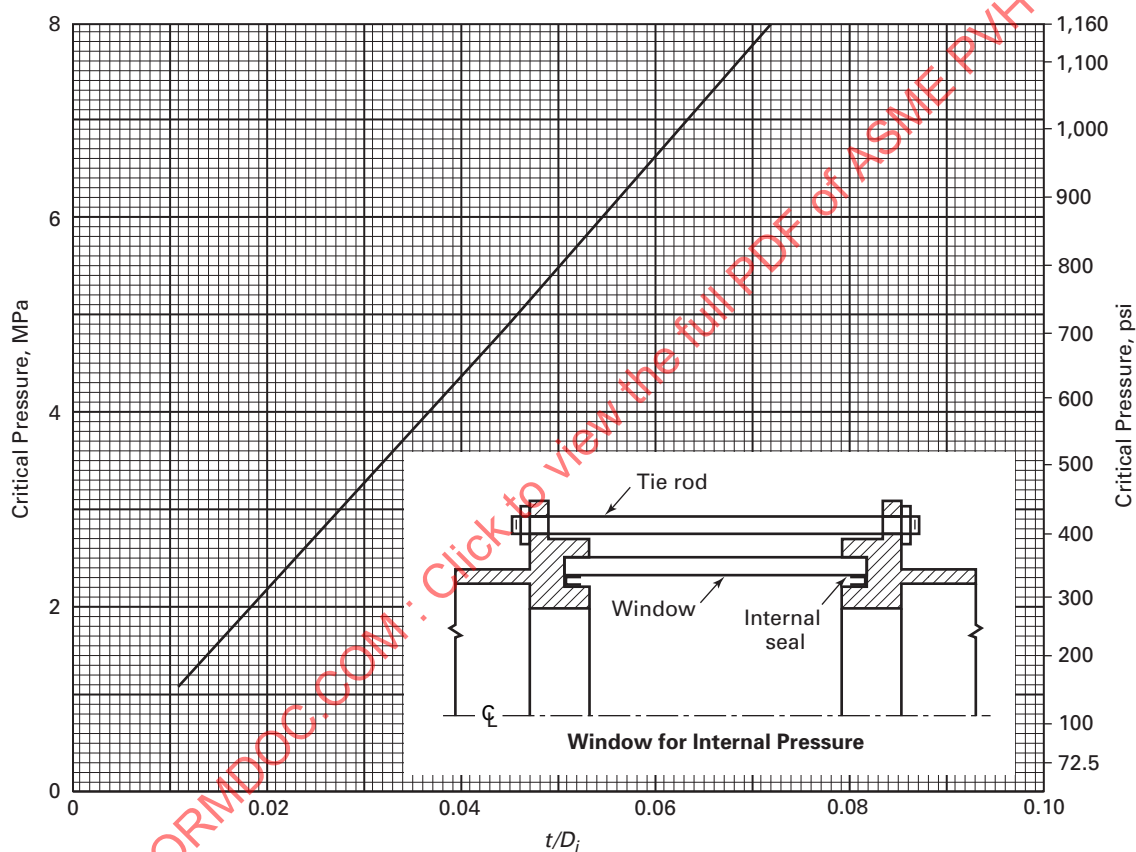


Fig. 2-2.5.1-9 Short-Term Critical Pressure of Cylindrical Acrylic Windows Pressurized Internally — Part 2

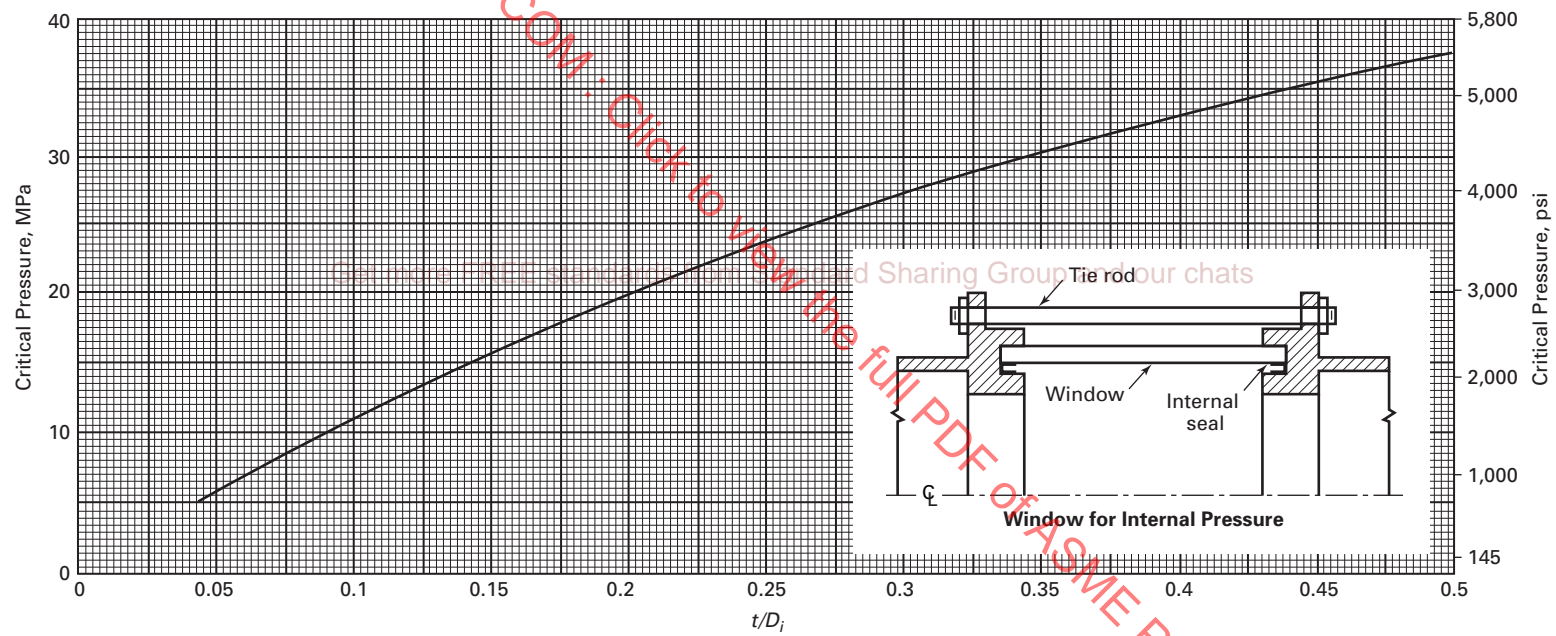


Fig. 2-2.5.1-10 Short-Term Critical Pressure of Cylindrical Acrylic Windows Pressurized Externally

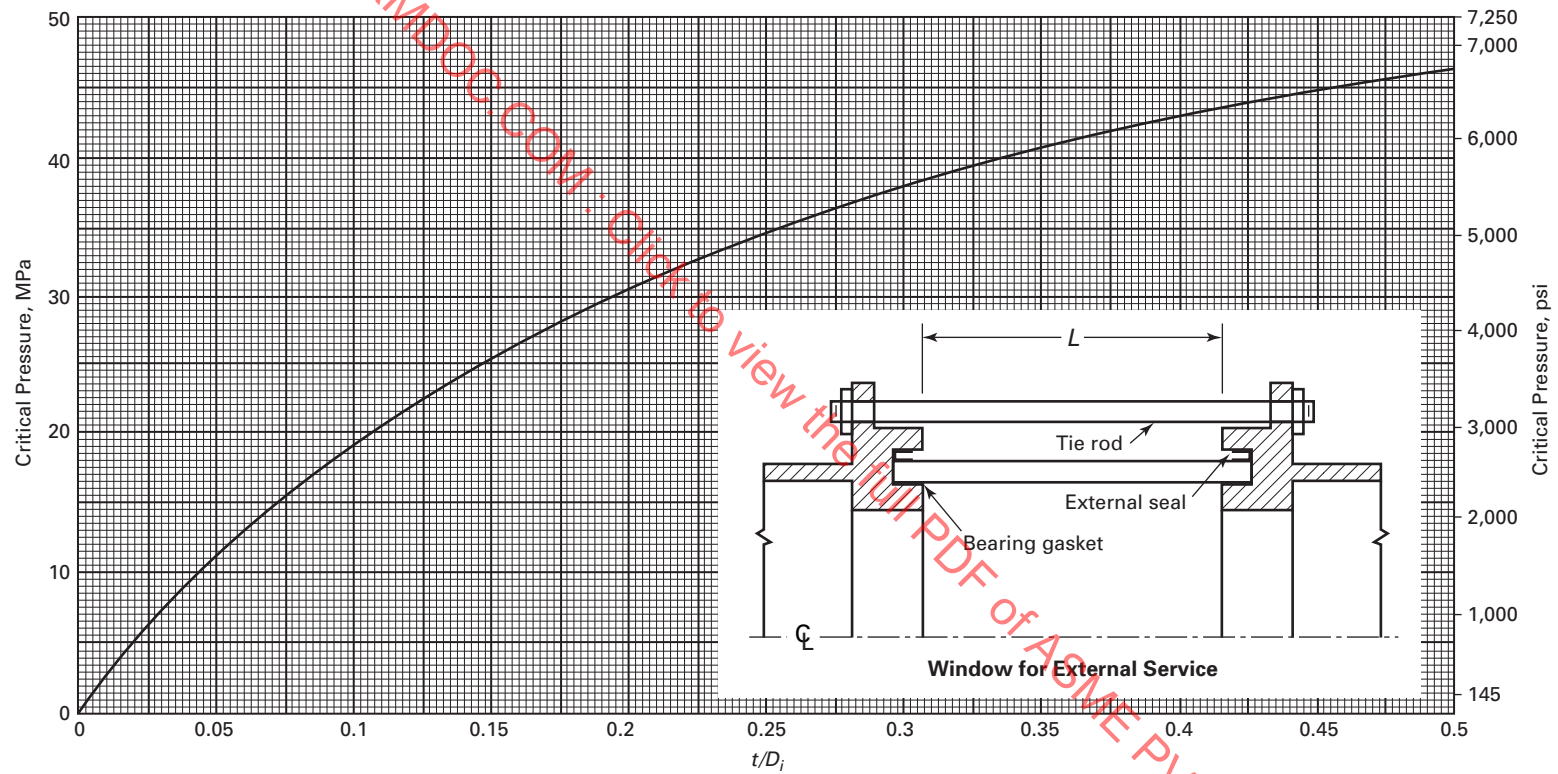


Fig. 2-2.5.1-11 Short-Term Elastic Buckling of Cylindrical Acrylic Windows Between Supports Under External Hydrostatic Pressure — Part 1

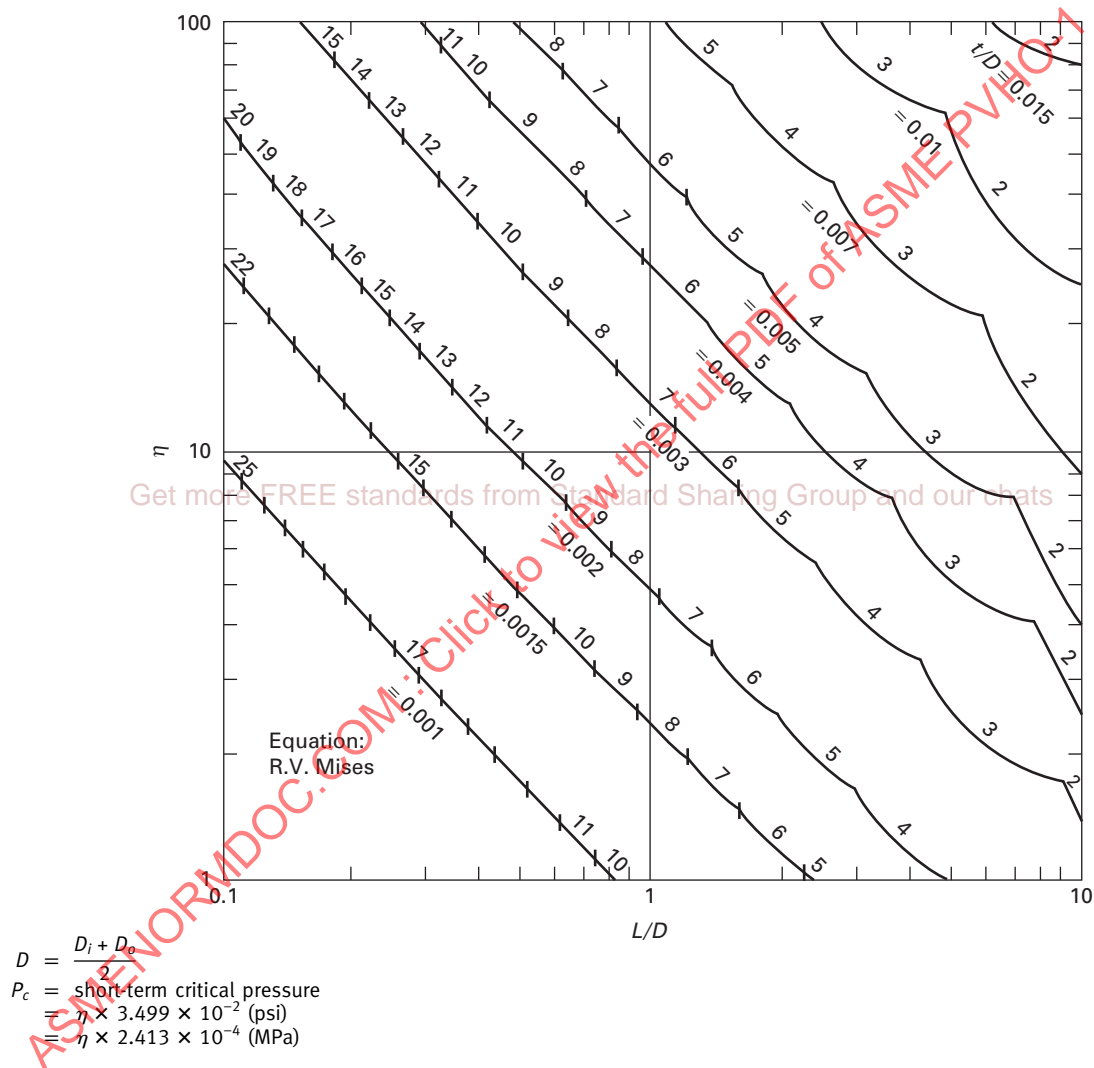


Fig. 2-2.5.1-12 Short-Term Elastic Buckling of Cylindrical Acrylic Windows Between Supports Under External Hydrostatic Pressure — Part 2

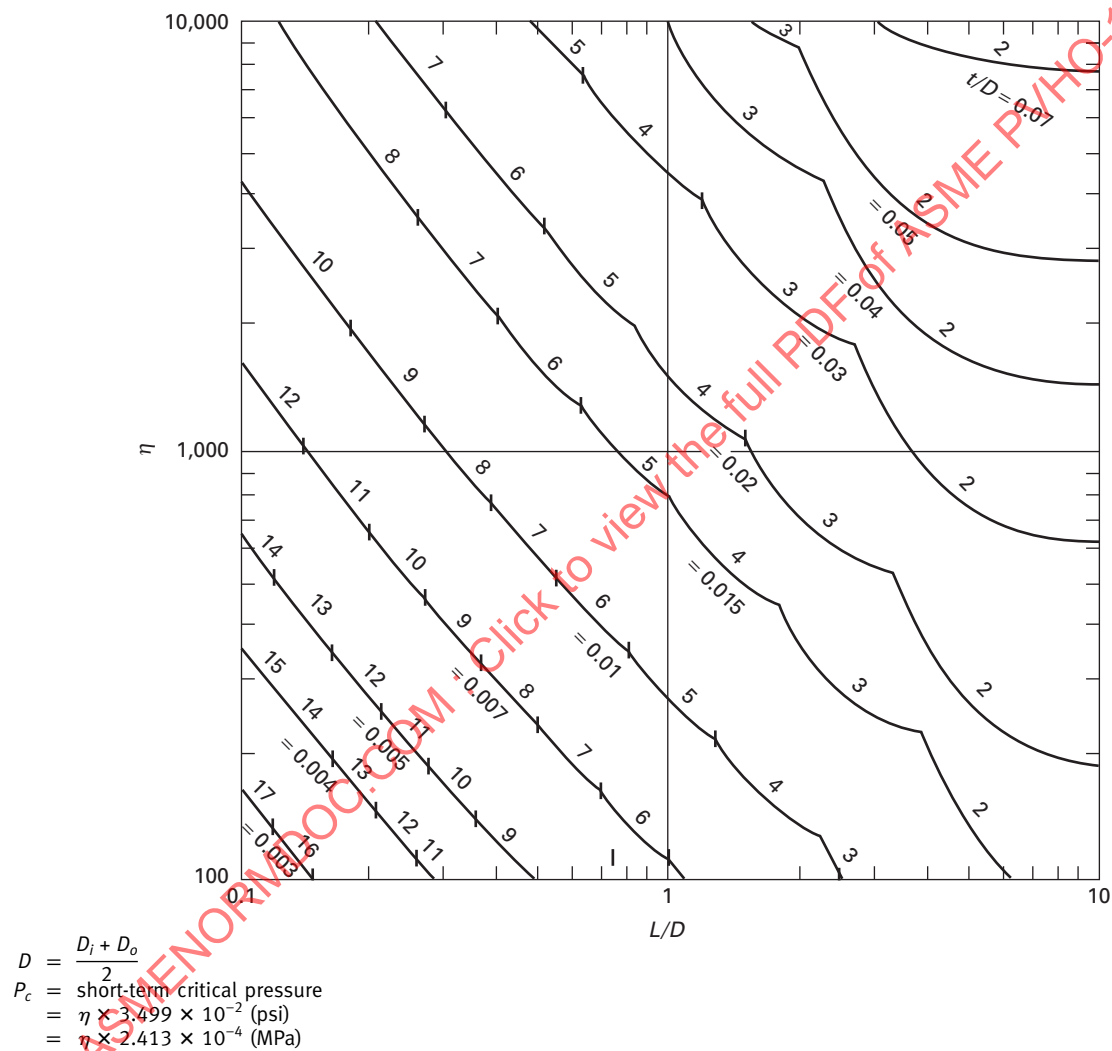
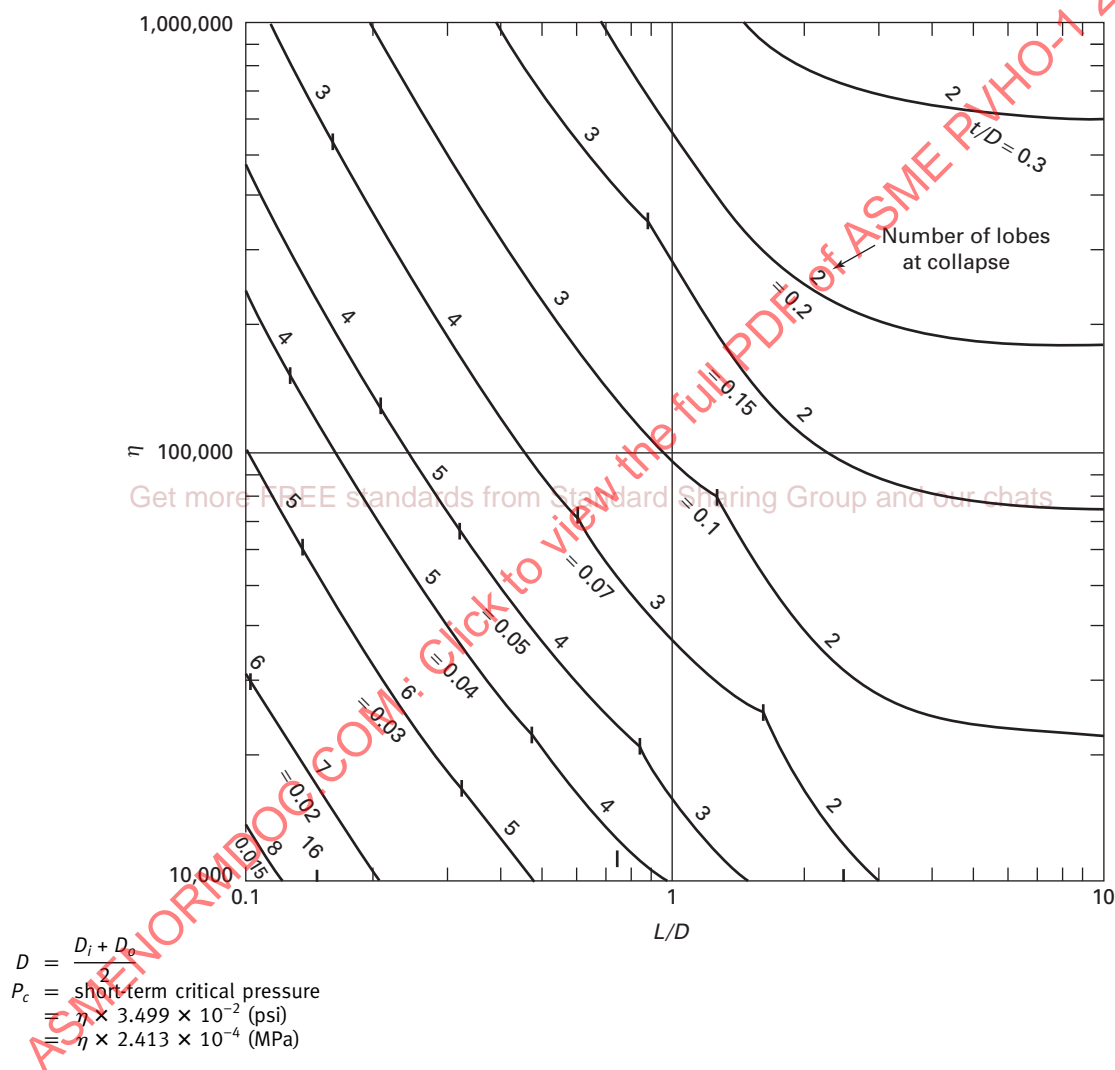


Fig. 2-2.5.1-13 Short-Term Elastic Buckling of Cylindrical Acrylic Windows Between Supports Under External Hydrostatic Pressure — Part 3

(16)



(16) Fig. 2-2.5.1-14 Short-Term Critical Pressure of Hyperhemispherical and NEMO-Type Acrylic Windows — Part 1

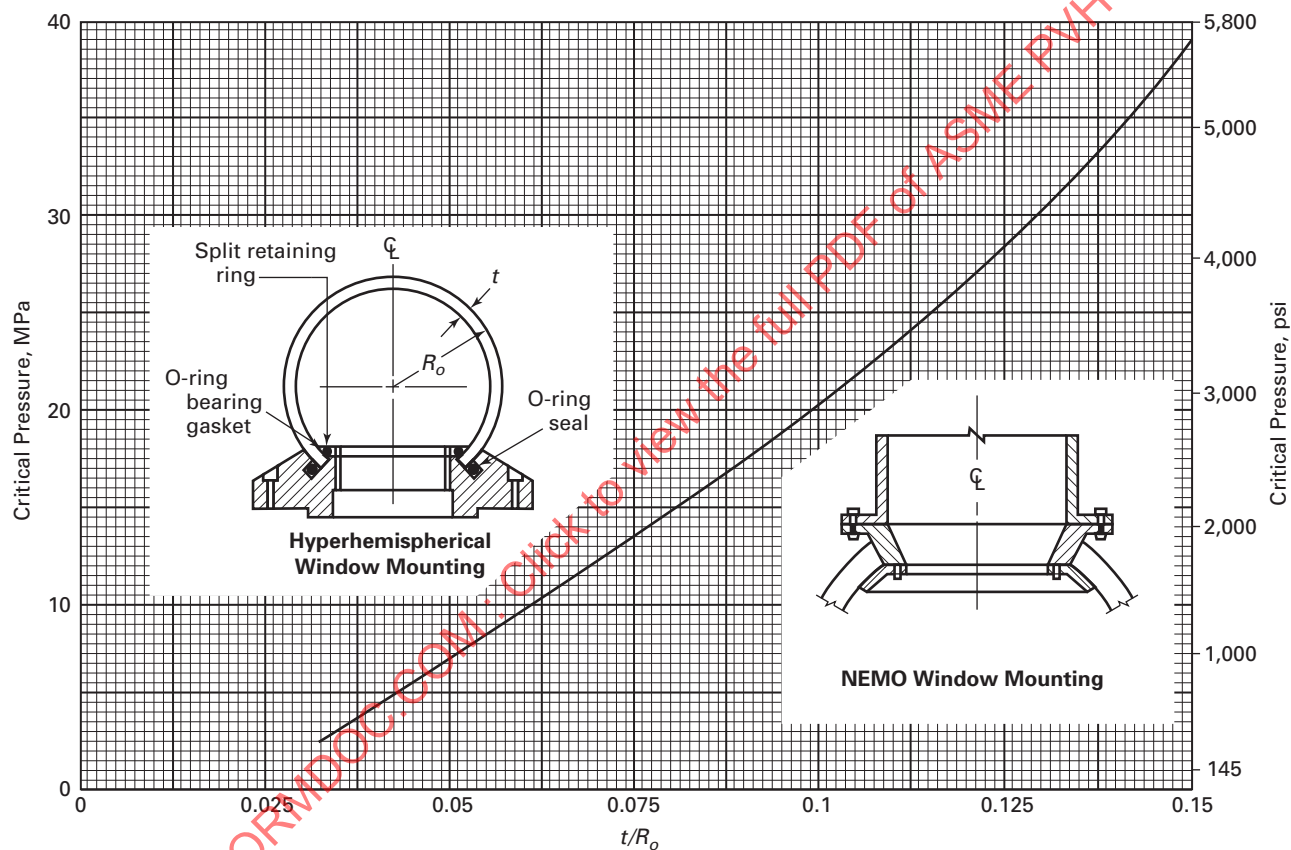
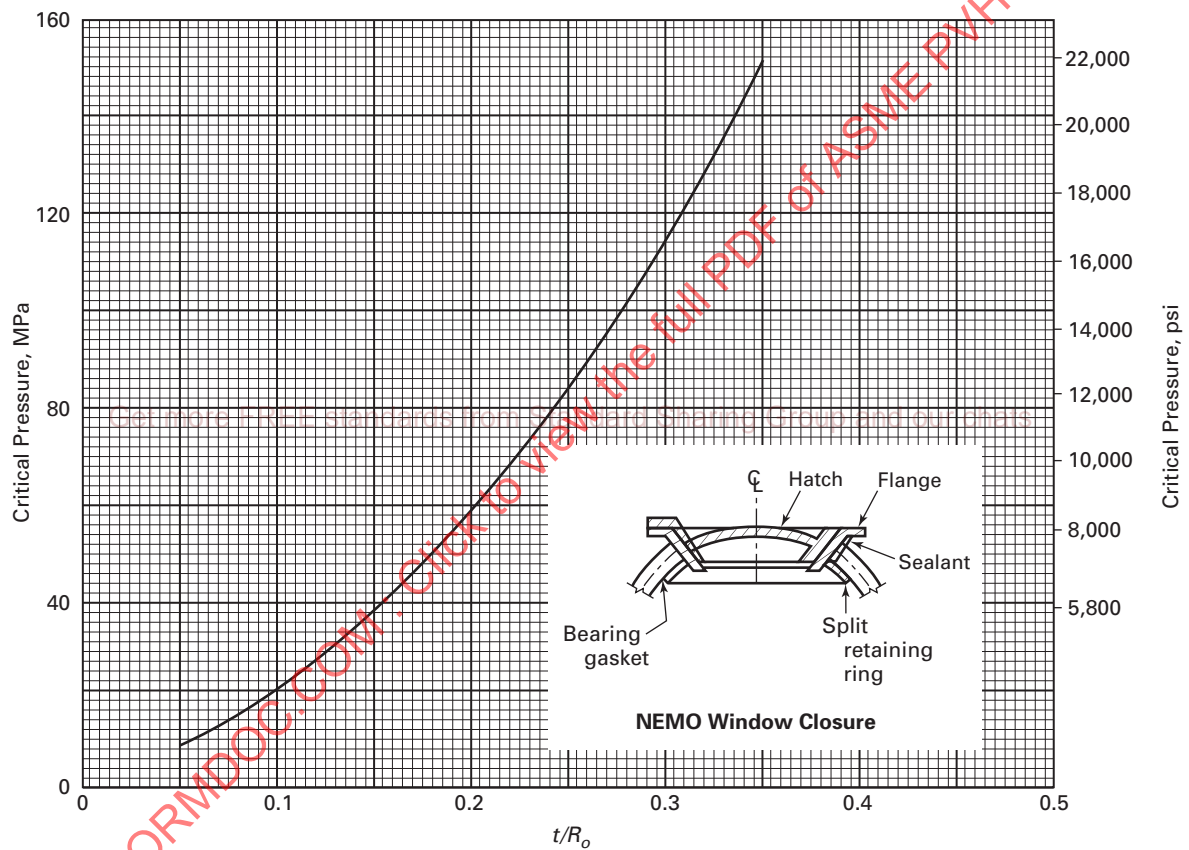


Fig. 2-2.5.1-15 Short-Term Critical Pressure of Hyperhemispherical and NEMO-Type Acrylic Windows — Part 2 (16)



2-2.6.4 STPP Test Procedure. The STPP of a window with nonstandard geometry, or with standard geometry and lower CF, shall be experimentally verified with a minimum of five windows. The STPP windows tested may consist of any combination of model-scale (of the same size) or full-scale windows.

(a) The windows shall be individually pressurized at 650 ± 100 psi/min (4.5 ± 0.7 MPa/min) in the design temperature environment to the STPP.

(b) All five windows shall survive the STPP test without catastrophic failure.

2-2.6.5 LTPP Test Procedure. The LTPP of a window with nonstandard geometry, or with standard geometry and lower CF, shall be experimentally verified as per the following paragraphs, using model-scale (of the same size) or full-scale windows:

(a) The windows shall be individually subjected to sustained pressure loading at design temperature.

(b) Each window shall be subjected to a different hydrostatic pressure, and the duration of sustained pressure preceding the catastrophic failure shall be recorded.

(c) The pressures to which five individual windows shall be subjected are 0.9, 0.8, 0.75, 0.7, and 0.65 times the average STCP established experimentally in para. 2-2.6.4.

(d) The experimental data points of para. (c) above shall be plotted on log-log coordinates, and the relationship between critical pressures and duration of loading shall be represented empirically by a straight line. The experimental points generated in para. 2-2.6.4 with 30-min sustained loading duration shall be also plotted on the same graph. The testing of any window specimen that has not failed in 10,000 hr of sustained loading may be terminated at that time and its data point omitted from the graph.

(e) The extension of the plotted line to 80,000 hr of sustained loading shall exceed the LTPP. The extrapolated failure at 80,000 hr shall be at least two times the design pressure.

(f) An alternative to the LTPP tests defined in paras. (b) through (e) above shall be sustained pressure loading of individual windows for a duration of 10,000 hr at design temperature per one of the following test programs:

(1) One window shall be tested at a sustained pressure equal to 0.9 STPP.

(2) Two windows shall be tested at a sustained pressure equal to 0.85 STPP.

(3) Three windows shall be tested at a sustained pressure equal to 0.8 STPP.

(4) Four windows shall be tested at a sustained pressure equal to 0.75 STPP.

(5) Five windows shall be tested at a sustained pressure equal to 0.7 STPP.

If all windows of any one of the five selected test programs above survive sustained pressurization for

10,000 hr without catastrophic failure, the window design is considered to have satisfied fully all requirements of the LTPP test.

2-2.6.6 CPP Test Procedure. The crack-free CPP of the window with nonstandard geometry, or with standard geometry and lower CF, shall be experimentally verified on a minimum of two model-scale windows (of the same size) or a single full-scale window.

(a) The window shall be pressure cycled 1,000 times from zero to CPP in the design temperature environment.

(b) The length of the individual pressure cycles may vary from one cycle to another, but the average length of the sustained loading and relaxation phases in all of the pressure cycles shall equal or exceed 4 hr.

(c) At the completion of 1,000 pressure cycles, the window shall be visually inspected with the unaided eye (except for correction necessary to achieve 20/20 vision) for the presence of cracks.

(d) Absence of visible cracks shall be considered proof that the window design meets the crack-free CPP requirement of this Standard.

2-2.6.7 Test Temperature Criteria. The temperature of the window, the window test assembly, and its pressurizing medium during the performance of proof tests is allowed to deviate from the specified design temperature by the following margin:

(a) for the short-term pressurization of para. 2-2.6.4, $+10^{\circ}\text{F}$ (5.5°C)

(b) for the long-term pressurization of para. 2-2.6.5, $+10^{\circ}\text{F}$ (5.5°C)

(c) for the cyclic pressurization of para. 2-2.6.6, $+25^{\circ}\text{F}$ (14°C)

2-2.6.8 Fixturing. All STPP, LTPP, and CPP testing shall be performed with each window mounted securely in a test fixture designed to withstand the maximum test pressure to which the window may be subjected.

(a) The window seat dimensions of the test fixture for full-size windows shall be the same as those used for the viewport flanges with operational full-size windows.

(b) The window seat dimensions of the test fixture for model-scale windows shall be scaled down from test fixtures for full-size windows.

2-2.6.9 Scaling. The successful qualification of a window design with nonstandard geometry, or with standard geometry and lower CF, for a chosen design pressure and temperature under the procedures of paras. 2-2.6.2 through 2-2.6.8, qualifies also other window designs with the same geometry and same or higher t/D_1 ratios for the same or lower design pressure and temperature.

2-2.7 Design Life

2-2.7.1 General. The design life of a window is a function of its geometry, conversion factor, t/D_i ratio, and service environment. Windows that are exposed to only compressive or very low tensile stresses have a longer design life than those that are exposed to high tensile stresses. The design life of windows in the first category shall be 20 yr, while for the windows in the latter category it shall be 10 yr. The design life of windows under this Standard is defined in paras. 2-2.7.2 through 2-2.7.8.

2-2.7.2 Flat Disk Windows. The design life of flat disk windows shown in Fig. 2-2.2.1-1 and meeting the requirements of this Standard shall be 10 yr from the date of fabrication.

2-2.7.3 Conical Frustum Windows. The design life of conical frustum windows shown in Fig. 2-2.2.1-1 and meeting the requirements of this Standard shall be 10 yr from the date of fabrication for $t/D_i < 0.5$ and 20 yr for $t/D_i \geq 0.5$.

2-2.7.4 Double Beveled Disk Windows. The design life of double beveled disk windows shown in Fig. 2-2.2.1-1 and meeting the requirements of this Standard shall be 10 yr from the date of fabrication for $t/D_i < 0.5$ and 20 yr for $t/D_i \geq 0.5$.

2-2.7.5 Spherical Sector With Conical Edge, Hyperhemisphere With Conical Edge, and NEMO-Type Windows With Conical Edge Penetrations. The design life of spherical sector with conical edge, hyperhemisphere with conical edge, and NEMO-type windows with conical edge penetrations shown in Figs. 2-2.2.1-2 and 2-2.2.1-4 and meeting the requirements of this Standard shall be 20 yr from the date of fabrication.

2-2.7.6 Spherical Sector Windows With Square Edge and Hemispherical Windows with Equatorial Flange. The design life of spherical sector windows with square edge and hemispherical windows with equatorial flange shown in Figs. 2-2.2.1-2 and 2-2.2.1-3 and meeting the requirements of this Standard shall be 10 yr from the date of fabrication.

2-2.7.7 Cylindrical Windows for Internal Pressure Applications. The design life of cylindrical windows for internal pressure applications shown in Fig. 2-2.2.1-3 and meeting the requirements of this Standard shall be 10 yr from the date of fabrication.

2-2.7.8 Cylindrical Windows for External Pressure Applications. The design life of cylindrical windows for external pressure applications shown in Fig. 2-2.2.1-3 and meeting the requirements of this Standard shall be 20 yr from the date of fabrication.

2-2.7.9 Increase in Cyclic Design Life. For standard-geometry PVHO viewports having a design pressure of

less than 2,000 psi (13.8 MPa), other than hyperhemispherical and NEMO types, the number of design pressure cycles can be increased in excess of that stated in PVHO-1 through experimental pressure testing procedures, provided the following procedures and requirements are met:

(a) For each window design, at least one window of identical shape, dimensions, and design pressure-temperature rating shall be pressure cycled from zero to design pressure to determine whether its cyclic pressure fatigue life exceeds the 10,000 cycle limit stated in PVHO-1. The pressure tests shall take place with the window installed in a test fixture whose window seat dimensions, retaining ring, and seals are identical to those of the PVHO chamber.

(b) The window shall be pressurized with gas or water. The design pressure shall be maintained for a minimum of 15 min, or 1.5 times the time it takes for creep to stabilize, whichever is greater, followed by depressurization that is to be maintained for a minimum of 10 min or 1.5 times the time it takes for creep to stabilize, whichever is greater. The pressurization and depressurization rates shall not exceed 650 psi/min (4.5 MPa/min).

(c) The temperature of the pressurizing medium during the test shall be the design temperature for which the window is rated with a tolerance of $+0/-5^\circ\text{F}$ ($+0/+2.6^\circ\text{C}$). Brief deviations from these temperature tolerances are allowed, provided that the deviations do not exceed $+10^\circ\text{F}$ (5.5°C) and last less than 10 min within each 24 hr of continuous testing.

(d) If leaks develop during pressure cycling, the window shall be removed and pertinent information (cycle count, cause, extent of damage, etc.) recorded. If no damage was noted to the window, new seals may be installed. The number of cycles credited to the window shall be those recorded at the last visual inspection prior to seal failure. After the new seal is installed, two pressure cycles (without leaks) shall be performed without credit to ensure proper seating, temperature stabilization, and creep normalization. If the new seal performs satisfactorily, the numbering of test cycles shall continue from the number recorded at the last visual inspection prior to seal failure, minus the above two cycles.

(e) At scheduled intervals during the pressure test, the windows shall be visually inspected for the presence of crazing, cracks, or permanent deformation. This examination may be performed without removal of the window from the chamber or test fixture.

(f) Crazing, cracks, or excessive permanent deformation visible with the unaided eye (except for correction necessary to achieve 20/20 vision) shall be considered failure of the windows and shall be so noted on the test report. Permanent deformation more than $0.001D_i$ in magnitude measured at the center of the window shall be considered excessive and shall be cause for rejection.

The number of credited test cycles shall not exceed the number of cycles achieved during the previous successful inspection.

(g) Pressure test reports shall certify the results of the pressure test. Copies of the pressure test reports shall be furnished to the purchaser.

(h) For windows having a design pressure design life of 10,000 cycles, an extension of one cycle may be granted by the Standard for each two test cycles after completion of the first 10,000 cycles, up to failure of the test window.

(i) The maximum number of design pressure cycles shall be shown on the Window Certifications.

2-2.8 Temperature and Dimensional Criteria

2-2.8.1 Thermal Expansion. Thermal expansion of acrylic shall be taken into account during specification of the dimensional tolerance for the window diameter to be shown on the fabrication drawing, when the material temperature range required by the fabrication (para. 2-2.4) substantially differs from the operational temperature range.

2-2.8.2 Shape and Sealing Arrangement. For wide operational temperature ranges, a window shape and sealing arrangement should be selected that will perform satisfactorily at both the maximum and minimum operational temperatures. Radially compressed O-ring seals and spherical sector windows with a square edge are not suitable for such service when the change in window diameter over the operational temperature range results in a diametral clearance >0.020 in. (>0.5 mm) between the window and its seat.

2-2.8.3 Clearance Criteria. The diametral clearance between the window and its seat cavity at maximum operational temperature shall not be less than $0.001D_o$ for flat disk and spherical sector windows with square edges. The external diameter of the conical frustums and spherical shell windows with conical edge may exceed the major diameter of the conical seat in the flange by $0.002D_o$ at maximum operational temperature, provided the edge of the window is beveled in such a manner that the conical bearing surface of the window never extends beyond the bearing surface of the seat.

2-2.8.4 Window and Seat Diameter. The nominal diameters of the window and of the window seat in the flange shall be identical. The actual diameters at standard temperature will differ, but still will be within the dimensional tolerances specified in para. 2-2.12.

2-2.9 Viewport Flanges

2-2.9.1 Contribution of Window to Reinforcement.

Due to the difference in moduli of elasticity of the plastic window and the metallic flange, it shall be assumed in stress calculations that the window does not provide any reinforcement for the hull material around the penetrations.

2-2.9.2 Calculation Method. Any of the analytical or empirical methods for stress and displacement calculations acceptable to the applicable Division of Section VIII of the Code may be used for dimensioning the thickness, width, and location of the flange around the viewport penetration.

2-2.9.3 Reinforcement. Reinforcement for penetrations of chambers shall meet the requirements of para. 1-7.11 and the requirements of the applicable Division of Section VIII of the Code.

2-2.9.4 Requirements for Large Openings. The following minimum requirements shall be met by viewport flanges shown in Figs. 2-2.10.1-1 through 2-2.10.1-4, with a finished diameter opening in excess of 24 in. (635 mm).

(a) Radial deformation of the window seat at maximum internal or external design pressure shall be less than $0.002D_i$.

(b) Angular deformation of the window seat at maximum internal or external design pressure shall be less than 0.5 deg.

Viewport flanges shown in Figs. 2-2.10.1-5 through 2-2.10.1-8 do not have to meet the radial and angular deformation limits stated in paras. (a) and (b) above.

2-2.10 Window Seats

2-2.10.1 Dimensional Requirements. The window seat cavity in the viewport flange must be dimensioned to provide the window bearing surface with support during hydrostatic testing and subsequent operation at maximum design pressure. The dimensions of window seat cavities for standard window geometries are shown in Figs. 2-2.10.1-1 through 2-2.10.1-8.

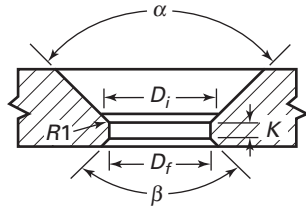
2-2.10.2 Surface Finish. The surface finish on the window seat cavity shall be 64 μ in. RMS or finer, except surfaces in contact with a bearing gasket shall not exceed 125 μ in. RMS.

2-2.10.3 Corrosion Mitigation. If the window seat is not fabricated of inherently corrosion-resistant material, the surface of the window seat cavity shall be protected against corrosion expected in the design environment. A weld overlay of corrosion-resistant material prior to final machining is acceptable. Other acceptable means are painting, anodizing, or plating with electroless nickel.

2-2.11 Window Seals

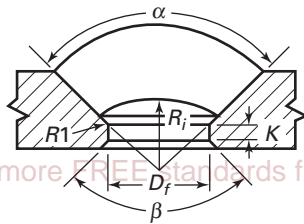
2-2.11.1 General Requirements. As primary seals for standard window geometries shown in Figs. 2-2.2.1-1 through 2-2.2.1-4, a soft elastomer compressed between the high-pressure face of the window and retainer ring shall be acceptable. The soft elastomeric seal may take the form of a flat gasket or a seal ring with O, U, or X cross section. The gasket or seal ring shall be of sufficient

Fig. 2-2.10.1-1 Seat Cavity Requirements — Conical Frustum Window, Spherical Sector Window With Conical Edge, and Flat Disk Window



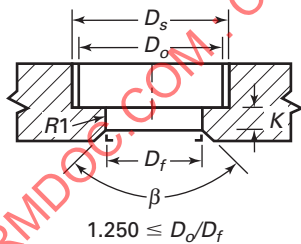
(a) Conical Frustum Window

Operational Pressure Range	D_i/D_f Ratios			
	Included Angle, deg			
	60	90	120	150
$N = 1$	1.02	1.03	1.06	1.14
$N = 2$	1.04	1.06	1.12	1.28
$N = 3$	1.08	1.09	1.17	1.36
$N = 4$	1.10	1.20	1.20	1.42



(b) Spherical Sector Window With Conical Edge

Operational Pressure Range	$[2R_i \sin(\alpha/2)]/D_f$ Ratios (Spherical Sector With Conical Edge)	
	Included Angle, deg	
	30–180	
$N = 1$	1.02	
$N = 2$	1.03	
$N = 3$	1.05	

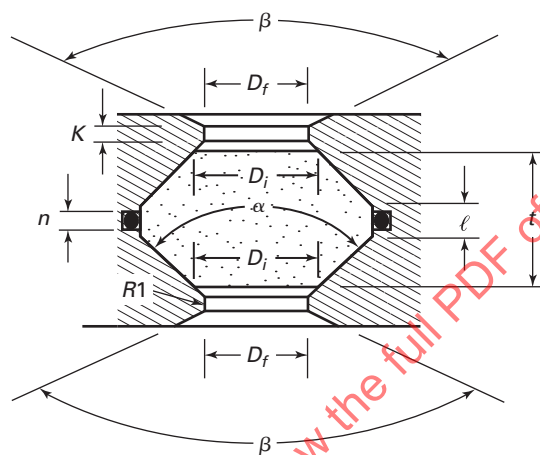


(c) Flat Disk Window

GENERAL NOTES:

- For α between values shown, interpolation is required.
- $\frac{1}{32}$ in. (1.0 mm) $\leq R1 \leq \frac{1}{16}$ in. (2.0 mm).
- K is selected on the basis of structural analysis.
- β is selected on the basis of optical requirements.

Fig. 2-2.10.1-2 Seat Cavity Requirements — Double Beveled Disk Window

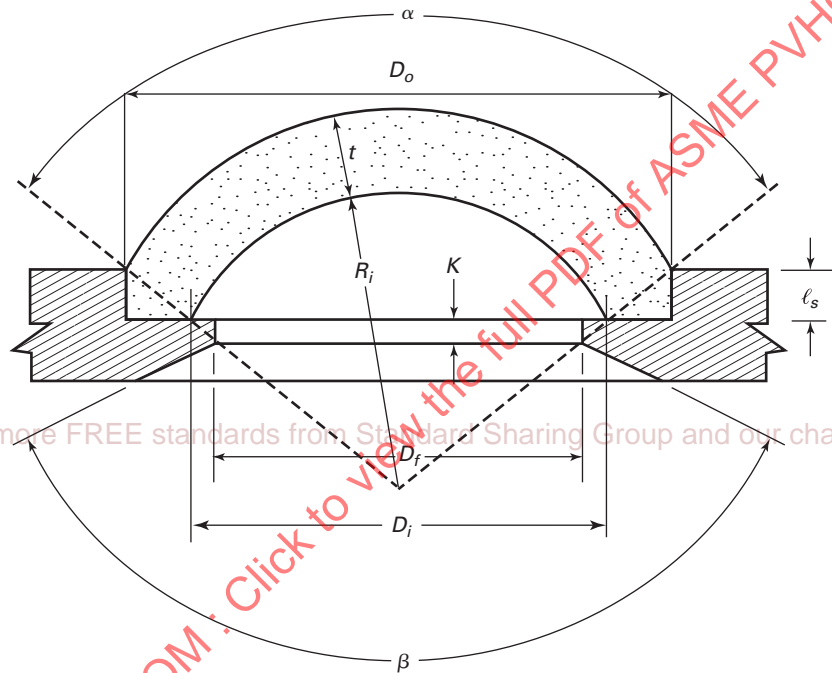
 **D_i/D_f Ratios**

Operational Pressure Range	Included Angle, deg			
	60	90	120	150
$N = 1$	1.02	1.03	1.06	1.14
$N = 2$	1.04	1.06	1.12	1.28
$N = 3$	1.08	1.09	1.17	1.36
$N = 4$	1.10	1.15	1.20	1.42

GENERAL NOTES:

- For α between values shown, interpolation is required.
- K is selected on the basis of structural analysis.
- β is selected on the basis of optical requirements.
- $l \leq 0.25t$.
- $n \leq l$.
- $\frac{1}{32}$ in. (1.0 mm) $\leq R1 \leq \frac{1}{16}$ in. (2.0 mm).

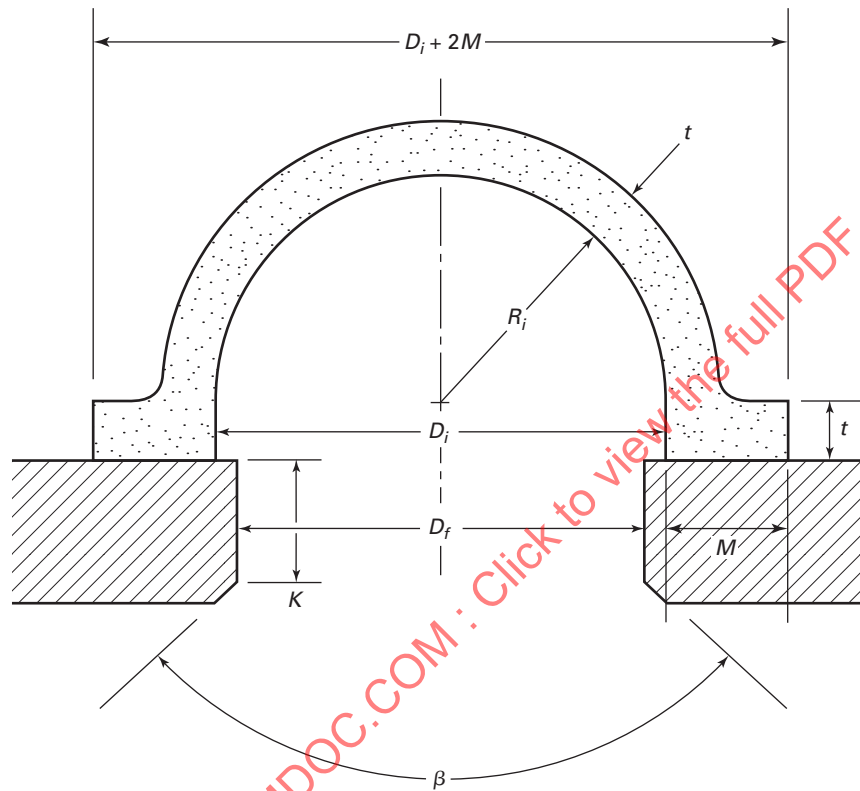
Fig. 2-2.10.1-3 Seat Cavity Requirements — Spherical Sector Window With Square Edge



GENERAL NOTES:

- (a) K is selected on the basis of structural analysis.
- (b) β is selected on the basis of optical requirements.
- (c) $D_o = 2 R_o \sin \alpha/2$.
- (d) $D_i = 2 R_i \sin \alpha/2$.
- (e) $D_i - D_f \geq 1/8$ in. (3.0 mm).
- (f) $\ell_s \geq t \sin (90 \text{ deg} - \alpha/2)$.
- (g) $R_o = R_i + t$.

Fig. 2-2.10.1-4 Seat Cavity Requirements — Hemispherical Window With Equatorial Flange



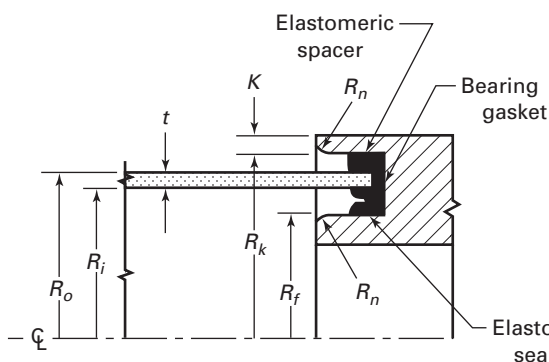
$1.5t \leq M \leq 2.0t$	
Operational Pressure Range	D_i/D_f
$N = 1$	1.02
$N = 2$	1.03
$N = 3$	1.05

GENERAL NOTES:

- (a) K is selected on the basis of structural analysis.
- (b) β is selected on the basis of optical requirements.

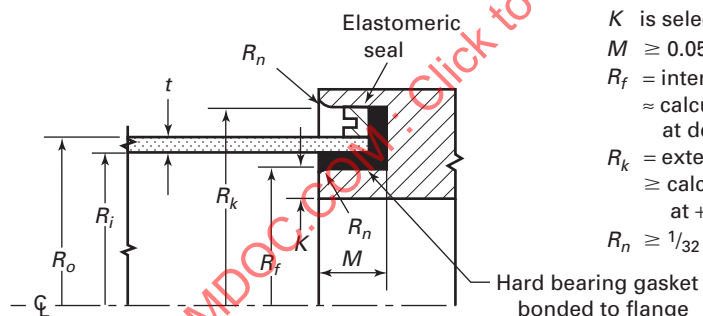
Fig. 2-2.10.1-5 Seat Cavity Requirements — Cylindrical Window

(16)



(a) Under Internal Pressure

- K is selected on the basis of structural analysis
- R_f = internal radius of window seat
 \leq calculated R_i of cylinder at zero internal pressure and -30°C minus gasket compressed 50%
- R_k = external radius of window seat
 \geq calculated maximum R_o of cylinder under sustained internal design pressure of 8 hr duration at design temperature plus gasket compressed 50%
- $R_n \geq 1/32$ in. (1.0 mm)

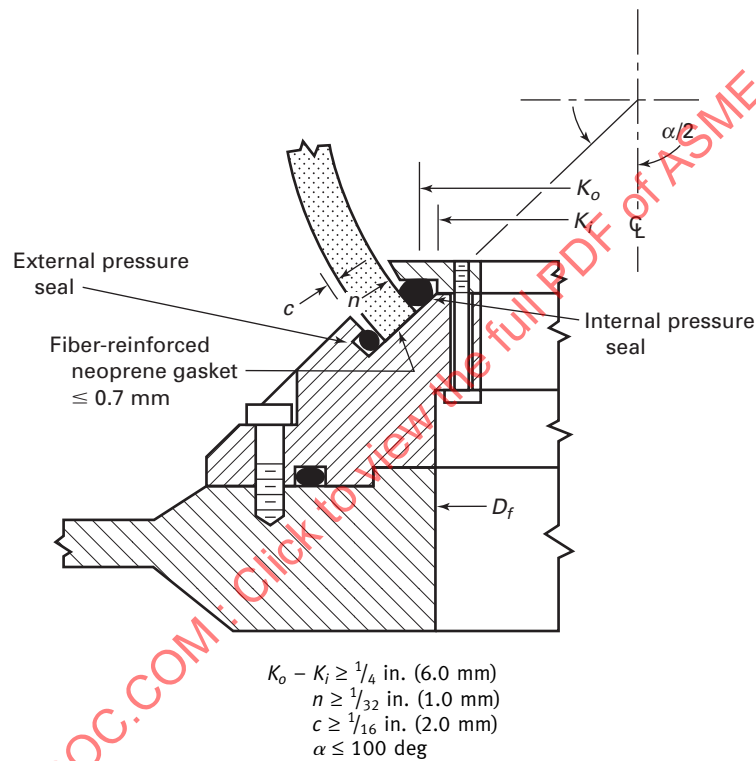


(b) Under External Pressure

- K is selected on the basis of structural analysis
- $M \geq 0.05 R_i$
- R_f = internal radius of window seat
 \approx calculated R_i of cylinder under zero external pressure at design temperature minus thickness of gasket
- R_k = external radius of window seat
 \geq calculated R_o of cylinder under zero external pressure at $+52^\circ\text{C}$ plus gasket compressed 50%
- $R_n \geq 1/32$ in. (1.0 mm)

Hard bearing gasket bonded to flange
 $R_i - R_f \leq 0.01 R_i$

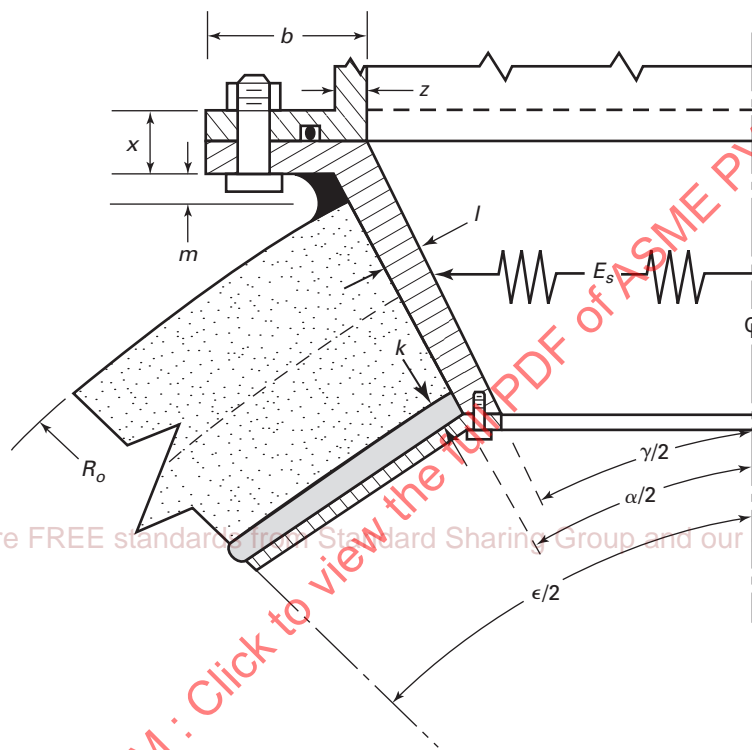
Fig. 2-2.10.1-6 Seat Cavity Requirements — Hyperhemispherical Window



D_f = diameter of the opening in the pressure hull
 K_i = inner diameter of the conical seat
 K_o = inner diameter of the penetration in the window
 α = included spherical angle of the opening

Fig. 2-2.10.1-7 Seat Cavity Requirements — NEMO Window (Standard Seat)

(16)

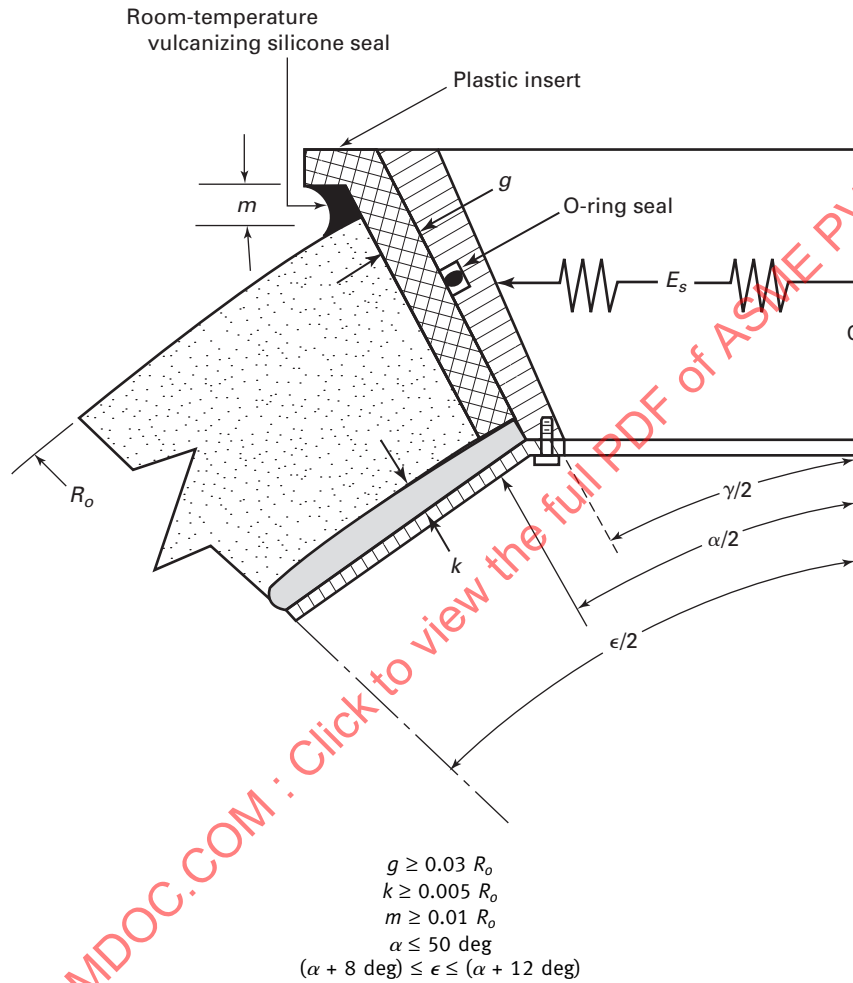


$$\begin{aligned}
 k &\geq 0.005 R_o \\
 m &\geq 0.01 R_o \\
 \alpha &\leq 50 \text{ deg} \\
 (\alpha + 8 \text{ deg}) &\leq \epsilon \leq (\alpha + 12 \text{ deg})
 \end{aligned}$$

- E_s = orientation of effective radial stiffness
 k = thickness of compressed gasket
 m = elevation of hatch ring
 α = spherical angle of window penetration
 ϵ = spherical angle of split retaining ring
 γ = spherical angle of hatch seat

GENERAL NOTE: The variables x , b , z , and l shall be proportioned in such a manner that the effective radial stiffness of all inserts at the penetration does not exceed the radial stiffness of acrylic sector with included angle α by more than 3,500%.

(16) Fig. 2-2.10.1-8 Seat Cavity Requirements — NEMO Window (Seat With Extended Cyclic Fatigue Life)



E_s = orientation of effective radial stiffness
 g = thickness of plastic insert
 k = thickness of compressed gasket (neoprene)
 m = elevation of hatch ring
 α = spherical angle of window penetration
 ϵ = spherical angle of split retaining ring
 γ = spherical angle of hatch seat

GENERAL NOTE: The variables x , b , z , and l shall be proportioned in such a manner that the effective radial stiffness of all inserts at the penetration does not exceed the radial stiffness of acrylic sector with included angle α by more than 3,500%.

thickness to permit adequate compression without permanent set. Double beveled disk and cylindrical windows shall use, as a primary seal, a seal ring radially compressed between the cylindrical surface of the window facing the pressure and the cylindrical window seat in the flange. Hyperhemispherical and NEMO-type windows may also use, as a primary seal, an elastomeric potting compound that adheres to both the external spherical surface of the window and the lip of the mounting flange.

2-2.11.2 Flat Disk Windows. Flat disk windows with design pressure less than 15 psi (100 kPa) may use, as the primary seal, an elastomeric potting compound that, after injection into the annular space between the edge of the window and the cylindrical surface of the seat (which have been coated beforehand with appropriate primer), shall, after room-temperature cure, adhere to both the window and the seat surfaces. The primer and elastomeric potting compound selected for this application shall be compatible with the window material, and the potting compound shall retain its elastomeric characteristics in the operational temperature range and environment.

2-2.11.3 Retainer Rings. Whenever a gasket is used as the face seal, the retainer shall precompress the gasket to ensure a minimum of 0.01 in. (0.25 mm) compression of the gasket between the retaining ring and the face of the axially displaced window at design pressure.

For conical frustum and spherical sector windows with conical edge, the magnitude of the maximum axial displacement may be calculated on the basis of Fig. 2-2.10.1-1, using the specified D_i/D_f ratios as the maximum predicted limits of axial displacement during pressurization to design pressure based on the assumption that the minor diameter, D_i , of the window will vertically displace to the D_o of the window.

For flat disks, spherical sectors with square edges, and hemispheres with equatorial flanges, the magnitude of maximum axial window displacement may be calculated by multiplying the thickness of the bearing gasket by 0.30.

2-2.11.4 Gasket Compression. The compression of the soft elastomeric gasket by the retainer ring around the circumference of the window shall be uniform. The magnitude and uniformity of compression shall be checked by measuring, around the circumference of the window, the distance between the surface of the window and the external surface of the retainer ring before and after torquing down on the ring. The values of gasket compression measured at fastener locations and measured midway between fasteners shall not differ from each other by more than 25%, and the minimum value shall be equal to or exceed the magnitude of compression specified by para. 2-2.11.3 at standard temperature.

2-2.11.5 Electrogalvanic Requirements. The retainer ring and the fasteners shall be fabricated from materials that are electrogalvanically compatible with the viewport flanges. Unreinforced plastics and fiber-reinforced plastic composites are not acceptable materials for this application.

2-2.11.6 Retainer Ring Design Factor. The retainer ring and the associated fastening arrangement shall be designed with a safety factor of 4, based on the ultimate strength of materials. The design pressure forcing the window against the retainer ring shall not be less than 5 psig.

2-2.11.7 Minimum Compression. The minimum compression of seal rings shall be governed by the specifications of the seal ring manufacturer for the given seal ring size and service.

2-2.11.8 Secondary Seal. A secondary seal is required between the window and the steel cavity seat for flat disks, spherical sectors with square edge, and hemispheres with equatorial flange. The secondary seal also serves as a bearing gasket for the window. This gasket must be bonded with contact cement to the metal flange seat. Thickness of the gasket shall not exceed $\frac{1}{8}$ in. (3.0 mm). Neoprene-impregnated nylon cloth, neoprene of 90 durometer hardness, and cork gaskets are acceptable for such application.

2-2.11.9 Seal Ring Grooves

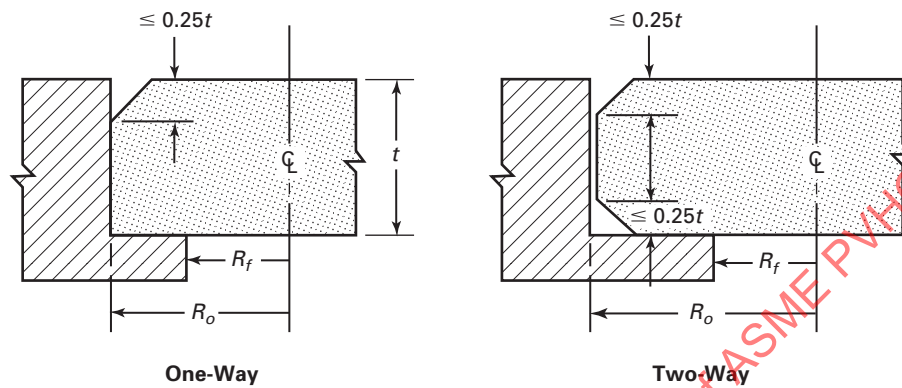
(a) Seal ring grooves are not permitted in either the surface of any window shape or the bearing surface of the seat in the mounting, unless data showing that identical window assemblies that have successfully met the criteria of para. 2-2.6.6 are included with the window design certification package.

(b) Seal ring grooves are permitted in the window seat in the mounting, provided that the groove is located in the nonbearing surface of the seat. The edges of the O-ring groove shall be beveled with a radius of 0.01 in. $< R < 0.02$ in. (0.25 mm $< R < 0.50$ mm).

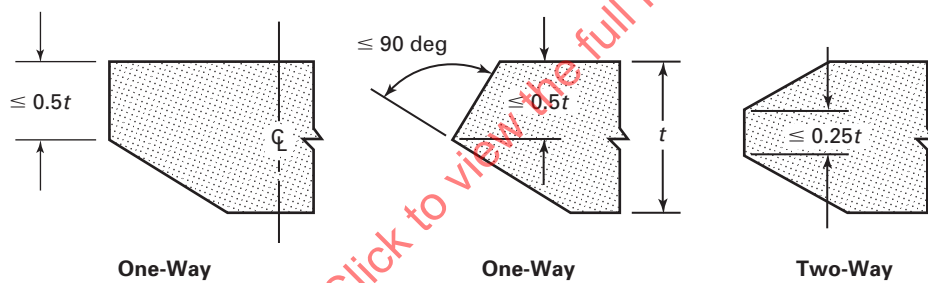
2-2.11.10 Edge Seals. Edges of bearing surfaces at the high-pressure faces of windows may be beveled for containment of O-rings provided that the width of the bevel as shown in Figs. 2-2.11.10-1 and 2-2.11.10-2 shall not exceed $0.12t$ for spherical sectors, $0.62t$ for hyperhemispheres, $0.5t$ for conical frustums, $0.25t$ for flanged hemispheres and for flat disks under one-way pressurization, and $0.125t$ for spherical sectors with square edges and for cylinders. For flat disks serving as two-way windows, both edges may be beveled, provided $D_o/D_i > 1.25$ and D_o is measured only to the edge of the plane-bearing surface.

2-2.11.11 Clear Viewport Retaining Covers. Clear viewport retaining covers are permitted for O-ring-sealed flat disk and conical frustum standard-geometry PVHO windows in applications where reverse pressure (16)

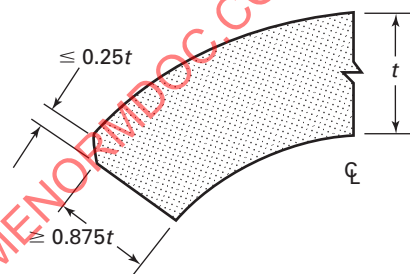
(16) Fig. 2-2.11.10-1 Bevels on Window Edges — Flat Disk Windows, Conical Frustum Windows, Spherical Sector Windows, Hyperhemispheres



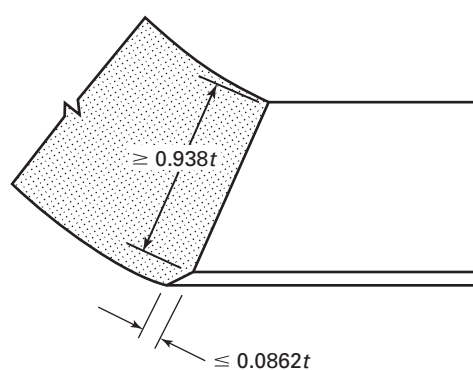
(a) Flat Disk Windows



(b) Conical Frustum Windows

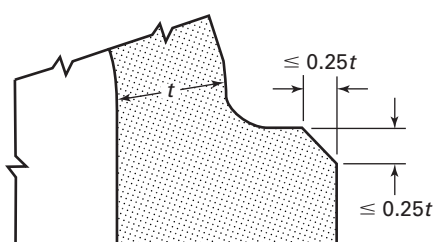


(c) Spherical Sector Windows

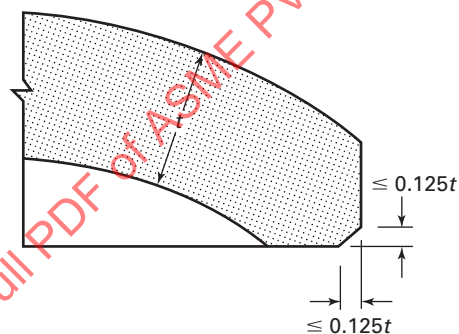


(d) Hyperhemispheres

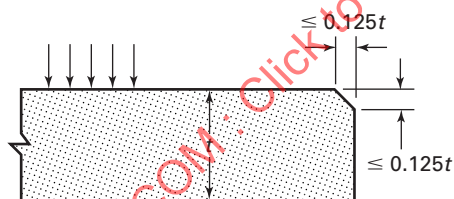
Fig. 2-2.11.10-2 Bevels on Window Edges — Flanged Hemispherical Window, Spherical Sector Window With Square Edge, External Pressure and Internal Pressure of Cylindrical Windows



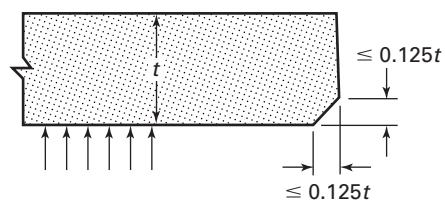
(a) Flanged Hemispherical Window



(b) Spherical Sector Window With Square Edge



External Pressure



Internal Pressure

(c) Cylindrical Windows

on the viewport window is not possible and the design pressure is less than 135 psig provided the following provisions are met:

(a) The thickness of the clear viewport retaining cover shall not be less than 0.25 in. (6 mm) or $0.025D_o$, whichever is greater.

(b) Where retaining screws are used to secure the clear viewport retaining cover, the clearance holes between the retaining screws and the cover shall be large enough to compensate for thermal expansion and contraction of the cover material. Flat washers shall be used between the screwhead and clear viewport retaining cover.

(c) Provisions shall be made for equalizing the pressure between the clear viewport retaining cover and the viewport window, e.g., a $\frac{1}{16}$ -in. (1.6-mm) diameter hole located in the cover inside the O-ring seal diameter.

(d) Acrylic plastic (per ASTM D4802-02 or equivalent) and clear polycarbonate plastic (per ASTM C1349-04 or equivalent) are acceptable materials for clear viewport retaining covers.

(e) The requirements of paras. 2-2.11.3, 2-2.11.4, 2-2.11.6, and 2-2.11.7 apply to clear viewport retaining covers. See Fig. 2-2.11.11-1 for acceptable configurations for clear viewport retaining covers.

2-2.11.12 Configurations. The configuration of window mountings and seal arrangements shown in Figs. 2-2.5.1-1 through 2-2.5.1-15 represent designs acceptable under this Standard and are shown there only for the guidance of designers.

2-2.11.13 Replacement Windows. Replacement windows for pressure chambers fabricated to design criteria of ANSI/ASME PVHO-1-1977 or ANSI/ASME PVHO-1-1981 may incorporate O-ring grooves in nonbearing surfaces of the window provided

(a) the window meets all the requirements of the 1977 or 1981 edition

(b) the accompanying design certification notes that the window is a replacement for an existing pressure vessel built to the 1977 or 1981 edition

2-2.12 Dimensional Tolerances and Surface Finish

2-2.12.1 Thickness. Thickness of the window shall be everywhere equal to or greater than the nominal value determined by the procedures of para. 2-2.5.1.

2-2.12.2 Conical Windows

(a) The major diameter of the conical bearing surface on a window shall be machined within $+0.000/-0.002D_o$ of the nominal value.

(b) The included conical angle of the window shall be within $+0.25/-0.000$ deg of the nominal value.

(c) The included conical angle of the window seat in the flange must be within $+0.000/-0.25$ deg of the nominal value.

(d) The conical seat in the flange shall not deviate more than $0.001D_o$ in. from an ideal circle when measured with a feeler gauge inserted between the mating conical surfaces of the seat and of the window at its outer circumference. The axial force used to seat the window during this test shall not exceed $10D_o$ lb ($4.53D_o$ kg) applied uniformly around its circumference.

(e) The major diameter of the conical seat cavity in the flange must be within $+0.002D_o/-0.000$ of the nominal value.

2-2.12.3 Spherical Sector Windows. The concave or convex surface of a spherical window shall not differ from an ideal spherical sector by more than $+0.5\%$ of the specified nominal external spherical radius for standard CF values (see Tables 2-2.3.1-3 and 2-2.3.1-4 and Figs. 2-2.5.1-6, 2-2.5.1-7, 2-2.5.1-14, and 2-2.5.1-15). Measurements shall be made from an external segmental template whose radius falls within the specified dimensional tolerance and whose length is equal to the window's included conical angle or 90 deg, whichever is the lesser value. The thickness of the spherical window may decrease from its base to its apex provided that the minimum thickness meets the requirements of para. 2-2.5 for the design pressure and design temperature of the particular spherical window geometry.

2-2.12.4 Flat Disk Windows

2-2.12.4.1 Window External Diameter. The dimensional tolerance of the external diameter of the window shall be based on the type of sealing arrangement for the window.

(a) The external diameter of the flat disk window shall be within $+0.000/-0.010$ in. ($+0.000/-0.25$ mm) of the nominal value if the window is to be sealed in the seat cavity with a radially compressed O-ring.

(b) The external diameter of the flat disk window shall be within $+0.000/-0.060$ in. ($+0.000/-1.5$ mm) of the nominal value if the window is to be sealed in the seat cavity with a seal ring wedged into the annular space between the retaining ring, the window's bevel, and the cylindrical surface of the seat cavity.

(c) The external diameter of the flat disk window shall be within $+0.0/-0.125D_o$ of the nominal value if the window is to be sealed in the seat cavity with a flat elastomeric gasket axially compressed by the retaining ring.

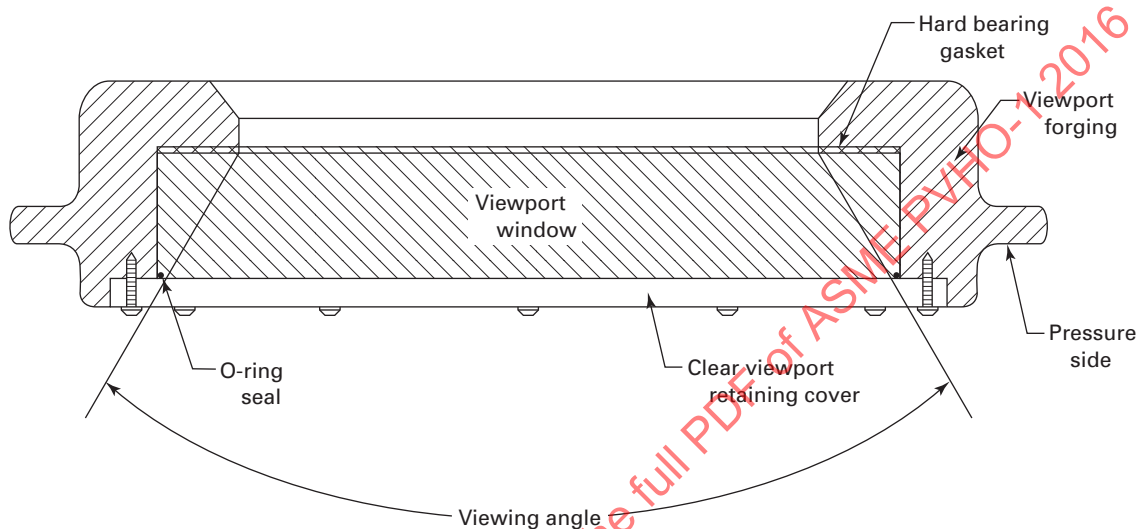
(d) The external diameter of the flat disk window shall be within $+0.00/-0.02D_o$ of the nominal value if the window is to be sealed in the seat cavity with a room-temperature curing elastomeric compound injected into the annular space between the edge of the window and the cylindrical surface of the seat.

(e) The plane bearing surface of the flat disk window shall not deviate more than $0.001D_o$ from an ideal plane.

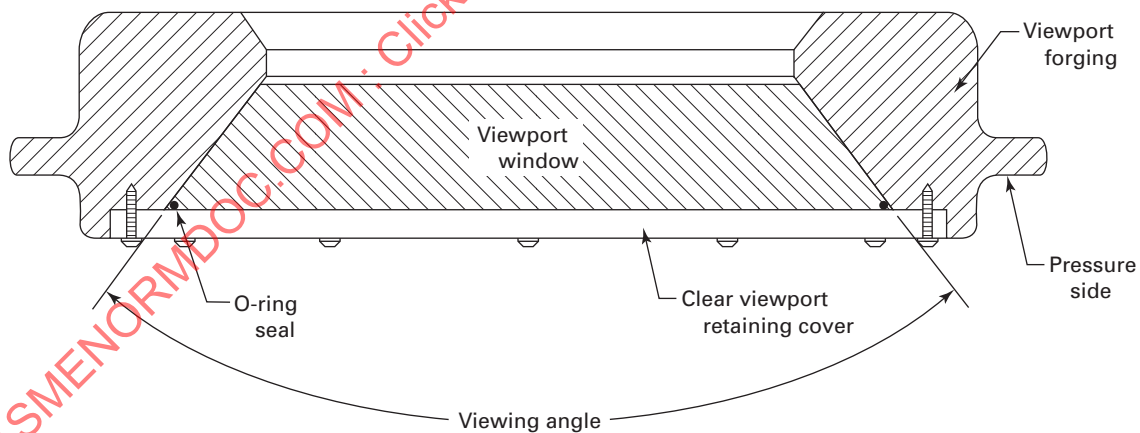
2-2.12.4.2 Seat Cavity Diameter. The dimensional tolerance on the external diameter of the window seat

Fig. 2-2.11.11-1 Acceptable Configurations for Clear Viewport Retaining Covers

(16)



(a) Flat Disk Viewport Cross Section



(b) Conical Frustum Viewport Cross Section

cavity shall be based on the type of sealing arrangement for the window.

(a) The diameter of the seat cavity for a flat disk window shall be within $+0.01/-0.00$ in. ($+0.25/-0.00$ mm) of the nominal value if the window is to be sealed in the seat cavity with a radially compressed O-ring.

(b) The diameter of the seat cavity for a flat disk window shall be within $+0.06/-0.00$ in. ($+1.5/-0.00$ mm) of the nominal value if the window is to be sealed in the seat cavity with a seal ring wedged into the annular space between the retaining ring, the window's bevel, and the cylindrical surface of the seat cavity.

(c) The diameter of the seat cavity for a flat disk window shall be within $+0.125/-0.000$ in. ($+3.2/-0.00$ mm) of the nominal value if the window is to be sealed in the seat cavity with a flat elastomeric gasket axially compressed by the retaining ring.

(d) The diameter of the seat cavity for a flat disk window shall be within $+0.01D_o/-0.000$ of the nominal value if the window is to be sealed in the seat cavity with a room-temperature curing elastomeric compound injected into the annular space between the edge of the window and the cylindrical surface of the seat.

(e) The plane bearing surface of the seat cavity shall not deviate more than $0.002D_o$ from an ideal plane when measured with a feeler gauge inserted between the mating plane surfaces of the flat disk window or a circular plug gauge and the bare seat cavity. The axial force used to seat the window or the plug gauge shall not exceed $10D_o$ lb ($4.53D_o$ kg) applied uniformly around its circumference.

2-2.12.5 Spherical Windows

(a) The external diameter of the spherical window with square seat shall be within $+0.000/-0.0005D_o$ of the nominal value.

(b) The diameter of the seat cavity for a spherical window with square seat shall be within $+0.0005D_o/-0.000$ of the nominal value.

(c) The plane bearing surface of the seat cavity shall not deviate more than $0.001D_o$ from an ideal plane when measured with a feeler gauge inserted between the mating plane bearing surfaces of the spherical window with a square edge and the seat cavity. The axial force used to seat the window shall not exceed $10D_o$ lb ($4.53D_o$ kg) applied uniformly around its circumference.

2-2.12.6 Cylindrical Windows. The maximum out-of-roundness of a cylindrical window shall not differ from an ideal cylinder by more than $+0.5\%$ of the specified nominal external radius for standard CF values (see Table 2-2.3.1-5).

2-2.12.7 Surface Finish. The bearing surface of the window shall have an as-cast or machined finish no rougher than $32 \mu\text{in. RMS}$.

2-2.12.8 Viewing Surface. Window viewing surfaces shall be polished to meet the requirements of para. 2-3.7(e).

2-2.12.9 Other Surfaces. All other surfaces shall be machined or sanded to attain at least a $63\text{-}\mu\text{in. RMS}$ finish. Saw cut finish is not acceptable on any window surface.

2-2.13 Documentation

2-2.13.1 Drawing Requirements. The manufacturer shall be responsible for the translation of the design of the window and its related viewport flange, retainer rings, and seals into drawings that can be used for fabrication.

2-2.13.2 Window Identification. Drawings that provide construction details shall bear notice that the windows have been designed and shall be built to ASME PVHO-1. Drawings shall identify the appropriate edition.

2-2.13.3 Design Certification. The designer shall fill out a design certification as described in para. 2-1.3.2(a). All pertinent design data shall be shown, and any additional information used in the design shall be referenced on the certification. The designer may develop an appropriate certification form using PVHO-1 Form VP-2 as a representative sample.

2-2.13.4 Drawing Transmittal. The manufacturer shall transmit the design certification plus construction drawings to the window fabricator at the time of fabrication.

2-2.14 Windows With Inserts for Penetrators

2-2.14.1 General. Inserts that serve as bulkheads for electrical, mechanical, optical, or hydraulic penetrators can be incorporated into acrylic windows provided that the penetrations and inserts meet the requirements of this subsection. These requirements are grouped into categories of window shapes, pressure service, penetration location, penetration configuration, insert material, insert configuration, seating arrangements, insert retainment, pressure testing, and certification.

2-2.14.2 Shape Limitations. The window shapes in which penetrations can be incorporated without reducing their working pressure are spherical shell sectors with conical seats (see Fig. 2-2.2.1-2), hemispheres with or without flanges (see Fig. 2-2.2.1-3), hyperhemispheres, and NEMO spheres (see Fig. 2-2.2.1-4).

2-2.14.3 Penetration Limitations. Windows with penetrations can be incorporated into pressure vessels for external or internal pressure service provided that the design pressure acts only on the convex surface of the window.

PVHO-1 Form VP-2 Acrylic Window Design Certification

Window Description

Window Drawing No. _____

Maximum allowable working pressure _____ psi _____ MPa

Maximum design temperature _____ °F _____ °C Minimum design temperature _____ °F _____ °C

Window shape _____

Conversion factor table number _____

Pressure range, N _____ Conversion factor, CF _____

Short-term critical pressure and fig. no. _____

Experimental Verification [Note (1)]

No. 1 _____ No. 2 _____

Thickness t (actual) _____

No. 3 _____ No. 4 _____

 D_o (actual) _____ D_i (actual) _____

No. 5 _____ STCP _____

Water temperature _____ °F _____ °C

(Note each test specimen FS for full scale or MS for model scale.)

Type of failure _____

Test conducted at _____

Test supervised by _____

Window Design

Inner diameter, D_i (nominal) _____ Included angle (nominal) _____External radius of curvature (nominal) _____ Minimum H/D_i (calculated) _____Minimum t (calculated) _____ D_i/D_f (nominal) _____Minimum D_i (calculated) _____Diametral interference/clearance between D_o of window and window seat at maximum design temperature (calculated) _____Diametral interference/clearance between D_o of window and window seat at minimum design temperature (calculated) _____Actual t (specified on drawing) _____Actual D_i (specified on drawings) _____ Actual D_o (specified on drawings) _____

Actual external radius of curvature (specified on drawings) (spherical or cylindrical) _____

Drawing no. of window _____ Drawing no. of flange _____ Drawing no. of assembly _____

Description of pressure vessel (for which the window has been designed) _____

The viewport design complies with all of the requirements of the Safety Standard for Pressure Vessels for Human Occupancy, subsection 2-2.

viewport designer _____

date _____

authorized representative of chamber manufacturer or owner _____

date _____

name and address of chamber manufacturer or owner _____

date _____

GENERAL NOTE: This form may be reproduced and used without written permission from ASME if used for purposes other than republication.

NOTE:

(1) If STCP is determined experimentally according to para. 2-2.5.2, then the critical pressures of all five windows tested, the testing laboratory, and the test supervisor should be noted here.

2-2.14.4 Penetration Locations (Spherical Shell Sector). On spherical shell sectors with conical seats, hemispheres without flanges, hyperhemispheres, and NEMO spheres, the penetrations may be located anywhere, provided

(a) the spacing between the window seat and the edge of the penetration exceeds two diameters of the penetration

(b) the spacing between edges of adjacent penetrations measured on the concave surface exceeds the radius of the larger penetration

2-2.14.5 Penetration Location (Hemispheres). On hemispheres with flanges, the penetration may be located only within the area between the apex and latitude of 60 deg, provided the spacing between edges of adjacent penetrations exceeds the radius of the larger penetration measured on the concave surface.

2-2.14.6 Penetration Configuration. The penetrations shall have circular configurations.

2-2.14.7 Area of Single Penetration. The area of a single penetration shall not exceed 15% of the window's surface prior to machining of the penetration in the window.

2-2.14.8 Total Area. The total area of all penetrations in a single window shall not exceed 30% of the window's concave surface.

2-2.14.9 Seats. All penetrations shall have conical seats forming surfaces of imaginary solid cones.

2-2.14.10 Included Angle. The included solid angle of any conical seat shall be chosen to make the imaginary apex of the solid cone coincide with the imaginary center of concave curvature.

2-2.14.11 Maximum Diameter. The maximum size of the penetration diameter shall be defined by a solid cone angle of 60 deg, provided the area of the penetration, defined as $\pi(M_o)^2/4$ (see Fig. 2-2.14.11-1), does not exceed the limits specified in paras. 2-2.14.7 and 2-2.14.8.

2-2.14.12 Tolerances. The angular and dimensional tolerances for penetrations, as well as for the surface finish on the seat, are shown in Fig. 2-2.2.1-1.

2-2.14.13 Insert Material. The inserts for the penetrations shall be made from metal or from plastic, provided the material properties satisfy the following criteria:

(a) Any metal approved by this Standard may be used for the fabrication of inserts, provided that the selected alloy is corrosion resistant to stagnant seawater and its tensile and compressive yield strengths exceed 25,000 psi (172 MPa). Steel alloys without corrosion resistance may be substituted for corrosion-resistant alloys if the insert is cadmium or nickel plated after completion of all machining operations.

(b) Acrylic meeting the criteria of Table 2-3.4-2 and polycarbonate plastic meeting the criteria of Table 2-2.14.13-1 are acceptable materials for the fabrication of inserts, provided that in service they shall only

(1) come in contact with fluids and gases defined by para. 2-1.2(c)

(2) be subjected to temperatures that are lower than the design temperature of the window

Cast unfilled monolithic Type 6 nylon meeting the criteria of Table 2-2.14.13-2 may be used for the fabrication of bearing gasket inserts for NEMO windows (see Fig. 2-2.10.1-8).

2-2.14.14 Temperature Considerations. Since the temperature of a shorted-out electrical connector may exceed the design temperature of the plastic insert, the designer shall forestall the potentially unacceptable temperature rise by limiting the magnitude and/or duration of power input to the connector during an electrical short.

2-2.14.15 Insert Tolerances. The angular and dimensional tolerances for inserts are shown in Fig. 2-2.14.15-1. All surfaces on the insert shall have a finish of 32 μ in. RMS or finer.

2-2.14.16 Insert Shape. The inserts shall have the shape of a spherical sector or of a truncated cone, where

(a) the solid included angle of the bearing surface on the insert matches the conical seat in the penetration

(b) the bearing surface of the insert extends past the edges of the seat in the penetration (Fig. 2-2.14.16-1)

2-2.14.17 Metal Inserts. Any number or size of holes may be drilled and tapped in the metal insert to receive hydraulic, electrical, optical, or mechanical bulkhead penetrators, provided that the openings and their reinforcements conform to the appropriate Division of Section VIII of the Code.

2-2.14.18 Polycarbonate Inserts. Smooth holes may be drilled in the polycarbonate insert to receive hydraulic, electrical, optical, or mechanical bulkhead penetrators, provided

(a) the spacing between edges of adjacent holes in the insert exceeds the diameter of the larger adjacent hole.

(b) the spacing between the edge of the insert and the edge of any hole exceeds the diameter of that hole.

(c) the surface finish inside the holes is 32 μ in. RMS or finer. The holes shall be sized for the penetrators to support the edges of the holes when the window assembly is subjected to design pressure.

2-2.14.19 Acrylic Inserts. Smooth holes may be drilled in the acrylic insert to receive hydraulic, electrical, optical, or mechanical bulkhead penetrators provided

(a) the spacing between edges of adjacent holes in the insert exceeds two diameters of the larger adjacent hole.

Fig. 2-2.14.11-1 Dimensional Tolerances for Penetrations in Acrylic Windows

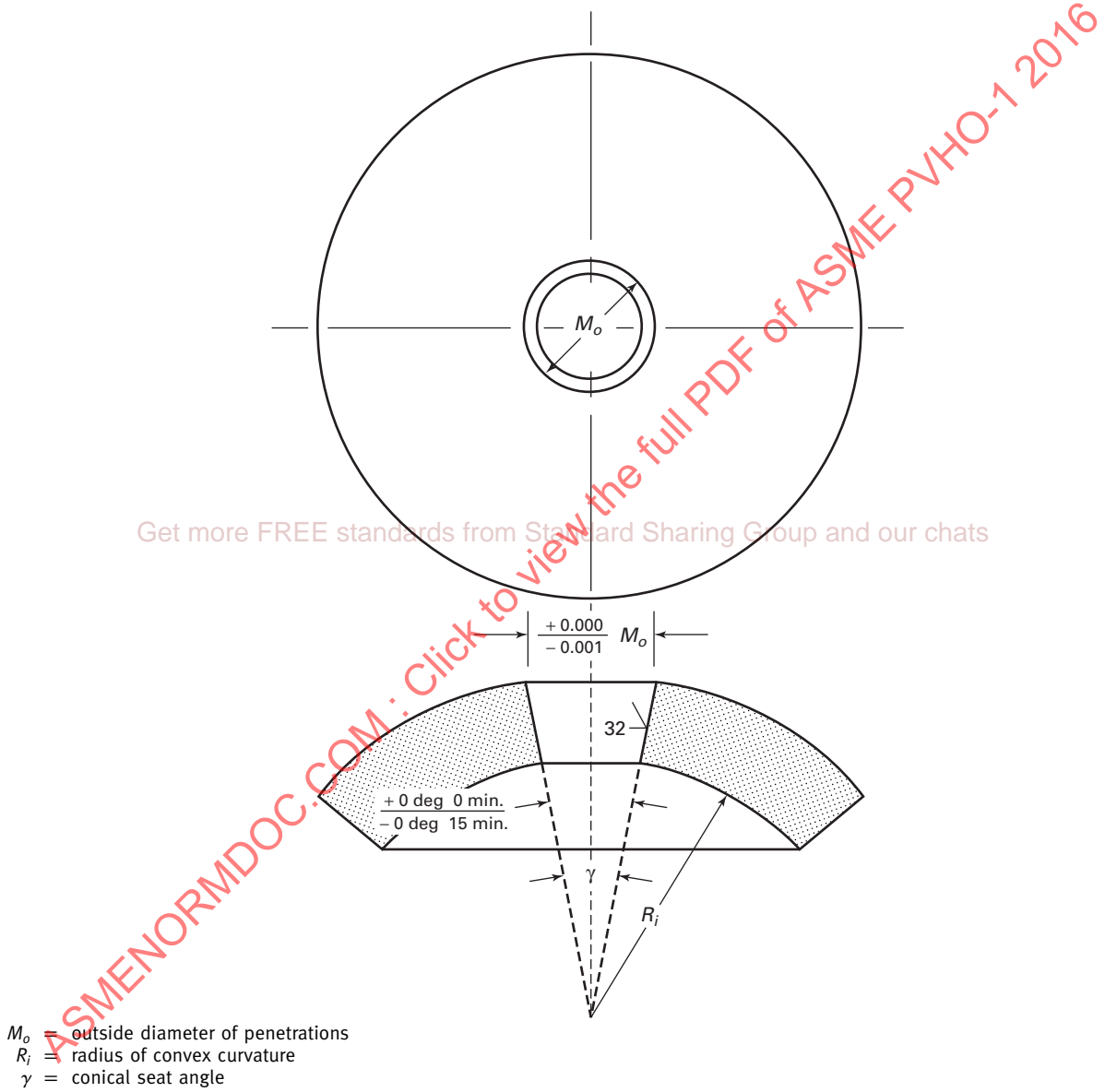


Table 2-2.14.13-1 Specified Values of Physical Properties for Polycarbonate Plastic

Test Procedures	Physical Property	Specified Values	
		U.S. Customary Units	Metric Units
ASTM D638 [Note (1)]	Tensile:		
	(a) ultimate strength	≥9,000 psi	≥62 MPa
	(b) elongation at break	≥20.0%	≥20%
	(c) modulus of elasticity	≥300,000 psi	≥2 069 MPa
ASTM D695 [Note (1)]	Compressive:		
	(a) yield strength	≥12,000 psi	≥82.8 MPa
	(b) modulus of elasticity	≥300,000 psi	≥2 069 MPa
PVHO-1 method, para. 2-3.7(c)	Compressive deformation at 4,000 psi (27.6 MPa) and 122°F (50°C) for 24 hr	≤2%	≤2%
ASTM D732 [Note (1)]	Shear, ultimate strength	≥9,000 psi	≥62 MPa
ASTM E308	Ultraviolet transmittance	≤5%	≤5%

GENERAL NOTE: Test coupons shall be taken from each plate that serves as machining stock for inserts and shall be tested to verify that the physical properties of the material meet the requirements in this table.

NOTE:

- (1) These tests require testing a minimum of two specimens. For others, test a minimum of one specimen. Where applicable, use the sampling procedures described in para. 2-3.7. Where two specimens are required in the test procedure, the average of the test values shall be used to meet the requirements of the minimum physical properties of this table.

(16) Table 2-2.14.13-2 Specified Values of Physical Properties for Cast Nylon Plastic

Test Procedures	Physical Property	Specified Values	
		U.S. Customary Units	Metric Units
ASTM D638 [Note (1)]	Tensile:		
	(a) ultimate strength	≥9,500 psi	≥65.5 MPa
	(b) elongation at break	≥30.0%	≥30.0%
	(c) modulus of elasticity	≥350,000 psi	≥2 415.0 MPa
ASTM D695 [Note (1)]	Compressive:		
	(a) yield strength	≥6,000 psi	≥41.4 MPa
	(b) modulus of elasticity	≥250,000 psi	≥1 725.0 MPa
PVHO-1 method, para. 2-3.7(c)	Compressive deformation at 4,000 psi (27.6 MPa) and 122°F (50°C) for 24 hr	<1.4%	<1.4%
ASTM D732 [Note (1)]	Shear, ultimate strength	≥4,300 psi	≥29.7 MPa

GENERAL NOTE: Test coupons shall be taken from each casting that serves as machining stock for inserts and shall be tested to verify that the physical properties of the material meet the requirements in this table.

NOTE:

- (1) These tests require testing a minimum of two specimens. Where applicable, use the sampling procedures described in para. 2-3.7. Where two specimens are required in the test procedure, the average of the test values shall be used to meet the requirements of the minimum physical properties of this table.

Fig. 2-2.14.15-1 Dimensional Tolerances for Inserts in Acrylic Windows

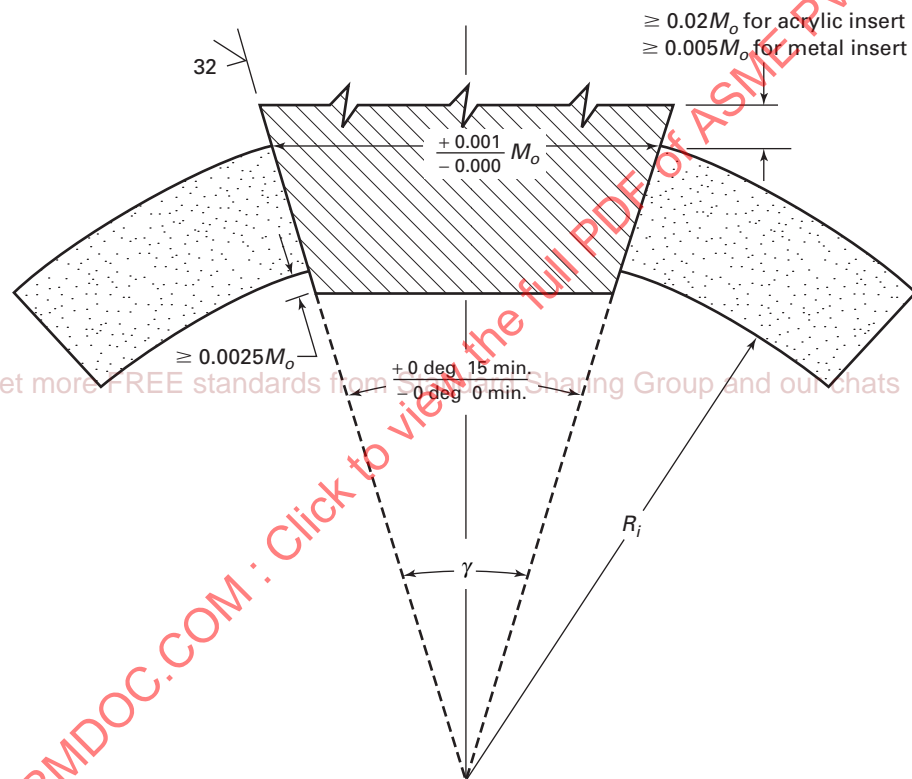
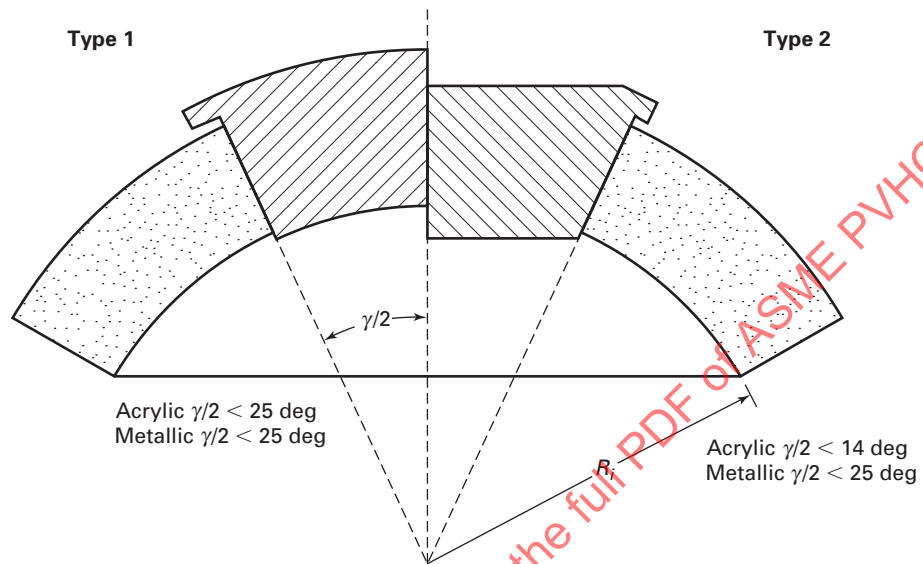
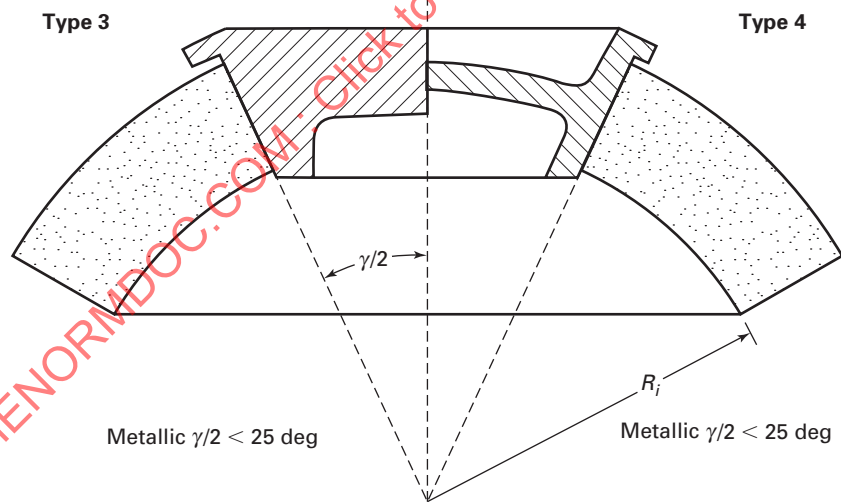


Fig. 2-2.14.16-1 Typical Shapes of Inserts



(a) For Metallic and Acrylic Materials



(b) For Metallic Materials

(b) the spacing between the edge of the insert and the edge of the hole exceeds two diameters of the hole.

(c) the surface finish inside the holes is 32 μ in. RMS or finer. The holes shall be sized for the penetrators to support the edges of the holes when the window assembly is subjected to design pressure.

2-2.14.20 Insert Thickness. The thickness of the insert shall depend on the material from which the insert is fabricated.

(a) For plastics, the thickness of the inserts in the shape of spherical sectors or conical frustums shall be calculated on the basis of maximum allowable tensile and compressive stresses specified for the chosen material by the appropriate Division of Section VIII of the Code.

(b) An alternate approach requires hydrostatic testing of the new insert design in an acrylic seat to 3 times the desired design pressure without producing permanent deformation $\geq 0.2\%$. The pressurization shall be at a 650-psi/min (4.5-MPa/min) rate.

2-2.14.21 Duplicate Inserts. Duplicate inserts of the same material, design, and construction need not be proof tested but shall be pressure tested according to subsection 2-7.

2-2.14.22 Insert Seals. All inserts require two separate seals to prevent entry of water through the joint between the bearing surface of the insert and the seat in the window: a primary seal and a secondary seal.

(a) Sealing between the insert and the window shall be provided by two seals. A primary seal shall serve as the contact between the two conical mating surfaces on the insert and window. A secondary seal shall serve as the contact between the two conical mating surfaces on the insert and window. A secondary seal shall serve as elastomeric material held captive between the convex window surface and a flange on the insert.

(b) Experimentally proven secondary seal designs shown in Fig. 2-2.14.22-1 represent designs acceptable under this Standard and are provided for guidance only.

2-2.14.23 Insert Seal Grooves. Grooves for containment of seals shall not be machined in either the conical seat on the window or the conical bearing surface on the insert in contact with the window. It is acceptable to incorporate an O-ring groove in the conical bearing surface of a metallic insert if a gasket of approved material is interposed between the metallic insert and the seat on the window (see Fig. 2-2.10.1-8).

2-2.14.24 Insert Retention. The inserts shall be mechanically restrained against ejection from their seats in the window by accidental application of pressure to the concave surface of the window or bending moments to the feedthroughs.

(a) The mechanical restraint shall be capable of retaining the insert against a pressure of 15 psi (0.1 MPa)

applied against the concave surface of the window and bending moments generated by wave slap and hydrodynamic drag against cables, hydraulic lines, or mechanical linkages attached to the insert. The tensile stress resulting from bending moment shall not exceed 2,500 psi (12.2 MPa).

(b) Experimentally proven restraint designs shown in Fig. 2-2.14.24-1 represent designs acceptable under this Standard and are provided for guidance only.

2-2.14.25 Insert Stress Relief. All inserts shall be stress relieved after all the fabrication processes have been completed. Acrylic shall be stress relieved according to the schedules of Table 2-4.5-1. Polycarbonate shall be stress relieved for a period of 8 hr at 250°F (120°C).

2-2.14.26 Insert Inspection. Each finished insert shall be subjected by the fabricator to a quality control inspection. The quality control inspection shall consist of dimensional and visual checks whose objective is to determine whether the finished insert meets the dimensional tolerances, material quality, and surface finish requirements specified in subsection 2-2.13.

2-2.14.27 Insert Pressure Test. Each insert shall be pressure tested at least once prior to being accepted for service.

(a) The pressure test shall take place with the insert installed in the window, or an acrylic test fixture whose thickness, surface curvatures, and penetration dimensions are identical to those in the window.

(b) The pressure test shall be conducted according to procedures described in subsection 2-7.

(c) The test pressure and temperature shall be determined by the design pressure and temperature of the window in which the insert shall be installed for service.

2-2.14.28 Insert Inspection. Each insert shall be individually certified. The certification shall include the following:

- (a) design certification
- (b) material manufacturer's certification
- (c) material properties certification
- (d) fabrication data report
- (e) pressure testing certification

2-2.14.29 Insert Certification Procedure. Each of the certifications shall follow the procedure described in para. 2-1.3.2, except that the material certifications for polycarbonate and metallic inserts shall differ from the one specified for acrylic.

(a) For polycarbonate, the supplier shall provide a report listing the results of tests performed according to Table 2-2.14.13-1 on coupons cut from the stock used in the fabrication of inserts.

(b) For metal, the supplier shall provide a certified mill test report. The report shall include the results of all the tests as required by the material specifications,

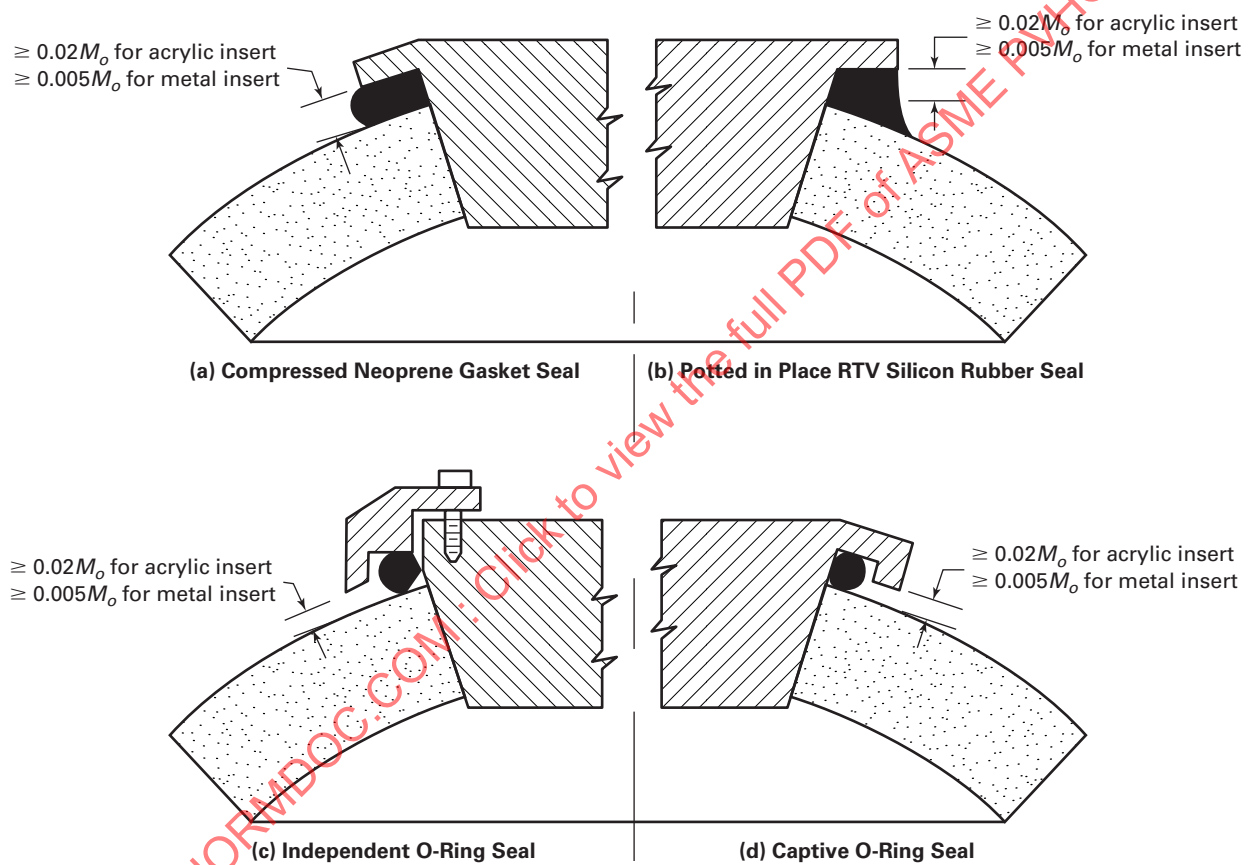
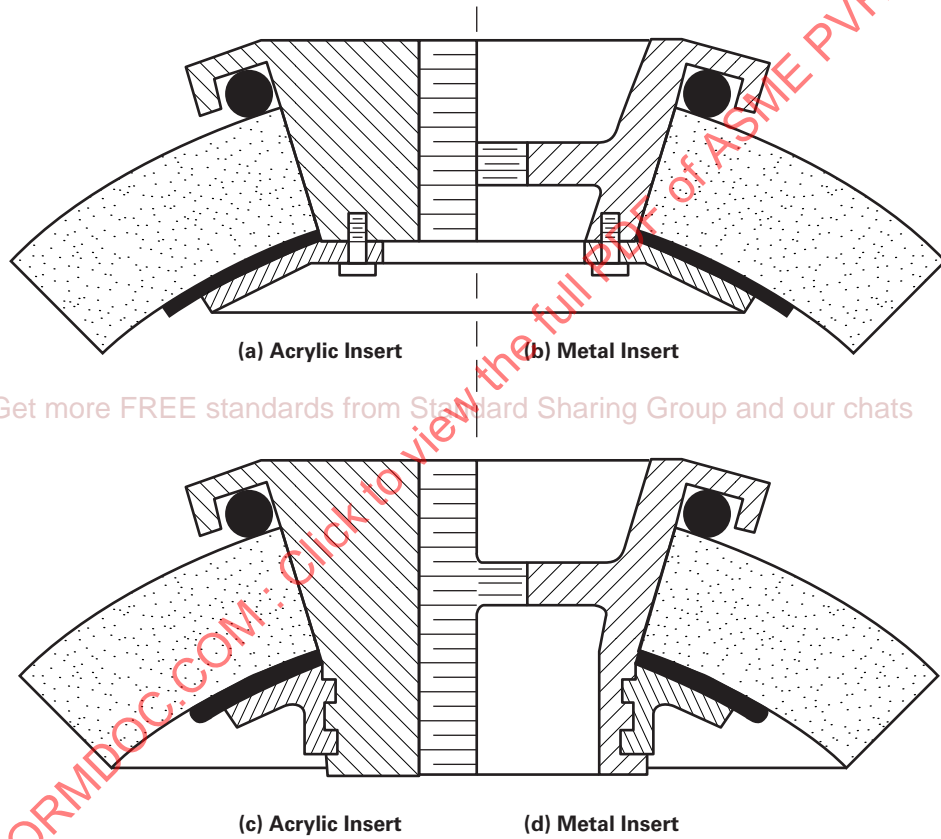
Fig. 2-2.14.22-1 Seal Configurations for Inserts in Acrylic Windows

Fig. 2-2.14.24-1 Restraints for Inserts in Acrylic Windows



including chemical analysis and mechanical tests. In addition, the results of any applicable supplementary tests shall be recorded.

2-3 MATERIAL

2-3.1 Material Restrictions

Windows shall be fabricated only from cast polymethyl methacrylate plastic, hereafter referred to as acrylic.

2-3.2 Laminated Sheets

Laminating several sheets of acrylic to arrive at the desired window thickness is not permitted.

2-3.3 Acrylic Bonding

Joining of acrylic castings by bonding is permitted provided the following requirements are met:

- (a) The joint shall be subjected only to membrane compressive stresses.
- (b) The properties of the bond joint shall meet or exceed those specified in para. 2-3.10.
- (c) The joint shall be pressure tight during hydrostatic testing of the window.

2-3.4 Acrylic Requirements

The acrylic used for fabrication of windows shall satisfy the following two general requirements:

(a) The casting process used in production of acrylic shall be capable of producing material with the minimum physical properties shown in Table 2-3.4-1. The manufacturer of material shall provide certification to the window fabricator that the typical physical properties of the material satisfy the criteria of Table 2-3.4-1. The material manufacturer's certification shall convey the information in a form equivalent to PVHO-1 Form VP-3. The certification shall identify the material by lot number and shall be marked in such a way that each casting shall be positively identified with the lot number. If the manufacturer is not willing to certify that the typical physical properties of the castings meet the requirements in Table 2-3.4-1, experimental verification of all properties shown in Table 2-3.4-1 becomes mandatory.

(b) The acrylic castings from which the windows are produced shall meet the minimum physical properties specified in Table 2-3.4-2 after the castings have been annealed per para. 2-4.5. The acceptance tests of castings shall be conducted for the window fabricator by the manufacturer of acrylic or by an independent materials testing laboratory. The results of the material acceptance tests (specified in Table 2-3.4-2) for sheet or custom castings shall be certified on a form equivalent to PVHO-1 Form VP-4. This certification shall be provided to the window fabricator and shall become a part of the certification information forwarded to the chamber manufacturer or user.

2-3.5 Acrylic Form

Acrylic castings shall be supplied in sheet form or as custom castings. All acrylic sheet castings shall have a nominal thickness of $\frac{1}{2}$ in. (12.5 mm) or greater.

For purposes of this Standard, acrylic in the form of custom castings is classified as either Type 1 or Type 2 castings.

(a) *Type 1 custom castings* are defined as being of such thickness and configuration, and produced by such a process as to meet the requirements of Table 2-3.4-1 without experimental verification. To classify a casting as a Type 1 custom casting, the manufacturer of acrylic shall certify that he has produced castings of similar shape and thickness and of the same material in the past and that such castings have met the requirements of Table 2-3.4-1.

(b) *Type 2 custom castings* are defined as being produced in such a thickness or configuration, or by such a process that the manufacturer of acrylic must experimentally verify that the acrylic castings possess the minimum physical properties specified in Table 2-3.4-1. All custom castings failing to meet the requirements of Type 1 shall be classified as Type 2 custom castings.

2-3.6 Material Property Tests

Acceptance tests performed according to para. 2-3.4(b) on a single casting can be used not only to certify the particular casting, but also, under special circumstances, to certify an entire lot.

(a) Acceptance tests performed according to para. 2-3.4(b) on one sheet casting chosen at random from a lot of acrylic cast sheets shall serve to certify all sheets of that lot provided that the manufacturer of acrylic shall positively and permanently identify each sheet so certified with a lot number and the designation ASME PVHO-1.

(b) The manufacturer of acrylic sheet castings may certify that a product of a given thickness meets the typical physical properties specified in Table 2-3.4-1 without identification of lot number. Each casting so certified shall have acceptance tests performed on it according to para. 2-3.4(b) and at that time have assigned to it an inventory control identification that shall be affixed to the casting by the window fabricator and used in lieu of a lot identification in all ASME PVHO-1 documentation.

(c) Acceptance tests performed according to para. 2-3.4(b) on specimens cut from one Type 1 custom casting shall serve to certify all castings of that lot. The manufacturer shall positively and permanently identify each certified casting with lot number and safety standard designation ASME PVHO-1.

(d) Single Type 1 custom castings shall have acceptance tests performed according to paras. 2-3.4(a) and (b) on specimens cut from each casting.

Table 2-3.4-1 Specified Values of Physical Properties for Each Lot

Test Procedures	Physical Property	Specified Values	
		U.S. Customary Units	Metric Units
ASTM D256 [Note (1)]	Izod notched impact strength	≥0.25 ft-lb/in.-min	≥13.3 J/m
ASTM D542	Refractive index	1.49 + 0.01	1.49 + 0.01
ASTM D570 [Note (1)]	Water absorption, 24 hr	≤0.25%	≤0.25%
PVHO-1 method, para. 2-3.7(c)	Compressive deformation at 4,000 psi (27.6 MPa), 122°F (50°C), 24 hr	≤1.0%	≤1.0%
ASTM D638 [Note (1)]	Tensile:		
	(a) ultimate strength	≥9,000 psi	≥62 MPa
	(b) elongation at break	≥2%	≥2%
	(c) modulus	≥400,000 psi	≥2 760 MPa
ASTM D695 [Note (1)]	Compressive:		
	(a) yield strength	≥15,000 psi	≥103 MPa
	(b) modulus of elasticity	≥400,000 psi	≥2 760 MPa
ASTM D732 [Note (1)]	Shear, ultimate strength	≥8,000 psi	≥55 MPa
ASTM D785 [Note (1)]	Rockwell hardness	≥M scale 90	≥M scale 90
ASTM D790 [Note (1)]	Flexural ultimate strength	≥14,000 psi	≥97 MPa
ASTM D792 [Note (1)]	Specific gravity	1.19 ± 0.01	1.19 ± 0.01
PVHO-1 method, para. 2-3.7(d)	Ultraviolet (290 nm–330 nm) light transmittance	≤5%	≤5%
PVHO-1 method, para. 2-3.7(e)	Clarity, visually rated	Must have readability	Must have readability
ASTM D696	Coefficient of linear thermal expansion at	≤10 ⁻⁵ (in./in. °F)	≤10 ⁻⁵ (mm/mm °C)
	°F °C		
	–40 –40	2.9	5.22
	–20 –29	3.0	5.40
	0 –18	3.2	5.76
	20 –7	3.4	6.12
	40 4	3.7	6.66
	60 16	4.0	7.20
	80 27	4.3	7.74
	100 38	4.7	8.46
	120 49	5.1	9.18
	140 60	5.4	9.72
ASTM D648	Deflection temperature of plastics under flexure at 264 psi (1.8 MPa)	≥185°F	≥85°C
PVHO-1 method, para. 2-3.8	Total residual monomer:		
	(a) methyl methacrylate	≤1.6%	≤1.6%
	(b) ethyl acrylate		

GENERAL NOTE: The manufacturer shall certify that the typical physical properties of the acrylic satisfy the criteria in this table.

NOTE:

- (1) These tests require testing a minimum of two specimens. For others, test a minimum of one specimen. Where applicable, use the sampling procedures described in para. 2-3.7. For other tests, use the sampling procedures described in the appropriate ASTM test methods. Where two specimens are required in the test procedure, the average of the test values shall be used to meet the requirements of the minimum physical properties of this table.

PVHO-1 Form VP-3 Material Manufacturer's Certification for Acrylic

The _____ in. (cm) × _____ in. (cm) acrylic sheet/custom castings of _____ in. (cm) nominal thickness in Lot No. _____ have been produced by _____ under the trademark of _____.

These castings possess typical physical properties satisfying the minimum values specified in Safety Standard for Pressure Vessels for Human Occupancy, Section 2, Table 2-3.4-1, in accordance with the material manufacturer's Quality Assurance Manual Edition _____, Rev. _____, dated _____.

authorized representative of manufacturer of plastic

date

name and address of manufacturer of plastic

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(e) Type 2 custom castings shall have tests performed according to paras. 2-3.4(a) and (b) on specimens cut from each casting to experimentally verify that the acrylic possesses the physical properties specified in both Tables 2-3.4-1 and 2-3.4-2. Tests for experimental verification of properties in Table 2-3.4-1 shall serve also to certify the properties in Table 2-3.4-2.

(16) 2-3.7 Properties Test Specifications

Testing of acrylic castings for the physical and optical properties specified in Tables 2-3.4-1 and 2-3.4-2 shall follow ASTM methods where applicable. Where possible, samples for testing shall be taken from an integral part of the casting. A test coupon casting may be used to supply material for testing provided the test coupon and window castings meet the lot requirements. Samples for testing shall be cut so that no surface of the test sample is closer to an unfinished cast surface than the normal trim line. Where possible, test samples shall be cut from the central portion of the original casting (e.g., a large casting cut into several windows). The test methods for physical properties specified in Table 2-3.4-2 shall be as follows:

(a) Tests for tensile properties shall be performed per ASTM D638, using a testing speed of 0.20 in./min (5.0 mm/min) $\pm 25\%$.

(b) Tests for compressive deformation shall be per ASTM D695.

(c) *Tests for Compressive Deformation*

(1) *General.* Tests for compressive deformation shall be performed using specimens loaded to 4,000 psi (27.6 MPa) and tested at 122°F (50°C). The sample size

is a $\frac{1}{2}$ -in. (12.5-mm) cube. To test nominal $\frac{1}{2}$ -in. (12.5-mm) thick material, machine the specimen in such a manner that the as-cast surfaces serve as the load-bearing surfaces. Do not stack samples to reach $\frac{1}{2}$ in. (12.5 mm) height; instead test a sample, $\frac{1}{2}$ in. \times $\frac{1}{2}$ in. (12.5 mm \times 12.5 mm) nominal thickness. For materials that are cast with irregular surfaces or thicker than $\frac{1}{2}$ in. (12.5 mm), machine the samples from the casting such that compression face is as close as possible to the bottom side of the casting.

(2) *Procedure.* Place the test specimen between the anvils of the testing machine. Apply the load to the specimen without shock and take the initial reading 10 sec after the full load is on the specimen. At the end of 24 hr, take a second reading and record the total change in height. Determine the original height of the specimen by measuring the specimen after it is removed from the testing machine and adding this to the total change in height as read on the dial of the testing machine.

(3) *Calculation.* Calculate the deformation as the percentage change in height of the test specimen after 24 hr, as follows:

$$\text{Deformation, \%} = (A/B) \times 100$$

where

A = change in height in 24 hr (= height after load application – height after 24 hr)

B = original height (= height after removal + total change)

Table 2-3.4-2 Specified Values of Physical Properties for Each Casting

Test Procedures	Physical Property	Specified Values	
		U.S. Customary Units	Metric Units
ASTM D638 [Note (1)]	Tensile:		
	(a) ultimate strength	≥9,000 psi	≥62 MPa
	(b) elongation at break	≥2%	≥2%
	(c) modulus of elasticity	≥400,000 psi	≥2 760 MPa
ASTM D695 [Note (1)]	Compressive:		
	(a) yield strength	≥15,000 psi	≥103 MPa
	(b) modulus of elasticity	≥400,000 psi	≥2 760 MPa
ASTM D790 [Note (1)]	Flexural ultimate strength	≥14,000 psi	≥97 MPa
PVHO-1 method, para 2-3.7(c)	Compressive deformation at 4,000 psi (27.6 MPa) and 122°F (50°C) for 24 hr	≤1.0%	≤1.0%
PVHO-1 method, para 2-3.7(d)	Ultraviolet transmittance [for 0.5 in. (12.5 mm) thickness]	≤5%	≤5%
PVHO-1 method, para. 2-3.7(e)	Visual clarity	Must pass readability test	Must pass readability test
PVHO-1 method, para. 2-3.8	Total residual monomer:		
	(a) methyl methacrylate	≤1.6%	≤1.6%
	(b) ethyl acrylate		

GENERAL NOTE: To be verified by testing of specimen from each casting or lot as defined in para. 2-3.5.

NOTE:

- (1) These tests require testing a minimum of two specimens. For others, test a minimum of one specimen. Where applicable, use the sampling procedures described in para. 2-3.7. Where two specimens are required in the test procedure, the average of the test values shall be used to meet the requirements of the minimum physical properties of this table.

PVHO-1 Form VP-4 Material Testing Certification for Acrylic

1. Test specimens have been ☐ cut from casting or ☐ supplied already cut by _____
2. Test specimen taken from ☐ acrylic sheet or ☐ custom castings No. _____ in Lot No. _____ of _____
- in. (cm) nominal thickness that have been produced by _____ under the
(material manufacturer)
- trademark of _____ possess the following physical and chemical properties:

Test Method	Property	Results
PVHO-1 method, para. 2-3.7(c)	Compressive deformation at 4,000 psi (27.6 MPa) and 122°F (50°C)	_____
ASTM D638	Tensile: (a) ultimate strength (b) elongation at break (c) modulus of elasticity	_____ _____ _____
ASTM D695	Compressive: (a) yield strength (b) modulus of elasticity	_____ _____
PVHO-1 method, para. 2-3.7(d)	Ultraviolet transmittance [for 1/2 in. (12.5 mm) thickness]	_____
PVHO-1, para. 2-3.7(e)	Visual clarity	_____
PVHO-1, para. 2-3.8	Total residual methyl methacrylate and ethyl acrylate monomers	_____% _____%

The experimentally proven properties satisfy the minimum values specified in Table 2-3.4-2 of the Safety Standard for Pressure Vessels for Human Occupancy.

authorized representative of material testing laboratory

date

name and address of material testing laboratory

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(4) *Report.* The report shall include the following:

- (-a) original height of the test specimen
- (-b) thickness of the cube
- (-c) conditioning procedure
- (-d) temperature of test and the force applied
- (-e) change in height of the test specimen in 24 hr
- (-f) deformation (flow or combined flow and shrinkage) expressed as the percentage change in height of the test specimen calculated on the basis of its original height

NOTE: Measurements shall be made in consistent units measured to the nearest 0.001 in. (0.0254 mm).

(d) Test for the presence of an ultraviolet absorber (ultraviolet transmittance) shall be made using a scanning ultraviolet monochromator having a bandwidth of 10 nm or less and a minimum sensitivity of 0.02%, a photometer having reproducibility of +1% of full scale, and the practices of ASTM E308 to measure the spectral transmittance in the 290 nm to 330 nm wavelength band. Report the value of one specimen of $\frac{1}{2}$ in. \pm 0.01 in. (12.7 mm \pm 0.25 mm) thickness with light passing through polished faces. Report the maximum percent transmission detected between 290 nm and 330 nm and the peak location where the maximum percent transmission was located. Measurements can be made on the casting or on the monomer mix from which the plastic is to be cast. Solid samples shall have two polished faces through which the light passes.

(e) The clarity of a finished window shall be visually rated. Clear print of size 7 lines per column inch (25 mm) and 16 characters to the linear inch (25 mm) shall be clearly visible when viewed from a distance of 20 in. (500 mm) through the thickness of the finished window.

(f) Since an ASTM standard method is not available for measurement of residual acrylic monomer, the procedure specified in para. 2-3.8 is recommended.

2-3.8 Testing for Unpolymerized Acrylic

A sample of suitable size shall be obtained and analyzed for unpolymerized methyl methacrylate and unpolymerized ethyl monomers using gas liquid chromatographic techniques (described in Snell and Otto, *Encyclopedia of Industrial Chemical Analysis*, Interscience Publisher, 1972, Vol. 4, pp. 211–217, and Vol. 16, p. 99, or one giving equivalent results). Samples for testing shall be cut so that the center point of the analyzed piece is no closer to the original edge or surface of the casting than the thickness divided by 2. The following (after Cober and Samsel, SPE Transactions "Gas Chromatograph, a New Tool for Analysis of Plastics," April 1962, pp. 145–151) is a suitable procedure:

(a) The instrument shall be a Beckman GC-2A gas chromatograph with a hydrogen flame detector, or equivalent, and a 6-ft (1.8-m) column of $\frac{1}{4}$ in. (6.0 mm) stainless tubing operated at 212°F (100°C). Pack the column with 25% diethylene glycol adipate polyester

(LAC-2R-446, Cambridge Industries Co.) and 2% phosphoric acid on an 80–100 mesh Celite filter aid. The acrylic to be analyzed shall weigh approximately 2.0 g and shall be dissolved in exactly 50 mL of methylene chloride. Inject a 3- μ L aliquot of the plastic-solvent solution into the gas chromatographic apparatus. Compare the area of the resulting peaks with the areas produced by the injection of a standard solution. Prepare the standard solution by dissolving 20 mg to 30 mg of pure monomers in 50 mL of methylene chloride.

(b) Acrylic that does not dissolve shall be analyzed by swelling the plastic and extracting the soluble portion. Place a solid piece of insoluble acrylic about 1 g and 20 mL of methylene chloride in a glass bottle, and place on a shaker for 24 hr. After 24 hr, the fluid portion shall be analyzed for monomeric methyl methacrylate and monomeric ethyl acrylate per para. 2-3.5(a).

2-3.9 Windows Greater Than 6 in. Thick

Windows in excess of 6 in. (150 mm) thickness shall require material testing of two samples from the casting. One sample shall be taken from the surface of the casting. The second sample shall be taken from the interior of the casting at a distance from any surface equal to half the thickness. The properties of each sample shall meet the requirements of Table 2-3.4-2.

2-3.10 Bond Testing

The physical properties of bonds shall meet or exceed the following:

(a) The tensile strength of the bond shall be at least 50% of the parent material strength as established by the ASTM D638 test on five tensile coupons cut from a bond quality control specimen that was bonded at the same time and in the same manner as the acrylic castings intended for actual service.

(b) The significant and critical dimensions of inclusions, as well as the critical spacing between adjacent inclusions, shall not exceed those specified in para. 2-5.4 for a given window shape. The critical size of inclusion population shall not exceed the cross-sectional area of the bonded joint in square centimeters divided by 10. The critical density of population shall not exceed 2 inclusions per square centimeter of contiguous joint cross-sectional area.

2-4 FABRICATION

2-4.1 Responsibilities and Duties for Window Fabricators

The window fabricator's responsibilities include the following:

(a) compliance with this Standard and the appropriate referenced standard(s)

(b) procurement control of material, parts, and services

(c) establishing and maintaining a Quality Assurance Program in accordance with Section 3

(d) documenting the Quality Assurance Program in accordance with Section 3

(e) furnishing the purchaser with appropriate Certification Report(s)

(f) ensuring that the subcontracted activities comply with the appropriate requirements of this Standard

The PVHO window fabricator shall retain overall responsibility, including certifying and marking PVHO windows.

2-4.2 Quality Assurance and Marking

Windows shall be fabricated only from acrylic castings satisfying the requirements of Sections 2 and 3. This shall be accomplished by the window fabricator through compliance with the following procedures:

(a) The window fabricator shall establish and maintain a current and documented Quality Assurance Program that complies with Section 3 of this Standard.

(b) All castings used for fabrication of windows shall be marked prominently with letters and/or numbers that are traceable to the material certifications (see PVHO-1 Form VP-3, PVHO-1 Form VP-4, and PVHO-1 Form VP-1).

(c) Each window shall be numbered per para. 2-6.1, and these numbers shall be traceable to the castings from which they were fabricated. This traceability shall be certified on the fabrication data report, which shall provide, in equivalent form, the information shown on PVHO-1 Form VP-1.

2-4.3 Use of Solvent

No fabrication process, solvent, cleaner, or coolant that degrades the original physical properties of the acrylic casting shall be used during fabrication.

2-4.4 Identification

During the fabrication process, each window shall be identified with identification and fabrication verification documents containing pertinent material and fabrication data.

2-4.5 Annealing

All window material shall be annealed after all forming, machining, and machine polishing have been completed. All annealing shall take place in a forced-air circulation oven. Annealing shall be in accordance with Table 2-4.5-1. Time and temperature data for all annealing cycles shall be entered into PVHO-1 Form VP-1. A copy of the final anneal's time/temperature chart shall be attached to PVHO-1 Form VP-1.

2-4.6 Polishing

Hand lapping and hand polishing to remove scratches caused by handling may be performed after final annealing.

2-4.7 Inspection

Each window shall be inspected in accordance with subsection 2-5, after the final anneal.

2-5 INSPECTION

2-5.1 General

The quality control inspection shall consist of dimensional and visual checks to ensure the finished window meets the dimensional tolerances, material quality, and surface finish requirements specified in subsections 2-2 through 2-4. Windows that meet the requirements of subsections 2-2 through 2-4 and the requirements of this section shall be accepted. In particular, dimensional measurements shall be made to show compliance with para. 2-2.12.

2-5.2 Inspection Temperature and Orientation

All dimensional and angular measurements shall be performed at a material temperature of 70°F to 75°F (21°C to 24°C). For hyperhemisphere, cylindrical, and NEMO-type windows, measurements for deviation from true circular form, such as out-of-roundness and sphericity, shall be conducted at least 24 hr after placing the window in the orientation of, and supported in a similar manner to, the intended service. Out-of-roundness measurements of cylindrical windows shall be taken at both ends and at 25%, 50%, and 75% of the window length.

2-5.3 Surface Scratches

Scratches (or machining marks) on the surfaces of and inclusions in the body of the window shall not be acceptable if they exceed the specified critical dimension, critical spacing, critical size of population, or critical density of population, or are found in a critical location.

2-5.4 Inclusion Inspection

The critical dimensions of inclusions, critical spacing, critical size of inclusion population, critical location, and critical density of inclusion population depend on the shape of the window. Only inclusions whose diameter or length exceeds the following specified significant dimension shall be considered during a visual inspection; all others shall be disregarded.

(a) For spherical sectors with conical edge, hyperhemispheres, NEMO windows, conical frustums and double beveled disks with $t/D_i \geq 0.5$, and cylinders under external pressure loading

(1) *significant dimension:* 0.015 in. (0.4 mm)

(2) *critical dimension:* 0.05t

(3) *critical size of population:* total volume of window in cubic centimeters divided by 10 000

(4) *critical density of population:* one inclusion per 1 in.³ (16 cm³) of contiguous volume

Table 2-4.5-1 Annealing Schedule for Acrylic Windows**Part A: Minimum Heating Times of Elevated Temperature Annealing of Acrylic**

Thickness, in. (mm)	Heat Time [Note (1)], hr, for Acrylic Placed in a Forced-Air Circulation Oven Maintained at a Set Temperature Within $\pm 5^{\circ}\text{F}$ ($\pm 2.8^{\circ}\text{C}$)			
	230°F, Max. (110°C)	212°F, Min. (100°C)	195°F, Min. (90°C)	185°F, Min. (85°C)
0.50 (12.70)	3.5	4.0	6.0	11.0
0.75 (19.05)	4.4	4.9	6.9	11.8
1.00 (25.40)	5.3	5.9	7.7	12.6
1.25 (31.75)	6.2	6.8	8.6	13.4
1.50 (38.10)	7.1	7.7	9.4	14.1
1.75 (44.45)	8.0	8.6	10.3	14.9
2.00 (50.80)	8.9	9.6	11.1	15.7
2.25 (57.15)	9.8	10.5	12.0	16.5
2.50 (63.50)	10.6	11.4	12.9	17.3
2.75 (69.85)	11.5	12.4	13.7	18.1
3.00 (76.20)	12.4	13.3	14.6	18.9
3.25 (82.55)	13.3	14.2	15.4	19.6
3.50 (88.90)	14.2	15.1	16.3	20.4
3.75 (95.25)	15.1	16.1	17.1	21.2
4.00 (101.60)	16.0	17.0	18.0	22.0
>4.000	4	6	6	6

(per in. of additional thickness over 4)

Part B: Maximum Cooling Rates for Acrylic Subjected to Elevated Annealing Temperatures

Thickness, in. (mm)	Maximum Cooling Rate, °F/hr (°C/h)	Time, hr, to Cool Acrylic From the Indicated Annealing Temperature at the Maximum Permissible Rate to the Maximum Allowable Removal Temperature of 120°F (49°C)			
		230°F (110°C)	212°F (100°C)	195°F (90°C)	185°F (85°C)
0.500 to 0.750 incl. (13 to 19, incl.)	25 (14)	4.5	3.5	3	2.5
0.875 to 1.125, incl. (22 to 28, incl.)	18 (10)	6	5	4	4
1.250 to 1.500, incl. (32 to 38, incl.)	13 (7.2)	8.5	7	6	5
1.750 (44)	11 (6.1)	10	8.5	7	6
2.000 (50)	10 (5.5)	11	9	7.5	6.5
2.250 (57)	9 (5)	12.5	10	8.5	7.5
2.500 (64)	8 (4.5)	14	11.5	9.5	8.5
3.000 (75)	7 (4)	16	13	11	9.5
3.250 (82)	6 (3.5)	18.5	15	12.5	11
3.500 (89)	6 (3.5)	18.5	15	12.5	11
3.750 (92)	6 (3.5)	18.5	15	12.5	11
4.000 (100)	5 (3)	22	18	15	13
4.000 to 6.000, incl. (100 to 150, incl.)	4 (2)	27.5	23	19	16.5
6.000 to 8.000, incl. (150 to 200, incl.)	3 (1.5)	37	30.5	25	22
8.000 to 10.000, incl. (200 to 250, incl.)	2 (1)	55	45.5	37.5	32.5
10.000 to 12.000, incl. (250 to 300, incl.)	1 (0.5)	110	91	75	65

NOTE:

(1) Includes period of time required to bring part up to annealing temperature, but not cooling time.

(5) *critical spacing between adjacent inclusions*: select the larger of the two adjacent inclusions and multiply its diameter by a factor of 2

(6) *critical locations*: no inclusions are permitted on or within critical spacing of all of the bearing and sealing surfaces

(b) For spherical sectors with square edge, hemispheres with equatorial flange, cylinders under internal pressure, conical frustums and double beveled disks with $t/D_i < 0.5$, and disks

(1) *significant dimension*: 0.015 in. (0.4 mm)

(2) *critical dimension*: 0.030 in. (0.8 mm)

(3) *critical size of population*: total volume of window in cubic centimeters divided by 10 000

(4) *critical density of population*: one inclusion per 1 in.³ (16 cm³) of contiguous volume

(5) *critical spacing between adjacent inclusions*: 0.25 in. (6 mm)

(6) *critical locations*: no inclusions are permitted on or within critical spacing of all of the surfaces

(c) Windows may be fabricated from acrylic castings with inclusions that exceed the 0.03-in. (0.8-mm) critical dimension specified by para. 2-5.4(b)(2), provided that the structural performance of the window is not compromised by the presence of these inclusions.

This is to be accomplished by restricting the inclusions to only certain types and sizes, and by compensating their effect on the critical pressure of the window with an increase in tensile strength of the acrylic, or an increase in design critical pressure of the finished window, or both.

(1) Inclusions are allowed in flat disks, cylinders under internal pressure, spherical sectors with square edges, hemispheres with equatorial flange, and double beveled disks and conical frustums with $t/D_i < 0.5$, provided that the following requirements are met:

(-a) Significant dimension of the inclusion is 0.03 in. (0.8 mm).

(-b) Critical dimensions of the inclusions are

(-1) voids, specks, and grains of dirt; fragments of metal, wood, or rubber: 0.06 in. (1.5 mm)

(-2) hair or cloth fibers: 2 in. (50.8 mm) long

(-3) plastic foil fragments: 0.15 in. long × 0.06 in. wide × 0.03 in. thick (3.8 mm × 1.5 mm × 0.76 mm)

(-c) Critical size of population is total volume of the casting in cubic inches divided by 1,000.

(-d) Critical density of inclusion population is one inclusion per cubic inch.

(-e) Critical spacing between adjacent inclusions is 0.25 in. (6.35 mm).

(-f) Critical locations are such that inclusions are not permitted closer than 0.125 in. (3.2 mm) from the finished window surface.

(2) The finished window containing one or more inclusions shall satisfy one of the following structural requirements:

(-a) The minimum tensile strength of inclusion-free tensile test specimens from the lot of casting used in manufacture of windows shall be ≥11,000 psi, and the short-term design-critical pressure of the window shall meet the requirement of this Standard.

(-b) The minimum tensile strength shall be ≥10,000 psi, and the window's short-term design-critical pressure shall exceed the requirements of this Standard by ≥10%.

(-c) The minimum tensile strength shall be ≥9,000 psi, and the window's STCP shall exceed the requirements of this Standard by ≥20%.

2-5.5 Scratch Characterizations

Critical dimensions of scratches (or machining marks), critical spacing, critical sizes of scratch population, critical locations, and critical densities of scratch population depend on the shape of the window. Only scratches whose depth exceeds the significant dimension shall be considered during a visual inspection; all others shall be disregarded.

(a) For spherical sectors with conical edge, hyperhemispheres, NEMO windows, conical frustums and double beveled disk with $t/D_i ≥ 0.5$, and cylinders under external pressure loading

(1) *significant dimension*: 0.01 in. (0.25 mm)

(2) *critical dimension*: 0.02 in. (0.5 mm)

(3) *critical size of population*: total length of all scratches in centimeters equals total area of scratched surface in square centimeters divided by 1 000

(4) *critical density of population*: none specified

(5) *critical spacing between scratches*: none specified

(6) *critical locations*: no scratches are permitted on the bearing and sealing surfaces

(b) For conical frustums and double beveled disks with $t/D_i < 0.5$, flat disks, and cylinders under internal pressure

(1) *significant dimension*: 0.003 in. (0.08 mm)

(2) *critical dimension*: 0.01 in. (0.25 mm)

(3) *critical size of population*: total length of all scratches in centimeters equals total area of scratched surface in square centimeters divided by 1 000

(4) *critical density of population*: none specified

(5) *critical spacing between scratches*: none specified

(6) *critical locations*: no scratches are allowed on the bearing and sealing surfaces, on any faces of double beveled disks and cylinders, or on low-pressure faces of conical frustums and disks

(c) For spherical sectors with square edge and hemispheres with equatorial flange of acrylic

(1) *significant dimension*: 0.003 in. (0.08 mm)

(2) *critical dimension*: 0.01 in. (0.25 mm)

(3) *critical size of population*: total length of all scratches in centimeters equals total area of scratched surface in square centimeters divided by 1 000

(4) *critical density of population*: none specified

(5) *critical spacing between scratches*: none specified

(6) *critical locations*: no scratches are permitted on bearing and sealing surfaces, on the low-pressure face of spherical sector with square edge, or in the heel and instep areas of flanged hemispheres

2-5.6 Repairs

Repairs to new windows that do not meet acceptance criteria shall be performed in accordance with subsection 2-9.

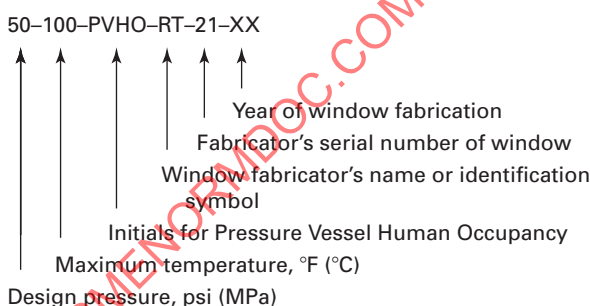
2-5.7 Inspection Report

After the quality control inspection, each acceptable window shall be certified as to fabrication processes on a fabrication data report. The report shall be made on a form equivalent to PVHO-1 Form VP-1. This report shall be forwarded to the chamber manufacturer or user as a part of the certification package.

2-6 MARKING

2-6.1 Marking Location, Configurations

Identification of each window with the window fabricator's certification shall be located on the window's seating surface. Identification shall consist of $\frac{1}{2}$ -in. (12.5-mm) letters and numbers made by the window fabricator with an indelible black felt marker, or $\frac{1}{8}$ -in. (3.2-mm) letters and numbers applied with epoxy ink. The identification shall contain information per the following example:



2-6.2 Certification Completion

At the time of marking, the window fabricator shall certify the overall fabrication of the window by completing window certification PVHO-1 Form VP-1. Only after completion of PVHO-1 Form VP-1 shall the window be considered to have met the requirements of this Standard, and the window can be marked in accordance with para. 2-6.1. This window certification shall be forwarded to the purchaser or used as part of the window certification package.

2-6.3 Marking Restrictions

The windows shall be marked by the window fabricator with PVHO identification per para. 2-6.1 only if the design, material manufacture, material testing, and fabrication have been completed and are on file with the window fabricator applying the markings after having met the requirements of para. 2-6.2.

2-6.4 Additional Marking

The window may also be marked with additional identifications. The size of letters, method of application, and their location on the window shall satisfy the requirements of para. 2-6.1.

2-6.5 Marking Certification Retention

The window certification and data reports (PVHO-1 Forms VP-1 through VP-5) shall be retained for each window as follows:

(a) One copy of PVHO-1 Forms VP-1 through VP-5 shall be retained by the window fabricator, and one copy of the forms shall be furnished to the window purchaser if the window fabricator performs the pressure test.

(b) If the window fabricator does not perform the pressure test, he shall note this on PVHO-1 Form VP-1. One copy of PVHO-1 Forms VP-1 through VP-4 shall be retained by the window fabricator, and one copy of the forms shall be furnished to the purchaser of windows.

(c) If the purchaser of windows does not require the window fabricator to perform the pressure test, the purchaser shall have the pressure test performed by a qualified pressure test laboratory, or pressure test the windows according to subsection 2-7, either of which requires the completion of PVHO-1 Form VP-5.

(d) It shall be the responsibility of the owner/user and the chamber manufacturer to possess and retain PVHO-1 Forms VP-1 through VP-5 for a period not less than the design life of the window plus 2 yr.

(e) It shall be the responsibility of the window fabricator to possess and retain PVHO-1 Forms VP-1 through VP-4 (and PVHO-1 Form VP-5 if he performs the pressure test) for a period not less than the design life of the window plus 2 yr.

2-7 PRESSURE TESTING

2-7.1 Frequency

Each window shall be pressure tested at least once prior to being accepted for service.

2-7.2 Test Configuration

The pressure test shall take place with the window installed in the chamber or placed within a test fixture whose window seat dimensions, retaining ring, and seals are identical to those of the chamber.

PVHO-1 Form VP-5 Pressure Testing Certification**Window Identification** _____**Window Description**

Maximum allowable working pressure _____

Maximum design temperature _____

Test ArrangementWindows tested in operational viewport/simulated viewport _____
(operational/simulated)

Operational/simulated viewport drawing no. _____

Window tested according to subsection 2-7 _____
(yes/no)

Test pressure _____ psi _____ MPa

Overpressure ratio (test pressure/maximum allowable working pressure) _____

Pressurizing medium temperature _____ °F _____ °C

Rate of pressurization (average) _____

Duration of sustained pressurization _____

Test Observations (yes/no)

Leakage _____

Permanent deformation _____

Crazing _____

Cracking _____

The acrylic window was pressure tested according to the procedure of subsection 2-7 of the Safety Standard for Pressure Vessels for Human Occupancy and was found to perform satisfactorily without any visible permanent deformation, crazing, or cracking.

pressure test supervisor _____ date _____

name and address of pressure testing laboratory _____

authorized representative of chamber manufacturer (windows for new chamber),
or user (windows for replacement in an existing chamber) _____ date _____

GENERAL NOTE: This form may be reproduced and used without written permission from ASME if used for purposes other than republication.

2-7.3 Test Duration

The window shall be pressurized with gas or water until design pressure is reached. The design pressure shall be maintained for a minimum of 1 hr, but not more than 4 hr, followed by depressurization at a maximum rate not to exceed 650 psi/min (4.5 MPa/min).

2-7.4 Test Temperature

The temperature of the pressurizing medium during the test shall be the design temperature for which the window is rated with a tolerance of $+0/-5^{\circ}\text{F}$ ($+0/-2.5^{\circ}\text{C}$). Brief deviations from these temperature tolerances are allowed, provided that the deviation does not exceed 10°F (5.5°C) and lasts less than 10 min.

2-7.5 Window Leakage

Windows that leak during the pressure tests shall be removed, fitted out with new seals, and retested. If, during the retest, the leakage continues, efforts will be made to complete the test by stopping the leak with a temporary seal. The inability of seals to operate properly during the test shall be noted in the test report, which shall be submitted at the conclusion of the pressure test to the chamber manufacturer/user.

2-7.6 Post-Test Inspection

At the conclusion of the pressure test, the windows shall be visually inspected for the presence of crazing, cracks, or permanent deformation. This examination may be performed without removal of the window from the chamber.

2-7.7 Rejection Criteria

Presence of crazing, cracks, or permanent deformation visible with the unaided eye (except for correction necessary to achieve 20/20 vision) shall be the cause of rejection of the windows and shall be so noted on the test report. Permanent deformation less than $0.001D_i$ in magnitude measured at the center of the window shall not be cause for rejection.

2-7.8 Alternate Test Procedure

A hydrostatic or pneumatic test in excess of design pressure may be substituted for the mandatory tests of paras. 2-7.3 and 2-7.4 for windows with a design temperature of 125°F (52°C) or less. During the hydrostatic or pneumatic test, the pressure shall be maintained for a minimum of 1 hr, but not more than 4 hr. The test pressure shall not exceed 1.5 times the design pressure or 20,000 psi (138 MPa), whichever is the lesser value. To prevent permanent deformation of windows tested above design pressure, the temperature of the pressurizing medium during the test shall be at least 25°F (14°C) lower than the design temperature. For windows with a 50°F (10°C) design temperature, the pressurizing medium during the test shall be 32°F to 40°F

(0°C to 4°C). All the other requirements of the mandatory pressure test specified in paras. 2-7.5 through 2-7.7 shall be retained.

2-7.9 Reporting Requirements

After pressure testing, a pressure test report shall be completed to certify the results of the pressure test. The information shall be reported on a form equivalent to PVHO-1 Form VP-5 by the party who performs the pressure test.

2-7.10 Records Retention

Pressure test records shall be kept on file for at least the design life of the window plus 2 yr.

2-8 INSTALLATION OF WINDOWS IN CHAMBERS

2-8.1 Cleaning

The window cavity seat in the flange shall be thoroughly cleaned. Aliphatic naphtha and hexane are suitable fluids for cleaning.

2-8.2 Lubrication

The window cavity seats for all window shapes possessing conical bearing surfaces shall be thoroughly coated with grease prior to placement of the window inside the window cavity so that the greased surfaces will act as secondary seals. Silicone greases are suitable for this purpose. Other greases shall be checked for chemical compatibility with acrylic.

2-8.3 Assembly

After placement of the window inside the window cavity, the primary elastomeric seal shall be placed on the high-pressure face of the window and the retainer tightened until the seal compression reaches the minimum value specified in para. 2-2.11.

2-9 REPAIR OF DAMAGED WINDOWS PRIOR TO BEING PLACED IN SERVICE

2-9.1 General

New fabricated windows that do not meet the acceptance criteria of subsection 2-5, or windows that have been damaged during inspection, shipment, pressure testing, storage, handling, or installation in chambers but prior to being placed in service, may be repaired, provided the requirements of this section are met.

2-9.2 Damaged Window Criteria

For the purpose of this Standard, a damaged window is one that meets the criteria of Section 2, is marked per subsection 2-6, and has a Window Certification but has sustained damage that requires repair prior to being placed in service.

2-9.3 Dimensional Assessment

Windows are considered to be damaged when the window can no longer meet the dimensional tolerances and surface finishes specified by subsection 2-5. The assessment of damage shall be performed by an authorized representative of the chamber manufacturer or user or by a window fabricator.

2-9.4 Damage Severity Determination

The damage to windows, depending on its severity, may be repaired by the chamber user himself or by an accredited fabricator of windows. Only slightly damaged windows may be repaired by the chamber user or his authorized agent, while severely damaged windows shall be repaired solely by a window fabricator.

2-9.5 Slightly Damaged Windows

The damage to windows is considered slight when it consists solely of scratches on the surfaces less than 0.020 in. (0.5 mm) deep or chips on the window edges less than 0.125 in. (3.2 mm) wide. Scratches deeper than 0.020 in. (0.5 mm), edge chips wider than 0.125 in. (3.2 mm), gouges, and cracks are considered severe damage.

2-9.6 Repairs of Slightly Damaged Windows

Slightly damaged windows may be repaired by the chamber user or his authorized agent, provided only hand sanding/polishing techniques are used, and the thickness and surface finish of the window after repair meet the requirements of Section 2. The use of power-driven tools (disk sanders, buffing wheels, lathes, milling machines, etc.) is not allowed. These repairs do not require post annealing.

2-9.7 Repair of Severely Damaged Windows

Special conditions are applicable to the repair of severely damaged windows.

(a) Severely damaged windows shall be repaired by a window fabricator.

(b) Repair of severely damaged windows shall be initiated by the window fabricator only after receipt of written authorization from the chamber manufacturer or user and inspection of the damaged window for identification marking. Damaged windows whose identification does not correspond to the written authorization shall not be repaired.

(c) The written authorization shall be accompanied by the original Design (PVHO-1 Form VP-2) and Fabrication Certifications (PVHO-1 Form VP-1).

(d) During the repair, the window fabricator may use all the fabrication processes customarily employed in the fabrication of new windows that meet the requirements of subsection 2-4.

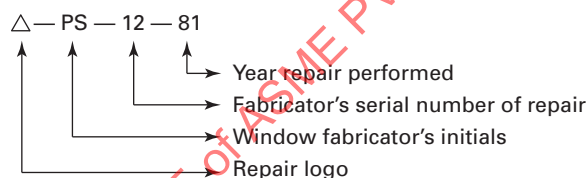
(e) Upon completion of repair, the window shall be annealed according to the schedule of Table 2-4.5-1.

(f) After annealing, the repaired window shall be inspected to ensure that the finished window meets the material quality, minimum thickness, dimensional tolerance, surface finish, and inclusion limitation requirements of Section 2.

(g) Repaired windows shall be marked with the identification of the window fabricator performing the repair.

(h) The repair identification shall consist of 0.5-in. (12.5-mm) letters and numbers made with indelible black marker or 0.125-in. (3.2-mm) letters and numbers made with epoxy ink located on the window's seating surface.

(i) The repair identification shall contain the following information, as per the following example:



The repair identification shall not obscure in any manner the original window identification.

(j) Original window identification marking that has been accidentally or intentionally removed during repair operations may be reapplied at this time, provided the restored original identification marking has identical wording to the original one that was removed, and the Repair Certification reflects this fact.

(k) The design life of the repaired window is determined by the original fabrication date shown on the window identification marking.

2-9.8 Repair of Spherical Window by Spot Casting

Windows with spherical surfaces whose dimensional tolerances, surface finish, or inclusions exceed the limits specified in paras. 2-2.12, 2-5.3, and 2-5.5 may be repaired by spot casting, provided the following conditions are satisfied:

(a) The repaired spot shall be subjected only to compressive stresses in service.

(b) The casting mix used for spot repairs shall have the same chemical composition and shall be polymerized in the same manner as the casting mix in the window casting.

(c) For repaired spots located in areas within 2 deg of the window's edge circumference, or areas not visible from the interior of the pressure vessel by an observer in a typical position required for operation of the vessel, the following limitations apply:

(1) The volume of a single repaired spot shall not exceed 10%, and the cumulative volume of all repaired spots shall not exceed 20% of the total window volume.

(2) There is no limit on the number of repaired spots.

(d) For repaired spots located in areas outside 2 deg of the window's edge circumference, and visible from the interior of the pressure vessel to an observer in a typical position required for operation of the vessel, the following limitations apply:

(1) The area of any repaired spot shall not exceed 0.025% of the total window area.

(2) Only two repaired spots are permitted.

(e) After completion of machining and polishing operations, the window shall be annealed per para. 2-4.5.

(f) Location and extent of spot casting repairs shall be noted on a sketch attached to PVHO-1 Form VP-6.

2-10 GUIDELINES FOR APPLICATION OF THE REQUIREMENTS OF SECTION 2

2-10.1 Introduction

(a) Section 2 presents the necessary information to design, fabricate, and pressure test acrylic windows that, when mounted and sealed in metallic seats, form the viewport assemblies acceptable as pressure-resistant barriers in pressure vessels for human occupancy.

(b) Restrictions are imposed on the service conditions to which the viewport can be subjected to preclude catastrophic failure of the window during its rated life. In order for the window to meet the high standard of safety demanded by human occupancy of the pressure vessel, each step in the production of the windows shall be certified for conformance to this Standard.

(c) Only high-quality cast acrylic (polymethyl methacrylate) is acceptable as the material for fabrication of windows under this Standard. Conformance of the material to the specifications of this Standard shall be proven by testing of material coupons (see subsection 2-3) and certification (PVHO-1 Forms VP-3 and VP-4).

2-10.2 Sample Design Procedures

(a) The design procedure consists of a series of steps, which allow the engineer to design a window meeting the requirements of this Standard (see subsection 2-2).

Step 1: Determine the design pressure, P , and temperature of the pressure vessel. Use the values as maximum design allowable for windows.

Step 2: Select the designed window shape from available standard window geometries (Figs. 2-2.2.1-1 through 2-2.2.1-4). Note the restrictions on the service in which they can be placed (see paras. 2-2.2 and 2-2.3).

If the design requirements cannot be met by a standard window geometry, a nonstandard window geometry of your own design may be chosen. In that case, disregard the remainder of design steps in paras. (a) through (c) of this section and follow instead the procedures specified in para. 2-2.6.

Step 3: Select the conversion factor (CF) appropriate for the chosen standard window geometry, pressure range, and temperature range (Tables 2-2.3.1-1 through 2-2.3.1-4). Use the pressure range into which the design pressure falls. The CF given by the table represents the lowest value acceptable to this Standard. Wherever feasible, select a higher value than shown in the tables.

Step 4: Calculate the short-term critical pressure (STCP) of the window by multiplying the design pressure, P , by the CF selected in Step 3.

Step 5: Calculate the dimensionless ratio(s) t/D_i or t/R for the chosen window geometry by finding the appropriate graph that relates the STCP to the window's dimensionless ratio (Figs. 2-2.5.1-1 through 2-2.5.1-12). Draw a horizontal line from the appropriate STCP on the ordinate to the graph. From where it intersects the graph, drop a vertical line to the abscissa. The intersection with the abscissa provides the sought-after dimensionless ratio. For design pressures, P , above 10,000 psi (69 MPa), use Table 2-2.3.2-1 to derive the required dimensional ratios. This table applies only to conical frustum windows with an included conical angle $\alpha \geq 60$ deg.

Step 6: Calculate the nominal window's dimensions on the basis of the dimensionless ratio. Wherever it is feasible, increase the nominal thickness to provide extra stock for future operational contingencies.

Step 7: Apply angular and dimensional tolerances to the nominal dimensions and specify surface finishes on the window (see para. 2-2.12). Enter all applicable data on drawings and PVHO-1 Form VP-2.

(b) The windows can achieve the predicted STCPs only if they are mounted in seats with appropriate cavity dimensions, stiffness, and surface finishes (see paras. 2-2.7, 2-2.10, and 2-2.12).

Step 1: Calculate seat cavity dimensions on the basis of Figs. 2-2.10.1-1 through 2-2.10.1-8. For windows with conical bearing surfaces, the magnitude of seat cavity surface overhang depends on both the included conical angle and the operational pressure range. The magnitude of overhang is given in terms of D_i/D_f ratios for any given combination of operational pressure ranges and conical angles. Operational pressure ranges 1, 2, 3, and 4 correspond to 0 psi to 2,500 psi, 2,500 psi to 5,000 psi, 5,000 psi to 7,500 psi, and 7,500 psi to 10,000 psi. For operational pressures above 10,000 psi (69 MPa), use Table 2-2.3.2-1.

PVHO-1 Form VP-6 Acrylic Window Repair Certification

Window Identification

1. Window Shape (From Visual Inspection)

Conical frustum _____ Double beveled _____
 Spherical sector with conical edge _____ Spherical sector with square edge _____
 Hemisphere with equatorial flange _____ Flat disk _____
 Hyperhemisphere with conical edge _____ NEMO _____
 Cylinder _____

2. Design Data (From PVHO-1 Form VP-2)

Original design certification prepared by _____
 Maximum allowable working pressure _____ Maximum design temperature _____
 Minimum thickness (calculated t) for above temperature and pressure _____

3. Original Fabrication Date (From PVHO-1 Form VP-1)

Original fabrication certification prepared by _____ (name of preparer)
 _____ (name of fabricator)
 Fabricated according to drawing _____ Identification marking _____
 Actual minimum thickness, t _____ Actual inside diameter, D_i _____
 Actual outside diameter, D_o _____

4. Repair Instructions (Refinish the following surfaces)

High-pressure face _____ Low-pressure face _____ Bearing surfaces _____
 Beveled edges _____ Sealing surfaces _____
 Spot casting meeting requirements of paras. 2-3.10 and 2-9.8 is
 authorized where appropriate _____
 The minimum thickness, t , of the repaired window is to meet or exceed _____
 The inside diameter, D_i , of the repaired window is to meet or exceed _____
 Repair of window has been authorized by _____ (name of company)
 _____ (name of authorized representative) _____ (signature of authorized representative)

5. Repair History (The following surfaces were refinished)

High-pressure face _____ Low-pressure face _____
 Bearing surfaces _____ Beveled edges _____
 Spot Casting Process
 Resin used _____ Catalyst used _____
 Polymerization technique _____
 Tensile strength of bond with acrylic per para. 2-3.10(a) _____
 Sketch of spot casting locations attached _____ (yes) _____ (no)
 Minimum thickness of repaired window _____
 The minimum thickness of repaired window meets or exceeds
 minimum calculated thickness of paras. 2-2.2 through 2-2.5 _____ (yes) _____ (no)
 The repaired window was annealed at _____ for _____ hr
 During fabrication the original window identification markings were Left intact _____ Removed and reapplied _____
 The repair marking applied to the window reads as follows _____

The refinished surfaces, spot castings, and minimum thickness of the repaired window meet all the requirements of Section 2 and the attached Design Certification PVHO-1 Form VP-2.

 authorized representative of window fabricator

 name and address of window fabricator

GENERAL NOTES:

- (a) The data for parts 1 through 4 of this form shall be provided and certified by the company/individual authorizing the repair of windows.
 (b) The repair process information required by part 5 shall be provided and certified by the window fabricator performing the repair.
 (c) This form may be reproduced and used without written permission from ASME if used for purposes other than republication.

Step 2: Calculate the stiffness compliance of the window seat with analytical formulas or finite element stress analysis computer programs to meet the requirements of para. 2-2.9. Since the window mounting forms a reinforcement around the penetration in the pressure vessel, its cross section shall also meet the requirements of the applicable Division of Section VIII of the Code.

Step 3: Apply angular and dimensional tolerances to the nominal dimensions and specify surface finishes on the seat cavity (see paras. 2-2.10 and 2-2.12). Enter all applicable data on the window seat drawing.

(c) Only certain sealing arrangements have been found to be successful with acrylic windows serving as pressure boundaries (see para. 2-2.11).

Step 1: Some of the proven seal designs acceptable under this Standard are shown in Figs. 2-2.5.1-1 through 2-2.5.1-6, 2-2.5.1-12, 2-2.10.1-2, and 2-2.10.1-5 through 2-2.10.1-8. Select the most appropriate sealing arrangement for your operational conditions. The bev-els on the edges of windows cannot exceed the limits shown in Figs. 2-2.11.10-1 and 2-2.11.10-2.

Step 2: Seal designs that deviate from the requirements of this Standard shall be subjected to an experimental validation program that will define their effect on the design life of the windows (see para. 2-2.7).

2-10.3 Sample Purchase Specification and Product Reviews

The designed window, in order to achieve the STCP, shall be fabricated by an accredited window fabricator using materials and a production process that meet the requirements of subsections 2-3 and 2-4, respectively.

Step 1: Ensure that the request for quotation and all drawings carry the following note:

"The cast acrylic, fabrication procedure, Quality Assurance Program, and finished window shall meet all the requirements of ASME PVHO-1."

This note alerts the fabricators to the additional factors imposed by certification requirements of this Standard.

Step 2: Provide the successful bidder with PVHO-1 Form VP-2, filled out by the window designer. PVHO-1 Form VP-2, together with the window drawing, shall form the basis for future identification of the window.

Step 3: Upon receiving the window from the window fabricator, inspect the finished product dimensionally and visually for compliance to this Standard (see para. 2-2.12 and subsection 2-4).

Review all of the paperwork, which shall accompany the window (PVHO-1 Forms VP-1 through VP-4). Check for completeness and signatures. Compare the marking on the window bearing surface with

(a) the identification number on PVHO-1 Form VP-1.

(b) the design temperature and pressure on PVHO-1 Form VP-2. Only when the window complies with the requirements imposed by this Standard, and the accompanying Window Certification, PVHO-1 Forms VP-1 through VP-4, is complete, can the fabrication be considered to have met all of the contractual obligations imposed by the above note on the window drawing.

2-10.4 Sample Pressure Test Instructions

The window can now be installed into a new pressure chamber or pressure tested in a test fixture and placed in storage for future use as a replacement. If the window is tested in a new chamber (see subsection 2-7 for details of pressure testing), the test shall be conducted without human occupants.

Step 1: Immediately after the pressure test; inspect the window visually for the presence of crazing, cracks, fractures, or permanent deformation.

Step 2: If the window passed the post-pressure test inspection successfully, fill out PVHO-1 Form VP-5.

Step 3: Review certifications, PVHO-1 Forms VP-1 through VP-5, for completeness.

2-10.5 Sample Calculations

(16)

The following sample calculations of hypothetical window and window seat dimensions illustrate the design procedure:

Step 1.1: Determine design conditions:

Design pressure = 1,000 psi

Design temperature = 125°F

Window diameter = 10 in.

Step 1.2: Select window shape:

Conical frustum with 90 deg included angle (Fig. 2-2.2.1-1)

Step 1.3: Select conversion factor:

$CF = 10, N = 1$

(Table 2-2.3.1-2)

Step 1.4: Calculate STCP:

$STCP = CF \times P = 10 \times 1,000$
= 10,000 psi (68.96 MPa)

Step 1.5: Select the dimensionless ratio for windows:

$t/D_i = 0.41$ for STCP = 68.96 MPa

$\alpha = 90$ deg (Fig. 2-2.5.1-5)

Step 1.6: Calculate nominal window dimensions:

$t/D_i = 0.41$

$D_i = 10$ in.

$$\alpha = 90 \text{ deg}$$

$$t = 0.41 \times 10 \text{ in.} = 4.1 \text{ in.}$$

Add 0.1 in. to thickness for future operational contingencies:

$$\text{Nominal } t = 4.2 \text{ in.}$$

$$\text{Nominal angle} = 90 \text{ deg}$$

$$\text{Nominal } D_i = 10 \text{ in.}$$

$$\text{Nominal } D_o = 18.4 \text{ in. (calculated)}$$

Step 1.7: Apply dimensional tolerances to windows (para 2-2.12):

$$D_o = 18.400 + 0.000 / -0.037 \text{ in. (to sharp edge)}$$

$$\alpha = 90 + 0.25 / -0.00 \text{ deg}$$

Bearing
surface finish = 32 μ in. RMS

Step 2.1: Calculate nominal dimensions for seat cavity:

$$D_o = 18.400 \text{ in.}$$

$$\alpha = 90 \text{ deg}$$

$$D_i/D_f = 1.03 \text{ for pressure range } N = 1 \text{ and included angle } 90 \text{ deg}$$

$$D_f = 10.000 / 1.03 = 9.709 \text{ in. (Fig. 2-2.10.1-1)}$$

Step 2.2: Calculate cross section of window mounting. (Use procedure of your own choice; NSRDC Report 1737 "Structural Design of Viewing

Ports for Oceanographic Vehicles," by K. A. Nott, 1963, can be very helpful.)

Step 2.3: Apply dimensional tolerances to window seat.

Step 3.1: Select sealing arrangement: neoprene O-ring seal compressed against beveled edge of major window diameter by a flat retaining ring (Fig. 2-2.5.1-4). The magnitude of the bevel cannot exceed the limits shown in Fig. 2-2.11.10-1. The size of the bevel chosen will provide adequate compression to a nominal 0.25-in. diameter O-ring.

Step 3.2: Enter the following final viewport dimensions on drawing:

Window:

$$D_o = 18.400 + 0.00 / -0.037 \text{ in. (to sharp edge)}$$

$$t = 4.200 + 0.020 / -0.00 \text{ in.}$$

$$\alpha = 90 + 0.25 / -0.000 \text{ deg}$$

Seal:

$$\text{O-ring thickness} = \frac{1}{4} \text{ in. (nominal)}$$

$$\text{O-ring inside diameter} = 17.75 \text{ in. (nominal)}$$

Seat:

$$D_o = 18.400 + 0.020 / -0.000 \text{ in.}$$

$$D_f = 9.709 + 0.010 / -0.000 \text{ in.}$$

$$\alpha = 90 + 0.000 / -0.25 \text{ deg}$$

Section 3

Quality Assurance for PVHO Manufacturers

3-1 GENERAL

This Section specifies the requirements for establishing and maintaining a Quality Assurance Program for PVHO manufacturers and window fabricators in accordance with the applicable edition of this Standard.

3-1.1 Scope

The responsibilities set forth herein relate only to compliance with this Standard.

3-1.2 Quality Assurance System Verification

This Section applies only to the structure and content of a Quality Assurance Program.

3-2 RESPONSIBILITIES

3-2.1 Compliance With This Standard

The PVHO manufacturer and window fabricator are responsible for implementing and maintaining the quality requirements as described in ISO 9001 or ISO 13485 whichever is applicable. It is not, however, the intent of this Standard to require a PVHO manufacturer's or window fabricator's Quality Assurance Program to be certified in accordance with ISO 9001 or ISO 13485 requirements by a third party, and nothing in this Standard should be construed to imply such a requirement.

3-2.2 Documentation of the Quality Assurance Program

The PVHO manufacturer and window fabricator shall be responsible for documenting the Quality Assurance Program in accordance with this Section.

3-2.3 Certification

The PVHO manufacturer and window fabricator shall certify compliance with this Standard by furnishing the purchaser with the appropriate PVHO-1 forms and by marking in accordance with the requirements of this Standard.

3-2.4 Right of Access

The purchaser or their authorized representative, authorized inspection agency representatives, and regulatory agency representatives shall be granted reasonable access to PVHO manufacturer and window fabricator's facilities for the purpose of conducting inspection or qualification activities.

3-2.5 Records

Records required for traceability shall be retained by the PVHO manufacturer and window fabricator in accordance with para. 1-7.9.

Section 4

Piping Systems

4-1 GENERAL

4-1.1 Scope

PVHO piping systems are subject to the requirements of this Section of the Standard and any additional requirements specified in the User's Design Specification in accordance with subsection 1-4.

Piping systems constructed under the requirements contained in this Section are limited to design temperatures between 0°F and 150°F (–17.8°C and 65°C), inclusive.

This Section shall be used as an adjunctive document to ASME B31.1 or ASME B31.3. The user or an agent on behalf of the user shall specify the appropriate section of ASME B31 to be used by the designer.

Specific piping within the PVHO piping system may also be subject to other Codes or Standards, such as ASME B31.9 Building Service Piping, NFPA Fire Protection Standards, NFPA-99 for Health Care Facilities, and building codes.

This Section provides guidance and engineering requirements deemed necessary to the safe design and construction of a PVHO piping system. This Section is not all inclusive and does not relieve the designer of the responsibility to use competent engineering judgment.

(e) data that shall be provided to the owner and the duration of retention of that data by the fabricator if other than that required by para. 4-1.2.4 of this Section and the disposition of the data should the fabricator go out of business

4-1.2.2 Design Certification. Conformance of the piping system design to the requirements of this Section of the Standard and the User's Design Specification shall be established by one of the following procedures:

(a) *Professional Engineer Certification.* A Professional Engineer, registered in one or more of the U.S. states or the provinces of Canada, or the equivalent in other countries, experienced in piping systems design, shall certify that the piping system was designed by them or under their direct supervision, or that they have thoroughly reviewed a design prepared by others, and that to the best of their knowledge, within the User's Design Specification, the piping system design complies with this Section of the Standard.

(b) *Independent Third-Party Certification.* The piping system design shall be reviewed by an independent classification society competent in pressure vessels for human occupancy systems, and such organization shall provide a certification that, within the User's Design Specification, the piping system design complies with this Section of the Standard.

(16) 4-1.2 Design and Fabrication

4-1.2.1 User's Design Specification. The user, or an agent on his behalf, who intends that a piping system be designed, fabricated, tested, and certified to be in compliance with this Section of the Standard, shall provide, or cause to be provided, a written User's Design Specification. This shall set forth requirements as to the intended use and operating conditions in such detail as to constitute an adequate basis for designing, fabricating, and inspecting the system as required to comply with this Section of the Standard. Those requirements shall include, as a minimum, the following:

- (a) limitations and boundaries of the piping systems
- (b) piping system maximum operating pressures, required pressurization and depressurization rates, ventilation rates, and the conditions under which those rates are to be maintainable [paras. 4-9-7.1(a) and (b)]
- (c) conditions affecting the requirements for and amounts of stored gas reserves
- (d) required number of breathing gas connections and their characteristics

4-1.2.3 Fabricator's Certification. The fabricator of the piping system shall be responsible for complying with the requirements of this Section of the Standard. The fabricator shall provide written certification of compliance with this Section of the Standard and with the User's Design Specification.

4-1.2.4 Data Retention. The fabricator shall retain (16) a copy of the User's Design Specification, the Design Certification, the Fabricator's Certification, and supporting data (test data, material test reports, as required by the User's Design Specification) for at least 5 yr. A copy of the piping system User's Design Specification, the Design Certification, and the Fabricator's Certification shall be provided to the user with the system.

4-1.2.5 Medical-Use PVHO Certifications. The piping (16) systems for PVHOs intended for use as medical devices, designed and manufactured according to the manufacturer's standard commercial design, shall comply with the U.S. Food and Drug Administration (FDA) Design Control Requirements (C.F.R.) Part 820, Quality

Table 4-2.1.1-1 Maximum Allowable Stress Values for Seamless Pipe and Tube Materials Not Listed in Nonmandatory Appendix A of ASME B31.1

Material	Specification	Temper or Grade	Strength, ksi	Maximum Allowable Stress Values in Tension, ksi
Alpha-brass	British Standard 1306	...	54	10.8
Copper water tube	ASTM B88, Types K & L	Drawn	36	6.0

GENERAL NOTE: 1 ksi = 1,000 psi.

System Regulations. Standard products meeting the requirements of the FDA are exempt from the requirements stated in paras. 4-1.2.1 through 4-1.2.4 of this Standard.

4-2 MATERIAL REQUIREMENTS

4-2.1 Acceptable Materials

4-2.1.1 Pipe and Tube. Pipe and tube for use in PVHO piping systems, except as otherwise restricted or permitted, shall be of a material for which allowable stress values are listed in Nonmandatory Appendix A of ASME B31.1, Nonmandatory Appendices A and B of ASME B31.3, or Table 4-2.1.1-1 in this Section.

4-2.1.2 Fittings. Unless otherwise restricted or permitted, the following apply:

(a) Fittings that are attached to a pipe or tube by welding, brazing, or threading shall conform to the specifications and standards listed in Table 126.1 of ASME B31.1 and Table 326.1 of B31.3.

(b) Fittings that are attached to a pipe or tube by other methods shall be of a material and type recommended by the fitting manufacturer for the application.

4-2.2 Limitations on Materials

4-2.2.1 Service Requirements. It is the responsibility of the designer to select materials suitable for the conditions of operation. All metallic materials used for oxygen service, breathing gas service, fire suppression, and water or steam service and all components subject to the requirements of para. 4-9.3 shall not use plating or coating with cadmium and shall not be manufactured from the following materials:

- (a) carbon steel
- (b) iron

Components of beryllium or those containing mercury shall not be used. Components containing asbestos shall not be used for breathing gas service applications.

4-2.2.2 Carbon Steel. The use of carbon steel pipe, tube, valves, and fittings in PVHO systems not subject to the requirements of para. 4-2.2.1 is permitted provided that they are compatible with anticipated cleaning and operational procedures and are adequately protected against corrosion, both internally and externally.

The effects of the migration of rust and other corrosion products into downstream components such as valves and regulators shall be considered.

4-2.2.3 Aluminum. Aluminum may be used only when adequate precautions are taken to prevent contact with fluorochlorocarbon lubricants and hydroxide-based absorbents. Further, the corrosive effect of seawater and combinations of hydroxide chemicals and seawater shall be considered in alloys intended for use in marine systems.

4-2.2.4 Castings. Cast components are subject to possible porosity and should be avoided in helium service. Cast, ductile, and malleable iron pipe, tube, and fittings shall not be used. Cast components of other materials may be used if not otherwise prohibited by this Standard.

4-2.2.5 Seawater Service. Materials that will be repeatedly or continuously exposed to seawater shall be compatible with seawater service.

4-2.2.6 Oxygen Service. Materials that will be exposed to oxygen and oxygen lubricants shall be compatible with the combination of oxygen, lubrication, and flowing conditions to which they are exposed. For guidance in the selection of materials suitable for oxygen service, refer to publications CGA G4.4 and ASTM G88.

4-2.3 Lubricants and Sealants

Lubricants and sealants are necessary in breathing gas systems for lubricating O-rings, lubricating moving parts of pressure control valves, and lubricating and sealing pipe thread joints; however, due to the possible presence of oxygen-enriched gases and the ultimate use of the gas for respiratory purposes, lubricants and sealants shall be selected with care.

(a) Lubricants and sealants used in breathing gas and oxygen systems shall be of a type recommended by the manufacturer for the intended service.

(b) Fluorochlorocarbon-based lubricants shall not be used on aluminum.

4-2.4 Nonmetallic Materials

4-2.4.1 Hose Materials and Pressure Ratings

(a) *Maximum Allowable Working Pressure (MAWP).* All hoses used in PVHO piping systems shall have a MAWP

equal to or greater than the design pressure of the line in which they are used, or a suitable relief valve set at the MAWP of the hose shall be provided.

(b) *Burst Pressure.* The burst pressure rating of any hose shall be at least 4 times its rated MAWP. The effect of fittings on the burst pressure shall be considered in establishing MAWP.

(c) *Liners.* The liners for hoses shall be appropriate for the intended service. Liners for use with breathing gases containing helium should also be relatively impervious to helium. Nylon, polytetrafluoroethylene (PTFE), and many natural and synthetic rubbers will normally satisfy these requirements.

(1) Liner materials are acceptable for breathing gas service if they will pass the off-gassing test contained in subsection 4-9.14 or they are rated by the manufacturer for breathing gas service. PTFE, nylon, and flexible metal liners meeting the requirements of subsection 4-2.2 and that have been cleaned for breathing gas service are acceptable for breathing gas and oxygen service without an off-gassing test.

(2) Hoses to be used for oxygen service shall use liner materials that are suitable for use with gaseous oxygen at the design pressure of the system or that are rated for such service by the manufacturer.

(3) Liner material shall be compatible with cleaning materials used to clean the hose assembly to the same level of cleanliness as the system of which it is a component.

(d) *Reinforcement Layer.* Reinforcement layer materials shall be compatible with the intended service.

(e) *Outer Jacket.* Jacket materials shall be compatible with the intended service. The outer jacket on hoses intended for helium service shall be perforated or sufficiently permeable to allow escape of gas that may seep through the inner liner. For other gas service applications, the designer should consider the possible needs for outer jacket perforation.

(f) *Fittings.* Fitting material shall be suitable for the intended service, and fitting materials shall comply with subsection 4-2.2. Fittings used on life-critical breathing devices shall be of types that are resistant to inadvertent disengagement.

4-2.4.2 Installation

(a) All permanently installed hoses shall be installed such that they are not subject to bending at radii less than the manufacturer's minimum rated bend radii and in accordance with all other applicable manufacturer's recommendations.

(b) Permanently installed hoses used to compensate for expansion and contraction shall be installed in accordance with manufacturer's recommendations. Where possible, hoses should be installed to always be in single plane bending and free of torsional or axial loading.

(c) Hoses installed in locations subject to abnormal levels of cyclic vibration shall be sized and selected for this type of service.

4-2.4.3 Marking. Hoses shall be marked with the manufacturer's name or trademark, type or catalog number, MAWP, test pressure, and test date. This information shall be permanently printed either on the hose or on a permanently attached corrosion-resistant metal tag. Metal tags, when used, shall be affixed so as not to abrade the hose or prevent the hose from normal bending or expansion due to pressure.

4-2.4.4 Hoses Subject to External Pressure. The following are required for hoses subject to external pressure:

(a) The hose construction shall be of a type that is resistant to collapse.

(b) The liner, if present, shall be securely bonded to the reinforcing layer.

(c) Fittings shall be of a type that forms a seal at the end of the hose. Fittings that leave the cut end of the hose open to pressure shall not be used.

(d) Hoses shall be installed in a manner that minimizes minor kinks, crushes, etc., which may not harm the internal working pressure capability of the hose but may cause it to collapse when subject to external pressure.

(e) Tight radius bends and torsional loads shall be avoided.

4-2.4.5 Testing

(a) Hoses that are received made up from the hose manufacturer and that were tested by the manufacturer in a manner substantially equivalent to the procedure described in subsection 4-9.14 need not be retested.

(b) Locally assembled hose assemblies shall be tested as prescribed in subsection 4-9.14 before being placed in service. Hose assemblies may be tested individually or as a portion of the system of which they form a part.

(c) Locally assembled hose material intended for external pressure service shall be tested as follows:

A representative section of hose shall be made up with fittings of the type intended for use with the hose using normally expected attachment procedures. The section of hose shall be bent 180 deg at a bend radius equal to the minimum bend radius expected in service. The hose shall be exposed to an external pressure 1.5 times its maximum system external pressure for 1 hr. Air is an acceptable pressurizing medium. The hose shall exhibit no evidence of collapse, either of the casing (outer jacket and reinforcing layer) and liner together, or of the liner separately. Hose collapse may be determined by observing the pressure drop at a specific flow rate of a fluid flowing through the hose. The pressure drop will increase significantly when collapse occurs. Note that liner collapse may occur with no visible deformation

occurring in the casing. Hose collapse may also be determined by filling the hose with water and measuring the amount of water displaced as the hose is pressurized.

4-2.4.6 Nonmetallic Pipe and Tube and Bonding Agents. Design properties of these materials vary greatly and depend upon the materials, type, grade, and lot. For new nonmetallic piping assemblies, particular consideration shall be given to the possibility of

- (a) destruction by fire
- (b) decrease in tensile strength at elevated temperature
- (c) toxic off-gassing, in-service, and fire condition
- (d) adequate support for flexible pipe
- (e) breathing gas compatibility

4-3 DESIGN OF COMPONENTS

4-3.1 Straight Piping Under External Pressure

For determining wall thickness and stiffening requirements for straight pipe and tubing under external pressure, the requirements of Section VIII, Division 1 or Division 2 of the ASME Boiler and Pressure Vessel Code shall be followed.

4-3.2 Straight Piping Under Internal Pressure

4-3.2.1 Minimum Wall Thickness. The thickness of pipe or tubing shall not be less than as required in ASME B31.1, para. 104.1, or as specified in para. 304.1 of ASME B31.3.

4-3.2.2 Additional Thickness Requirements. The thickness determined from the formulas in para. 104.1 of ASME B31.1 and para. 304.1 of ASME B31.3 are theoretically ample for both bursting pressure and material removed in threading. The following requirements are mandatory to furnish additional mechanical strength:

(a) Threaded steel or stainless steel pipe for use at pressures over 500 psig shall have a minimum ultimate tensile strength of 48,000 psi (330 MPa) and a wall thickness at least equal to Schedule 80 of ASME B36.10M. For pressures of 500 psi and less, threaded pipe shall have a wall thickness at least equal to Schedule 40 of ASME B36.10M.

(b) Threaded brass or copper pipe used for the services described above shall have a wall thickness at least equal to that specified above for steel pipe.

(c) Pipe or tubing subject to bending shall comply with the wall thickness requirements of Table 102.4.5 of ASME B31.1 or para. 332 of ASME B31.3.

4-3.3 Bending of Pipe and Tube

Pipe and tube bent or formed for a PVHO piping system shall be bent or formed as described in para. 102 of ASME B31.1 or para. 332 of ASME B31.3.

(a) Bending of pipe and tube in a PVHO piping system shall be performed in accordance with a written bending procedure.

(b) Pipe and tube may be bent by any hot or cold method and to any radius that will result in a bend surface free of cracks and buckles.

4-3.4 Stress Analysis of Piping Components

It shall be the responsibility of the designer to determine that the piping is adequately supported and that the piping system is sufficiently flexible to accommodate the relative movements and changes in temperature.

Should the designer determine that a stress analysis is required, it shall be performed in accordance with the requirements of para. 104.8 of ASME B31.1 or para. 319 of ASME B31.3.

4-3.5 Pressure Design of Fabricated Joints and Intersections

(a) Except as permitted in para. (b) below, where joints are fabricated and the service does not exceed 5 psig, ASME B31.1 para. 104.3 or ASME B31.3, para. 304.3 shall be followed.

(b) Fabricated branch joints made by brazing a branch line into an extruded opening in the run line may be used provided the following:

- (1) Line MAWP is 175 psig or less.
- (2) The joint meets the reinforcement requirements of para. 104.3.1(g) of ASME B31.1.

4-3.6 Pressure Design of Bolted Flanges and Blanks

The pressure design of bolted flanges and blanks shall be in accordance with para. 104.5 of ASME B31.1.

Gasket and seal materials and design shall be suitable for the intended service.

4-3.7 Design of Penetrations Through the Pressure Boundaries of PVHOs

See Nonmandatory Appendix B for guidelines for the design of piping penetrations through the pressure boundaries of PVHOs.

4-4 SELECTION AND LIMITATIONS OF PIPING COMPONENTS

4-4.1 Pressure Requirements

4-4.1.1 Maximum Allowable Working Pressure. The MAWP of all components shall be equal to or greater than the maximum operating pressure of the system or line of which they form a part.

4-4.1.2 Differential Pressures. Where components may be subject to differential system pressures, the differential pressure capacity of the component shall be equal to, or greater than, the maximum possible differential pressure; otherwise, suitable overpressure protection shall be provided.

4-4.1.3 Alternating Internal and External Pressures.

Components subject to alternating (i.e., both internal and external) pressure shall be designed for the maximum differential pressure that may exist in either direction.

4-4.1.4 Pressure Ratings. When possible, all pipe and tubing of the same material and diameter used in a single PVHO piping system shall have the same pressure rating. When this is not possible, special precautions shall be taken to prevent inadvertent mixing of materials.

4-4.2 Valves

The designer shall select valves suitable for the intended service.

4-4.2.1 Valves Subject to Internal and External Pressures. Valves subject to both internal and external pressures shall employ seals and stem packing suitable for bidirectional service.

4-4.2.2 Stop Valves. Stop valves shall be selected and installed to close with a clockwise rotation of the valve handle.

4-4.2.3 Ball Valves. Ball valves shall employ blow-out-proof stem designs.

4-4.2.4 Service Access. Valves in breathing gas and other life-sensitive systems shall be selected and installed to provide access for maintenance.

4-4.2.5 Quick-Opening Valves. Quick-opening valves shall not be used in oxygen systems with a MAWP over 125 psig. Quick-closing valves (e.g., an excess flow check valve) may be used regardless of pressure, provided that their capacity is sufficiently less than the capacity of upstream components so that closure of the valve will not result in a pressure rise at the inlet to the valve large enough to cause hazardous adiabatic compression heating of the gas.

4-4.2.6 Remotely Operated Valves. Remotely operated valves shall be selected and installed so that they fail in the safe position. Valves in services that cannot tolerate interruptions shall be provided with a manual override or bypass.

4-4.2.7 Relief Valves. Where tamper-proof design is required, relief valves used for protection against overpressures in excess of system service pressures shall be "V" stamped valves manufactured in accordance with Section VIII of the ASME Boiler and Pressure Vessel Code.

4-4.3 Filters

4-4.3.1 Element Collapse Pressure Rating. Elements of filters, used in breathing gas and other life-sensitive systems, shall have a collapse pressure rating equal to

or greater than the design pressure of the line in which they are installed, or the filter shall be fitted with a differential pressure device indicating when the element needs renewal or cleaning.

4-4.3.2 Element Construction. All particulate filters in pressurized lines in breathing gas and other life-sensitive systems shall use elements of the woven wire, screen, or sintered metal types. Sintered metal elements should be avoided in high-flow, high-vibration, or other applications conducive to element deterioration. Cloth and paper elements shall not be used.

4-4.3.3 Bypass Requirements. In systems where the ability to maintain uninterrupted service is required, all particulate filters shall be installed so that a clogged filter can be bypassed without disrupting the fluid flow to the end-use point.

4-4.4 Mufflers

Mufflers used for oxygen service (including vent lines from oxygen service systems) shall be fabricated of materials that are compatible with oxygen.

4-5 SELECTION AND LIMITATIONS OF PIPING JOINTS**4-5.1 Welded Joints**

Welded joints in PVHO piping systems shall be constructed in accordance with the requirements of paras. 127, 131, and 132 of ASME B31.1 or paras. 328, 330, and 331 of ASME B31.3, subject to the following additional requirements:

Welded joints of NPS (nominal pipe size) 2½ (DN 65) pipe size or smaller may be socket welded or butt welded. Welded joints larger than NPS 2½ (DN 65) pipe size shall be butt welded.

4-5.2 Brazed Joints

Brazing shall be performed in accordance with para. 333 of ASME B31.3.

(a) The Brazing Procedure Specification and the Procedure Qualification Record shall meet the requirements of either Section IX of the Code or AWS B2.2.

(b) Fabricator certification of the brazing procedure, procedure qualification, and brazer qualification is required.

4-5.3 Mechanical Joints

4-5.3.1 Seal Selection. Mechanical joint designs employing seals where effective sealing is not dependent on bolt preloading are recommended.

4-5.4 Threaded Joints**4-5.4.1 Pressure Limitations**

(a) Fittings shall have a pressure rating equal to or greater than the MAWP of the system in which they are used.

(b) Size–pressure limits for pipe threaded joints shall be as follows:

Size NPS, in.	Pressure
>3	Not permitted
2½–3	400 psig
2	600 psig
1¼–1½	800 psig
1	1,500 psig
≤¾	MAWP of the fittings or pipe, whichever is less

(c) Straight thread O-ring-sealed fittings may be used without limitation on size.

4-5.4.2 Helium Service. For helium service, pipe threads should be avoided; straight thread O-ring-sealed fittings are recommended over pipe thread fittings for helium service.

4-5.4.3 Lubricants. Any compound or lubricant used in threaded joints shall be suitable for the service conditions and shall not react unfavorably with either the service fluid or the piping materials.

4-5.4.4 Seal Welding. Threaded joints that are to be seal welded shall be made up without any thread compound, and the weld shall provide complete (360 deg) coverage. Seal welding shall be done by using qualified welders in accordance with Section IX of the ASME Code per para. 127.5 of ASME B31.1 or para. 328.2 of ASME B31.3. Seal welds shall not be considered as contributing to the mechanical strength of a joint.

4-5.4.5 Stainless Steel Threads. To reduce the possibility of galling where pipe threads are to be used between stainless steel components, there shall be a hardness difference between the thread surfaces of the two components of at least 5 points on the Rockwell B scale, or some other method of galling prevention shall be used.

4-5.4.6 Straight Threads. When straight thread O-ring-sealed fittings are used in locations that may subject the fitting to vibration or a torque that would tend to unscrew it, provision shall be made to prevent inadvertent loosening of the fitting.

4-5.4.7 Aluminum Threads. A suitable thread compound shall be used in making up threaded joints in aluminum fittings to prevent seizing. Aluminum pipe should not be threaded.

4-5.5 Joints and Fittings in Tubes

Factors such as vibration loads and frequent disassembly and reassembly of the piping system shall be considered in the selection of the type of tube fittings to be used.

4-5.5.1 Fittings Subject to Frequent Disassembly. The designer shall give special consideration to the selection of fittings in locations where frequent disassembly

and reassembly is likely. For these locations, one of the following fitting types shall be used:

- (a) flare fittings
- (b) welded or brazed fittings employing a flat-face seal mechanical union integral to the fitting
- (c) O-ring-sealed, straight thread fittings

4-5.5.2 Limitations. Compression-type fittings of aluminum shall not be reused. Bite-type fittings shall not be used on metallic pipe in PVHO piping systems. Welded fittings may be used subject to the requirements of para. 4-5.1. Brazed fittings may be used subject to the requirements of para. 4-5.2.

4-5.5.3 Restrictions. Fittings and their joints shall be compatible with the tubes with which they are to be used. They shall conform to the range of wall thickness and method of assembly recommended by the manufacturer, except that brass fittings may be used on stainless steel or nickel-copper tube under the following restrictions:

(a) *Flared Tube.* The tube shall be flared using a suitable flaring tool for the tube material, and a crushable metal gasket shall be used between the tube and the body of the fitting.

(b) *Compression Fittings.* The nuts and ferrules used shall be of the same material type (e.g., stainless steel or nickel-copper) as the tube, and the tube end shall be pre-swaged using a swaging tool or a suitable temporary fitting.

4-5.5.4 Cutting of Tube. All tube that is to be used with flare tube fittings shall be saw cut.

4-6 SUPPORTS

It shall be the responsibility of the designer to determine the support requirements of the piping system. The suggested support spacing is found in Table 121.5 of ASME B31.1 or Part 5, para. 321 of ASME B31.3.

Where detailed support designs and calculations are required, they shall be performed in accordance with para. 119 of ASME B31.1 or para. 319 of ASME B31.3, as applicable.

4-7 INSPECTION

4-7.1 Inspection of Welded Joints

All welds in PVHO piping systems that are subject to stresses due to pressure shall be inspected in accordance with the requirements of Table 4-7.1-1. The inspection procedures and acceptance standards shall be in accordance with para. 136 of ASME B31.1 or para. 340 of ASME B31.3. The fabricator (or his agent) shall ensure that all inspection personnel are qualified to perform the required inspections.

Table 4-7.1-1 Mandatory Minimum Nondestructive Examinations for Pressure Welds in Piping Systems for Pressure Vessels for Human Occupancy

Type of Weld	Examination Requirements
Butt welds (girth and longitudinal)	Pressure boundary and life-sensitive piping RT, all sizes Otherwise, RT for NPS over 2 in., MT or PT for NPS 2 in. and less
Branch welds (intersection and nozzle); size indicated is branch size	RT for NPS over 4 in., MT or PT for NPS 4 in. and less
Fillet welds, socket welds	PT or MT for all sizes and thicknesses

GENERAL NOTES:

- (a) RT = radiographic examination; MT = magnetic particle examination; PT = liquid penetrant examination; NPS = nominal pipe size; NDT = nondestructive testing.
- (b) For vent lines not subject to chamber pressure, MP or PT may be substituted for RT.
- (c) All welds shall be given a visual examination in addition to the type of specific nondestructive test specified.
- (d) It should be noted that it is impractical to radiograph some branch connections due to angle of intersection or configuration. If the joint configuration precludes RT, then other NDT methods should be substituted to establish the quality of the joint.
- (e) Nondestructive examinations specified above do not apply to components made to standards listed in Table 126.1 of ASME B31.1 or Table 326.1 of ASME B31.3.

4-7.2 Inspection of Brazed Joints

Brazed joints performed in accordance with para. 4-5.2 of this Section shall be subject to a visual inspection as a minimum. The following acceptance criteria shall apply:

(a) Preinserted alloy-type joints may be considered satisfactory when, before any face feeding, the total length of exposed brazing alloy between the outside surface of the pipe or tube and the outer end of the fitting is greater than $\frac{3}{4}$ of the circumference, with the greatest unexposed portion not exceeding 10% of the circumference.

(b) Face-fed joints shall show a complete ring of brazing alloy between the outside surface of the line and the outer end of the fitting.

4-8 TESTING

4-8.1 Hydrostatic Tests

Pressure testing of the piping systems may be carried out at either the component or system level. When component-level testing is specified in the User's Design Specification, a postassembly system leak test to operating pressure shall be performed.

Where a hydrostatic test is not possible or desirable, refer to subsection 4-8.2 for pneumatic test requirements.

4-8.1.1 Test Fluid. Water shall normally be used for a hydrostatic test fluid unless otherwise specified by the owner in the User's Design Specification. Test water shall be clean, oil free, and of such purity as to minimize corrosion of the material in the piping system.

4-8.1.2 Test Pressure. Piping systems shall be subjected to a hydrostatic test pressure not less than 1.5 times the MAWP of the system or subsystem. Any component requiring isolation shall be isolated.

4-8.1.3 Holding Time. The hydrostatic test pressure shall be continuously maintained for a minimum time of 10 min and for such additional time as may be necessary to conduct the examinations for leakage.

4-8.1.4 Examination. Examinations for leakage shall be made of all joints and connections. The piping system, exclusive of possible localized instances at pump or valve packings, shall show no visual evidence of weeping or leaking.

4-8.1.5 Air Vents. Where a complete piping system is to be hydrostatic tested, vents shall be provided at all high points of the piping system in the position in which the test is to be conducted to permit purging of air while the component or system is filling. As an alternative, the required venting may be provided by the loosening of flanges, tube fittings, or union joints in pipelines, or by the use of equipment vents during the filling of the system.

4-8.2 Pneumatic Tests

4-8.2.1 Limitations. Pneumatic testing shall not be used in lieu of other means of pressure testing except as limited in para. 4-8.2.3, or when one or more of the following conditions exist:

- (a) when the User's Design Specification requires or permits the use of this test as an alternative

(b) when piping systems are so designed that they cannot be filled with water

(c) when piping systems are to be used in service where traces of the testing medium cannot be tolerated (e.g., lines to gas analyzers)

4-8.2.2 Test Medium. The gas used as the test medium shall be oil free, nonflammable, and nontoxic or as specified in the User's Design Specification. Since compressed gas may be hazardous when used as a testing medium, it is recommended that special precautions for protection of personnel shall be observed during pneumatic testing.

4-8.2.3 Test Pressure. The pneumatic test pressure shall be not less than 1.2 nor more than 1.5 times the MAWP of the piping system. Any component requiring isolation shall be isolated.

4-8.2.4 Preliminary Test. A preliminary pneumatic test not to exceed 25 psig may be applied, prior to other methods of leak testing, as a means of locating major leaks. If used, the preliminary pneumatic test shall be performed in accordance with the requirements of paras. 4-8.2.2 and 4-8.2.3.

4-8.2.5 Application of Pressure. The pressure in the system shall be gradually increased to not more than $\frac{1}{2}$ of the test pressure, after which the pressure shall be increased in steps of approximately $\frac{1}{10}$ of the test pressure until the required test pressure has been reached.

4-8.2.6 Holding Time. The pneumatic test pressure shall be continuously maintained for a minimum time of 10 min, after which the pressure shall be reduced to system design pressure for examination for leakage.

4-8.3 Leak Testing

Using a suitable test medium, all joints and connections shall be examined for leakage by bubble testing or equivalent method at the maximum operating pressure. The piping system, exclusive of possible localized instances at valve packings, should show no evidence of leaking. For helium systems foaming of the test medium is allowed. Detectable leaks in oxygen systems shall not be permitted at any location.

Following either pneumatic or hydrostatic testing, the piping system shall be leak tested in final assembled condition.

4-9 SYSTEMS

There are various system and component selection considerations that may affect the operational safety of a PVHO piping system. Requirements regarding specific safety and component issues are found in this section. These requirements are not intended to be used in total-ity for all PVHO piping systems but rather should be applied by the designer as applicable to the specific industry in which the PVHO will be used.

It is the owner's and/or the designer's responsibility to determine which of these requirements is applicable to the PVHO piping system being designed.

Specific subsection 4-9 requirements being applied shall be enumerated in the User's Design Specification and thereby become mandatory.

4-9.1 System Design Requirements

The designer shall use the requirements in this section as appropriate for the specific industry PVHO piping system being designed. It is intended that only those requirements determined to be applicable by the designer be mandatory, and the designer should be thoroughly familiar with this section before application of these requirements. It is the designer's responsibility to determine the specific application of subsection 4-9 in accordance with accepted practice, jurisdictional requirements, and safety. Those requirements deemed mandatory by the designer because of industry, service, or regulatory requirement shall be listed in the User's Design Specification.

4-9.2 Pressurization and Depressurization Systems

4-9.2.1 Pressurization and Depressurization Rates.

The PVHO pressurization and depressurization systems shall be capable of providing the full range of pressurization and depressurization rates specified in the User's Design Specification. When the pressurization gas comes from a stored gas system, the pressurization rates specified in the User's Design Specification shall be maintainable at maximum PVHO pressure at all gas storage pressures over 50% of maximum.

4-9.2.2 Ventilation Rates. On all PVHOs designed for operation in a continuous ventilation mode, the pressurization and depressurization system shall be capable of maintaining all required ventilation rates while holding depth stable to within the range specified by the User's Design Specification. Such systems should also be provided with a means of indicating the rate of flow of ventilation gas through the PVHO.

4-9.2.3 Stored Gas Reserves. The requirements for stored gas reserves vary with the application for which a PVHO system shall be used. The designer shall consider all pertinent operational and jurisdictional requirements.

4-9.2.4 Exhaust Inlet Protection. The inlets to all PVHO exhaust lines shall be fitted with a device that prevents a PVHO occupant from inadvertently blocking the opening to the line with a part of his body or be located in normally unoccupied areas, such as under the PVHO floor. PVHO exhaust line inlets shall also be located such that, where applicable, discharge of the fire-suppression system will not result in water collecting in the bottom of the PVHO being injected into the exhaust line.

4-9.2.5 Exhaust Locations. The exhausts from the depressurization system of PVHOs located inside enclosures shall be piped to a location outside the enclosure and at least 10 ft (3 m) away from any air intake.

4-9.2.6 Noise. Noise in a PVHO may interfere with voice communication as well as present a risk of hearing damage if the level of noise is severe. The designer shall consider all sources of noise in the PVHO and shall design the system to prevent noise levels generated by routine PVHO operations from exceeding those determined in appropriate national standards to cause damage or discomfort to the PVHO occupants.

4-9.3 Pressure Boundary Valve Requirements

4-9.3.1 Internal Pressure PVHOs. All lines penetrating the pressure boundary of a PVHO subject to internal pressure only shall have a stop valve or a check valve, as appropriate, on the outside of the PVHO as close as possible to the penetration. Where stop valves are placed in locations that prevent ready access in an emergency, they shall be provided with operators that are controllable from suitable accessible locations. Depressurization lines, drain lines, and other lines that normally communicate between PVHO pressure and outside atmospheric pressure shall also have a second valve. This second stop valve may be located either inside or outside of the PVHO.

4-9.3.2 External Pressure PVHOs. All lines penetrating the pressure boundary of a PVHO normally subject to external pressure only shall have a stop valve or check valve, as appropriate, as close as practically possible to the penetration on the inside of the PVHO. A second stop valve shall be provided on lines that are normally open to external pressure.

4-9.3.3 Internal and External Pressure PVHOs. PVHOs that may be subject to both internal and external pressure shall meet the requirements of paras. 4-9.3.1 and 4-9.3.2.

4-9.3.4 External Override. When valves are provided inside a PVHO to permit the PVHO occupants to control the pressure in the PVHO, an external means of overriding the effect of those valves shall be provided.

NOTE: The external override need not be on the same lines or on lines of similar capacity. The fundamental requirement is that there be some means provided, in advance, for gaining access to the PVHO if the inside personnel becomes incapacitated.

4-9.3.5 Special Requirements for PVHOs Used for Saturation Service. For PVHOs designed to be used for saturation applications, all lines that are open to PVHO pressure except pressure relief lines and pressure reference lines (e.g., all lines used for pressurization, depressurization, external gas, or water conditioning systems) shall have double valves with one stop, or

check, valve inside the PVHO and the other valve outside.

4-9.3.6 Flow-Rate-Sensitive Valves. When check valves or stop valves cannot be used, a flow-rate-sensitive valve that closes automatically in the event of excess flow may be used. Flow-rate-sensitive valves, when used, may satisfy the second stop valve requirement of paras. 4-9.3.1, 4-9.3.2, and 4-9.3.5.

4-9.3.7 Remotely Operated Stop Valves. Remotely operated stop valves, whose operation is triggered upon uncontrolled loss of pressure, are an acceptable alternative to the flow-rate-sensitive valves described in para. 4-9.3.6. Such valves may be used to satisfy the second stop valve requirements of paras. 4-9.3.1, 4-9.3.2, and 4-9.3.5, provided individual valves may be closed manually without triggering closure of other valves. Remotely operated valves used in pressure boundary applications shall also have a manual actuation capability, or a secondary means of pressurizing and/or depressurizing the PVHO shall be provided for use if the valve becomes inoperable.

4-9.4 Depth Gauges

4-9.4.1 Quantity and Location

(a) Each internal pressure PVHO compartment in a PVHO system shall have at least one dedicated depth gauge (PVHO compartment pressure indicator) indicating compartment PVHO internal pressure to the PVHO or system operator. Each compartment or PVHO in PVHO systems other than medical monoplace PVHOs also shall have a second depth gauge that may be located either inside or outside the PVHO.

(b) External pressure PVHOs and PVHOs subject to both internal and external pressure shall have dedicated gauges indicating both internal and external pressures to the PVHO or system operator, and separate gauges indicating these pressures to the PVHO occupants, unless the occupants are also the operators, as in the case of a submersible.

4-9.4.2 Calibration. A means shall be provided to permit depth gauges to be checked, while in use, against other system depth gauges normally accessible to the PVHO or system operator or an external master gauge for accuracy.

4-9.4.3 Piping. The lines connecting depth gauges to their associated PVHOs shall not be used for any other purpose. The inside diameter of depth gauge lines shall not be smaller than 0.12 in. (3 mm).

4-9.4.4 Valve Arrangements. Valve arrangements used with depth gauges shall be designed so that the pressure source to which each gauge is connected is clearly indicated to the system operator.

4-9.5 Pressure Gauges Other Than Depth Gauges

All breathing gas and life-sensitive systems shall be fitted with at least one pressure gauge equipped with a gauge isolation valve. Measures to protect gauges from excessive vibration or sudden pressure changes shall be taken where appropriate.

4-9.6 Breathing Gas Systems

4-9.6.1 Breathing Gas Outlets. The number of breathing gas outlets provided in PVHOs shall be not less than the maximum rated number of occupants plus one, except for diving bells where the number of breathing gas outlets shall not be less than the maximum rated number of occupants. Each gas outlet shall have a stop valve. Each gas outlet shall be compatible (pressure and flow rate capacity, connection type, etc.) with the type of breathing apparatus listed in the User's Design Specification.

4-9.6.2 Redundancy of Breathing Gas Supply. The piping system shall be designed so that breathing gas can be delivered to the breathing gas outlets in PVHOs and to the divers' breathing gas manifold in diving bells from at least two supply sources.

4-9.6.3 Stored Gas Reserves. The designer shall consider all operational and jurisdictional requirements.

4-9.6.4 Multiple Gases. Where gases of different composition are connected to a distribution manifold or other distribution system, a positive means shall be provided to ensure that leaking valves will not result in an improper gas being supplied to the end-use point or result in backflow from one supply gas into the distribution system for another supply gas.

4-9.6.5 Labeling of Breathing Gas Outlets. All breathing gas outlets shall be labeled. Where the gas supplied is always known, the label shall indicate the type of gas supplied, such as "Oxygen." Where the gas supplied is subject to change based on operational requirements, the label shall contain a generic term, such as "Breathing Gas."

4-9.6.6 Separation of Breathing Gases. This Standard recognizes that complete separation of breathing gases of different types is generally not possible in PVHO applications. The designer shall take all reasonable steps to minimize the number of locations/situations where gases of different compositions need to use common distribution equipment and/or common outlets.

4-9.6.7 Pressure Control Valves in Demand Breathing Systems. Pressure control valves used in demand breathing systems shall meet the requirements of para. 4-9.7.6.

4-9.7 Pressure Control Valves

4-9.7.1 Performance Characteristics. The performance of a pressure control valve is characterized primarily by two factors, both of which shall be considered by the designer. These factors are

(a) the rate at which the outlet pressure decreases (from the set point) as flow demand increases. In many designs, there is a significant difference between outlet pressure at the no-flow condition and the outlet pressure at design service flow rates. In unbalanced single-stage pressure control valves, outlet pressure may also be influenced by changes in inlet pressure. The flow effect is usually the controlling factor in design.

(b) limit flow capacity. This factor is a function of upstream pressure, orifice size, downstream pressure, and outlet porting size.

4-9.7.2 Seats. All pressure control valves used in life-sensitive systems shall employ soft seats capable of bubble-tight shutoff.

4-9.7.3 Filters. All pressure control valves used in life-sensitive systems, except those used in overboard dump systems for breathing masks, shall be provided with an upstream particulate filter that meets the requirements of subsection 4-4.3.

4-9.7.4 Gauges. Gauges indicating the controlled pressure shall be provided with all pressure control valves, and they shall be located so as to be clearly visible to a person adjusting the setting of the pressure control valve.

4-9.7.5 Bypass Requirements. Except as otherwise required in para. 4-9.7.6(b), in systems where the ability to maintain uninterrupted service is required, all regulators shall be provided with either a redundant regulator of equal size or a manually operated bypass valve.

4-9.7.6 Pressure Control Valves Used in Demand Breathing Systems

(a) *Capacity Requirements.* The peak respiratory flow rates, both inspiratory and expiratory, in a demand breathing system are normally 3.0 to 3.14 times the net average flow as represented by the user's respiratory minute volume. Therefore, the capacity of pressure control valves used to support demand-type breathing apparatus shall be computed as follows:

$$Q = \pi (N) (D) (RMV) (F)$$

where

D = maximum usage depth, atm absolute

F = factor, to be taken as 1.0 unless data is available to support a lower number

NOTE: $F = 1$ assumes all gas users inhale or exhale simultaneously. Consequently, as N becomes large, F will approach 0.5. For $N = 1$ or 2, F shall be taken as 1.0. For $N > 2$, F may be reduced as warranted by testing or experience with prior designs. F may also be reduced if it can be shown, either experimentally or analytically, that sufficient volume exists between the pressure regulation point and the usage point(s) to provide an accumulator effect capable of providing whatever differences may exist between the instantaneous flow rate requirements and the regulator capacity provided. In no case may F be reduced below 0.5.

N = maximum number of breathing apparatus to be supported at one time

Q = regulator capacity at minimum design inlet pressure, ft^3/min (L/min)

RMV = maximum anticipated user respiratory minute volume, in ft^3/min (L/min) at usage pressure; the minimum RMV that may be used is $1.41 \text{ ft}^3/\text{min}$ (40 L/min) for a working diver and $0.7 \text{ ft}^3/\text{min}$ (20 L/min) for a resting diver or PVHO occupant

(b) Bypass Requirements

(1) The pressure control valves in piping circuits supplying breathing gas to divers using demand breathing apparatus in the water or in a diving bell shall be either of the following:

(-a) provided with a bypass loop containing a second pressure regulator of equal capacity and appropriate related components

(-b) arranged as a series of two or more pressure control valve stations each with a hand-operated bypass, appropriate related components, and a pressure control valve capable of accepting full initial supply pressure and providing regulated outlet conditions appropriate for the end-use function

(2) Hand-operated bypass valves may be used in systems supplying gas to PVHO mask breathing gas outlets provided that adequate overpressure relief is provided.

(3) Bypass capability is not required for pressure control valves supporting single consumers where a service interruption is tolerable, such as for pressure control valves dedicated to each of several mask breathing gas outlets in a PVHO.

(4) Bypass capability is not required for pressure control valves supporting overboard dump manifolds in PVHOs.

4-9.8 Pressure Relief Requirements

4-9.8.1 Overpressure Relief

(a) All systems that may be subject to internal pressures in excess of their design pressure shall be provided with overpressure relief devices capable of maintaining system pressure not to exceed 110% of design pressure.

(b) Systems located inside of PVHOs that are normally pressurized at less than PVHO pressure shall be

equipped with relief devices (check valves are acceptable) if any of the components in the system (such as vacuum gauges) are subject to damage, if PVHO pressure is released without a concurrent release of system pressure.

4-9.8.2 Underpressure Relief

(a) Piping or components located inside of PVHOs that are normally pressurized in excess of PVHO pressure shall be equipped with vacuum breakers if any of the components of the system (such as pressure gauges) are subject to damage, if the PVHO is pressurized without pressure in the system.

(b) Piping or components located inside of PVHOs that are normally pressurized to a level less than PVHO pressure (e.g., mask overboard dump lines, medical suction lines, etc.) shall be provided with vacuum relief valves capable of relieving underpressures in excess of the maximum limits established by the system designer.

4-9.8.3 Rupture Disks. Rupture disks shall not be used except on gas containers.

4-9.8.4 Division Valves. Where piping systems operating at different pressures are connected, a division valve shall be provided that shall be designed for the higher system pressure.

4-9.8.5 Pressure-Reducing Valves. Relief devices shall be provided on the low-pressure side of the pressure-reducing valves, or the piping and equipment on the low-pressure side shall meet the requirements for the full system pressure.

The relief devices shall be located as close as possible to the reducing valve. The total relieving capacity provided shall be such that the design pressure of the low-pressure piping system will not be exceeded by more than 10% if the reducing valve fails open.

4-9.8.6 Bypass Valves. Where manually operated bypass valves are permitted around pressure control valves, they shall not have a maximum flow capacity greater than the reducing valve unless the downstream piping is adequately protected by relief devices or meets the design requirements of the higher system pressure.

4-9.8.7 Stop Valves. There shall be no stop valves between piping being protected and its protective device or devices, except that stop valves may be installed between a relief valve and the piping being protected under the following conditions:

(a) when, in the judgment of the designer, the hazard from a relief valve failing open exceeds the hazard presented by the possible concurrent occurrence of system overpressure plus a closed stop valve

(b) when a stop valve is provided between a relief valve and the associated protected piping, the valve shall be per the designer's specification for the fluid piping being protected, and the relief device shall be per the Code, Section VIII, Division 1, UG-125 through UG-136 or Section VIII, Division 2, Part 9

4-9.8.8 Exhausts From Relief Devices

(a) Exhausts from relief devices that are located inside enclosed spaces shall be piped outside of the space if operation of the relief device could result in overpressurizing the space.

(b) Exhausts from relief devices that are located inside enclosed spaces on lines containing gases other than air shall be ducted out of the space.

4-9.9 Color Coding

4-9.9.1 Consistent Color Codes. PVHO piping systems shall employ a consistent color coding system. Suggested guidelines are listed in Nonmandatory Appendix C.

4-9.9.2 Owner's Responsibility. Color code requirements vary substantially between the various jurisdictions in which PVHO systems may be used. It shall be the responsibility of the designer to specify the required color coding system.

4-9.10 Labeling

4-9.10.1 Piping and Gas Storage Vessels. All piping and gas storage bottles shall be labeled to show contents, direction of flow (when appropriate), and MAWP.

4-9.10.2 Critical Components. The designer shall determine all critical components whose function is not obvious from their location and appearance. These components shall be labeled as to function.

4-9.10.3 Panel-Mounted Components. All components that are mounted in panels shall be labeled as to function.

4-9.11 Soft Goods

4-9.11.1 Breathing Gas Systems. Soft goods used in breathing gas service shall be compatible with intended service fluids at the anticipated maximum pressures and shall be compatible with all anticipated cleaning procedures.

For breathing gas systems using oxygen-enriched gases (greater than 25% oxygen), consideration shall be given to the soft goods flammability in the oxygen-enriched environment. ASTM G63 and ASTM Manual 36 provide guidance.

4-9.11.2 Other Systems. Soft goods used in other systems shall be compatible with the fluids contained, at the maximum anticipated conditions of temperature and pressures.

4-9.12 Lubricants and Sealants

See para. 4-2.3, ASTM G63, and ASTM Manual 36 regarding appropriate materials and practices.

4-9.13 Cleaning Requirements

4-9.13.1 Oxygen and Breathing Gas Systems. The cleaning of oxygen and breathing gas piping systems is

an essential part of PVHO piping system design and fabrication. The following are recommended guidelines:

(a) A written cleaning procedure with well-defined procedures, personnel responsibilities, acceptance/recleaning criteria, marking, packaging, and storage requirements shall be developed and implemented.

(b) Component handling procedures shall be developed and implemented so that components and systems, once cleaned, are not recontaminated.

(c) The cleaning procedures intended to be used with the piping system shall be considered by the designer during the selection of all materials, especially soft goods, and during the layout of the piping.

4-9.13.2 Components Located Inside PVHOs. Piping components that are to be located inside the PVHO shall also be cleaned on their exteriors. The exteriors of components for use inside marine systems should show no visible signs of oil or grease. The exteriors of components for use inside PVHOs with elevated oxygen environments should show no fluorescence typical of oil or grease when examined under ultraviolet light.

4-9.13.3 Prohibited Cleaning Materials. Trichloroethylene shall not be used to clean breathing gas systems or any components to be located inside a PVHO.

NOTE: When gas is passed through a moderately heated alkali bed (such as those used in most carbon dioxide scrubbers), residual trichloroethylene can decompose into highly toxic dichloroacetylene.

4-9.14 Off-Gassing Test for Hoses Used for Breathing Gas Service

4-9.14.1 Background. Some components used in the manufacture of hoses can give off vapors that are toxic if inhaled. For hoses to be considered acceptable for breathing gas service, they shall pass the off-gassing test described herein.

(a) *hydrocarbon*: for this test procedure, all organic compounds detectable by a total hydrocarbon analyzer.

(b) *methane equivalent*: concentration of methane in air that will cause a total hydrocarbon analyzer to give an indication equivalent to that obtained from the gas being analyzed.

4-9.14.2 Procedure

(a) Off-gassing measurements shall be made only on hoses that have not been flushed with air, gas, or water. Both the total hydrocarbon analyzer and the hose or hoses to be tested shall be maintained at a temperature not lower than 73°F (22.8°C) throughout the testing period.

(b) By this procedure, measurements are made of the increase in the hydrocarbon concentration of a stream of air flowing through the test hose at a flow rate of 28 LPM (1 CFM). The temperatures of the test hose, air supply, and analyzer shall not be lower than 73°F (22.8°C). A diagram of the flow arrangement is shown

Fig. 4-9.14.2-1 Flow Diagram of Apparatus for Measuring the Concentration of Hydrocarbons in a Stream of Air or Other Gas After It Has Passed Through a Test Hose

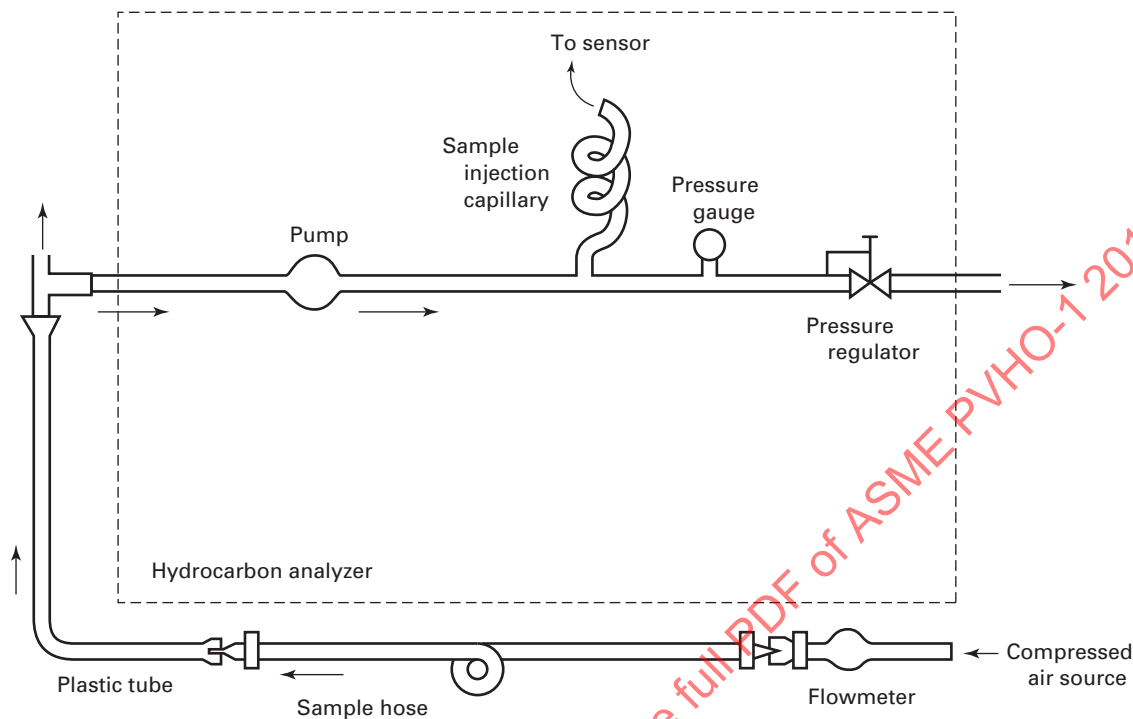


Table 4-9.14.2-1 Maximum Allowable Concentration of Hydrocarbons in Air Passing Through Hose

Hose Length, ft	Hydrocarbon Concentration as Methane Equivalents, mg/m ³
3	4
100	100

in Fig. 4-9.14.2-1. Before the air passes through the test hose, the air shall be clean and shall contain no more than 1 mg/m³ of hydrocarbons (methane equivalents). The analyzer shall be zeroed with air passing at the stipulated flow rate and temperature through the connector tubes only. The test hose shall then be inserted in the line and the airstream passed through it. For the

ensuing 15 min, readings of the hydrocarbon concentration shall be recorded. The test hose shall be rated on the reading at the end of the 15-min test period. Hoses that contaminate the air by greater amounts than specified in Table 4-9.14.2-1 shall not be acceptable.

4-9.14.3 MIL-H-2815 provides guidance in testing hoses.

Section 5

Medical Hyperbaric Systems

5-1 GENERAL

(16) 5-1.1 Scope

This Section, along with Sections 1 through 4 of the Standard, provides minimum requirements for the design, assembly, inspection, testing, and certification of PVHO systems used specifically in medical hyperbaric therapy.

5-1.2 User's Design Specification

The user, agent on the user's behalf, or the manufacturer shall provide or cause to be written a User's Design Specification in accordance with subsection 1-4 of this Standard. This specification shall set forth the requirements as to the intended use of the chamber and operating conditions in such detail as to constitute an adequate basis for designing the system as necessary to comply with this Standard. They shall include, as a minimum, the following:

- (a) rated number of occupants
- (b) maximum operating pressure
- (c) pressurization/depressurization rates, ventilation rates, and the conditions under which those rates are to be maintained
- (d) requirements affecting the amount of stored gas reserves
- (e) number of breathing gas outlets and their characteristics
- (f) temperature and humidity control requirements, if any
- (g) fire-suppression requirements
- (h) minimum and maximum operating temperatures
- (i) type(s) of breathing gas delivery systems
- (j) pressurization gas (air or oxygen)
- (k) the edition(s) of other codes and/or standards used in the development of the User's Design Specification

5-1.3 Documentation

(a) PVHO documentation shall be in accordance with para. 1-7.9 of this Standard and the requirements of other codes and standards as required.

(b) Viewport (window) documentation shall be in accordance with Section 2 of this Standard.

(c) All documentation should be retained by the user for the life of the PVHO. If the PVHO is transferred to a new user, all documentation should accompany the PVHO.

5-1.4 Windows

All chambers shall have at least one window in each compartment for viewing the chamber interior. Monoplace chambers shall have sufficient visual access to observe at least the patient's head, face, chest, and arms.

5-1.5 Quick-Actuating Closures

Quick-actuating closures that have the potential to be opened while pressurized, such as most medical lock outer doors, shall be designed in accordance with the requirements for quick-acting closures contained in UG-35, Other Types of Closures, in Section VIII, Division 1 of the Code.

5-1.6 Personnel Entry Lock

Chambers intended for medical treatment at 3 ATA or less that do not normally incur a decompression obligation for the patients shall not be required to have a personnel lock.

5-1.7 Penetrations

Additional penetrations to provide for access for sensor leads, etc., shall be provided as required by the User's Design Specification.

5-1.8 Personnel Egress

Consideration shall be given to the size and configuration of doorways and/or hatches for safe access and egress of personnel and patients.

5-2 PVHO SYSTEM DESIGN

System design shall be such that pressurization/depressurization rates, gas composition limits, contaminant control, ventilation, fire-suppression system performance, and heating and cooling requirements can be maintained in accordance with the User's Design Specification and other applicable codes and standards. (See NFPA 99, Health Care Facilities, Chapter 20, Hyperbaric Facilities for guidance.)

5-3 GAS SYSTEMS

5-3.1 Gas Storage Requirements

Storage for medical treatment systems vary in scope and detail depending on the type of system and the number of occupants; therefore, when establishing the

design specifications for the gas systems, the designer shall consider the specific requirements of the installation and Section 4 of this Standard.

5-3.2 Breathing Devices

The minimum flow rates sufficient to ensure patient comfort and safety shall be identified in the User's Design Specification. (See NFPA 99, Health Care Facilities, Chapter 20, Hyperbaric Facilities for guidance.)

Supply systems for patient hoods shall have the capability of supplying a minimum flow of oxygen of 40 L/min at chamber design conditions simultaneously to each hood.

5-3.3 Breathing Gas Outlets

Each PVHO treatment compartment, other than a monoplace chamber, shall be equipped with fittings for breathing mask, patient hood, or endotracheal device corresponding to the number of occupants.

5-4 CONTROL SYSTEMS AND INSTRUMENTATION

5-4.1 Controls Location

Primary operation shall be external to the chamber. If remote or automated controls are used, manual overrides shall be provided and easily accessible.

5-4.2 Communications

Control console or stations shall be equipped to provide communication with each compartment.

5-5 ENVIRONMENTAL SYSTEMS

5-5.1 Environmental Conditions

All systems and components shall be capable of operating satisfactorily and safely in accordance with their specifications at the environmental conditions stated. The designer shall give specific consideration to the comfort of the patients in deciding whether environmental control of the chamber atmosphere is required or whether ambient conditions will suffice.

5-5.2 Temperature

Patient comfort shall be maintained by supplemental heating or cooling, as required.

5-5.2.1 Multiplace Chambers. If multiplace chambers are equipped with heating or cooling systems, provision shall be made to shut off the heating or cooling system in the event of malfunction.

5-5.2.2 Monoplace Chambers. Temperature control for the chamber area shall be considered for monoplace chambers.

5-5.3 Humidity

A specific system for the control of humidity is not mandatory if other methods such as ventilation or circulation are sufficient to maintain patient comfort in accordance with the User's Design Specification.

5-5.4 Contaminants

Sources of volatile, toxic, or potentially toxic contamination shall be minimized to the extent practical. Possible sources of contamination include off-gassing of nonmetallic materials.

5-5.5 Lighting

There shall be sufficient lighting in or around a chamber to see the patient(s), the chamber control console, and chamber support equipment systems.

5-5.5.1 External Lighting. External lighting fixtures shall not come into contact with or be allowed to overheat the surface of a window in excess of its maximum design temperature in accordance with Section 2 of this Standard. (16)

5-5.5.2 Emergency Lighting. Emergency lighting shall be provided.

5-5.6 External Heat Sources (16)

External heat sources in addition to lighting fixtures shall not come in contact with or otherwise heat the surface of a window in excess of its maximum design temperature.

5-5.7 Access to Emergency Equipment

No permanent seat or stretcher shall block the aisles, hatches, doors, medical locks, handheld hoses, fire-suppression controls, or any emergency equipment.

5-5.8 Suction Systems

All systems for use inside a chamber shall have a trap in-line to keep waste materials out of the piping system.

If a suction system uses pressure differential for the vacuum while at depth, there shall be a vacuum source for use on the surface.

5-5.9 Accidental Depressurization

(a) If a sink, water supply, or drainage system is used, provisions shall be made to prevent unintentional depressurization of the system.

(b) Any toilet that is plumbed to discharge to the outside of the chamber shall have a holding tank and a dual-valve safety interlock system.

(c) Any toilet that flushes to the outside of the chamber shall be designed to preclude the possibility that a seal might be created between the seat and the person using the toilet.

Section 6

Diving Systems

6-1 GENERAL

6-1.1 Scope

6-1.1.1 This Section, along with Sections 1 through 4 of this Standard, provide the requirements for the design, fabrication, assembly, inspection, testing, certification, and stamping of PVHOs used in diving systems.

This includes but is not limited to

- (a) deck decompression chambers
- (b) diving bells
- (c) transfer locks
- (d) saturation living chambers
- (e) rescue chambers
- (f) hyperbaric evacuation systems
- (g) diving subsystems/components
- (h) diver lockout chambers
- (i) hyperbaric stretchers

6-1.1.2 The scope of this Section includes but is not limited to the following components:

- (a) doors
- (b) hatches
- (c) penetrations and fittings
- (d) medical and service locks
- (e) quick-opening closures
- (f) viewports
- (g) light transmitting devices
- (h) electrical penetrators
- (i) trunks and tunnels

6-1.2 User's Design Specification

A User's Design Specification, as described in subsection 1-4 of this Standard, shall be written for the PVHO diving system. The Specification shall set forth the requirements as to the intended use of the PVHO or component and the operating and environmental conditions in such detail as to constitute an adequate basis for design, fabrication, inspection, and testing of the PVHO or component necessary to comply with this Standard. The User's Design Specification shall include

- (a) number of intended occupants
- (b) maximum operating pressure/depth
- (c) required pressurization and depressurization rates, ventilation rates, and conditions under which rates are to be maintained
- (d) intended operational environment
- (e) maximum number of pressure cycles
- (f) maximum/minimum internal/external pressures

- (g) operating temperatures
- (h) storage conditions/temperatures
- (i) number, size, and type of penetrators, doors, hatches, windows, and service locks
- (j) corrosion allowance
- (k) environmental requirements
- (l) special design considerations applicable to normal and emergency service, such as requirements for the sizing of the diver lock-out hatch [i.e., the diver dress and potential underwater breathing apparatus (UBA) to be used]
- (m) fire suppression

6-1.3 Design Certification

Conformance of the completed PVHO to the requirements of the Standard and the User's Design Specification shall be established by the following procedures:

(a) A competent Professional Engineer, registered in one or more of the U.S. states or provinces of Canada, or the equivalent in other countries, experienced in the design of PVHOs, shall certify that the PVHO or component was designed or completely reviewed by the engineer or under the engineer's direct supervision, and that to the best of their knowledge, it meets the requirements of the User's Design Specification and complies with this Standard.

(b) Alternatively, the PVHO or component shall be reviewed by an authorized government agency or an independent classification society competent in pressure vessels for human occupancy, and such organization shall provide a certification that the PVHO or component complies with this Standard and the User's Design Specification.

6-1.4 Documentation

The user shall be provided with the following data and documentation:

- (a) User's Design Specification
- (b) PVHO and/or PVHO component certification
- (c) PVHO window certificates in accordance with Section 2 of this Standard
- (d) viewport and window drawings
- (e) applicable ASME data reports and partial data reports
- (f) any classification society certifications
- (g) vessel drawings necessary for the maintenance, inspection, and repair of the PVHO

(16) 6-1.5 Useful References

The designer should be familiar with the references contained in Nonmandatory Appendix F.

6-2 DESIGN

6-2.1 General

PVHOs, their components, and attachments shall be designed for the environmental conditions in which they are intended to operate. For example, particular attention shall be given to the corrosive effect of salt water, sea, air, and chlorinated water as applicable.

The PVHO shall be designed, fabricated, assembled, inspected, tested, and certified in accordance with Section 1 of this Standard. The design should facilitate the ability to conduct planned maintenance and inspections.

The design of the diving system shall incorporate appropriate backup systems and equipment to ensure the safety of both the occupants and the operating personnel in the event of any single failure.

6-2.2 Design Loads

The designer shall address in the design all forces acting on the PVHO. These may include but are not limited to

- (a) internal and external pressure forces
- (b) dynamic loads
- (c) local loads including impact, lifting force localized reactions, and discontinuities
- (d) loads due to expansion and contraction
- (e) loads due to weight of contents, or equipment mounting
- (f) transportation loads
- (g) test loading and configurations
- (h) entrapped water loads
- (i) loads due to lifting, handling, or mounting
- (j) loads due to external connections (e.g., bell or escape tunnel clamped to a chamber, piping connections, etc.)
- (k) wave loads
- (l) operation and emergency loads
- (m) vibration loads
- (n) seismic loads

The design shall consider the external forces transmitted to the PVHO.

For marine design purposes, these forces shall be at least 2.0g vertical, 1.0g transverse, and 1.0g longitudinal, unless otherwise determined, all acting simultaneously while the chamber is pressurized. Consideration shall be given to inclinations as follows:

Design	Roll, deg	List, deg	Pitch, deg	Trim, deg
Mounted on a conventional ship or construction barge	±22.5	±15	±10	±5
Mounted on a semisubmersible	...	±15	...	±15
Components in a bell	±45	±22.5	...	...

6-2.3 Environmental Requirements

Pressure vessels used in diving are exposed to conditions needing special consideration. These conditions may include

- (a) weather
- (b) frequent handling
- (c) weight and buoyancy
- (d) static/dynamic loads
- (e) exposure to marine conditions
- (f) corrosion
- (g) exposure to temperature extremes

6-2.4 Corrosion

The design shall consider corrosion allowance and/or mitigating process based on the operating environment as defined in the User's Design Specification. Areas of pressure vessels subject to corrosion shall be protected by an appropriate means.

6-2.5 External Pressure Rating

Components of PVHO pressure boundaries subject to external pressure shall be designed in accordance with Section 1 of this Standard.

6-2.6 Impact Protection

The designer shall provide protection to the pressure hull of the PVHO and critical components (e.g., viewports, emergency gas supplies, etc.) that may be subject to impact during operations and transportation. This protection should also be designed to minimize the risk of fouling or entanglement.

6-2.7 Buoyancy

Should the User's Design Specification require a positively buoyant bell, any ballast control mechanism shall be designed to prevent accidental activation or inadvertent release.

6-2.8 Occupant Requirements

6-2.8.1 All PVHOs shall have

- (a) sufficient gas supply for normal and emergency requirements
- (b) an entry lock or the capability of being mated to another PVHO as a method for access to the occupants while under pressure
- (c) the ability to monitor and control the depth
- (d) the ability to maintain a life-sustaining breathable environment
- (e) the ability to monitor oxygen and carbon dioxide levels of the breathing environment if the PVHO's life-sustaining breathable environment is maintained by carbon dioxide scrubbing

6-2.8.2 The designer shall apply principles of ergonomics to the arrangement of the PVHO. The recommended minimum internal dimensions and volumes are

(a) *saturation living chambers*: sized to allow occupants to stand and lie down, move in and out of the chamber, and permit meal services while saturated

(b) *transfer lock (TUP)*: 105 ft³ (3.0 m³) floodable volume

(c) *diving bell (SDC)*

(1) *two occupants*: 105 ft³ (3.0 m³) floodable volume

(2) *three occupants*: 160 ft³ (4.5 m³) floodable volume

(d) *deck decompression/recompression chamber (DDC)*: sufficient to accommodate a diver and an attendant

6-2.8.3 PVHOs intended for use as living chambers for longer than 24 hr in other than emergency situations shall have or be capable of connecting to another PVHO equipped with the following for the intended number of occupants:

(a) monitor and control the oxygen level, carbon dioxide level, ambient temperature, and primary life-support parameters

(b) one bunk per occupant

(c) potable water

(d) toilet

(e) shower

(f) medical or service lock

(g) built-in breathing system (BIBS) with a breathing gas

6-2.8.4 PVHOs shall be designed to allow access to internal bilge/void areas for cleaning and inspection.

6-2.9 Lubricants and Sealants

Lubricants and sealants selected for use in PVHOs shall be suitable for the hyperbaric environment in which they operate.

The designer shall address

(a) flammability

(b) toxicity

(c) compatibility with breathing gases

(d) odor

(e) skin irritation

(f) compatibility to materials

6-2.10 Fire Safety

The construction of the PVHO shall be such as to minimize hazards of smoke and fire. Systems shall be designed and equipped to avoid sources of ignition and minimize flammable materials. Toxicity of combustion products and flame-spread characteristics shall be considered in material selection.

6-2.11 Fire Suppression

The system designer shall address fire suppression. A formal risk analysis shall be conducted to establish the performance requirements for the system. The designer may elect to provide a passive prevention or an active suppression system.

Active suppression systems shall be tested for operation under the full range of required suppression system pressures. Extinguishing systems shall be compatible with life-support requirements of the PVHO. Carbon dioxide and dry powder are not suitable for use as extinguishing agents in enclosed environments.

6-2.12 Material Toxicity (Including Paints)

Materials and equipment inside manned compartments shall not give off noxious or toxic vapors within the limits of anticipated environments. Where compliance with this requirement has not been demonstrated through satisfactory service experience, an analysis or testing program shall be performed.

6-2.13 Electrical

Measures shall be taken to minimize any electrical hazards to divers and personnel in the diving system.

6-2.14 Gas Storage Cylinders and Volume Tanks

Gas storage cylinders and volume tanks shall meet the requirements of the ASME Code or other national or international standards recognized by the applicable regulatory authority. Cylinders used for the transportation of gases within the United States or on vessels operating in U.S. waters must also comply with the applicable sections of U.S. Department of Transportation regulations governing cylinders in Title 49 of the Code of Federal Regulations.

6-2.14.1 Gas Storage Cylinders. Individual cylinders or multiple cylinders grouped together by means of a manifold to form a cylinder bank shall be provided with

(a) a readily accessible isolation valve to stop gas flow to the system. This valve shall be rated for the maximum allowable working pressure (MAWP) of the cylinder.

(b) a protective device to relieve excess pressure. The relieving device shall meet the requirements of the applicable cylinder standard.

(c) clear labeling as to content in accordance with a recognized national or international standard.

(d) a means of eliminating moisture when used for storing reclaimed gases.

(e) moisture separators and filters that may be used to ensure no moisture enters the system.

(f) a means of monitoring internal pressure.

6-2.14.2 Volume Tanks. Each volume tank shall be provided with

(a) a readily accessible isolation valve to stop gas flow to the system. This valve shall be rated for the MAWP of the volume tank.

(b) a means of periodically draining moisture from the bottom of the tank.

(c) a means of relieving excess pressure.

(d) a method for monitoring internal pressure.

6-3 PRESSURE BOUNDARY

6-3.1 Personnel Access Doors/Hatches

The design of doors and hatches shall

(a) be in accordance with the requirements of Section 1 of this Standard.

(b) have a nominal diameter of at least 24 in. (610 mm) if used as a normal means of personnel ingress or egress.

(c) be provided on each side with a means of opening and closing hatches or doors (i.e., handle).

(d) be operable from both sides of the door or hatch.

(e) be such that reverse overpressurization of the door does not cause catastrophic failure of the locking dog or other similar devices if used.

(f) be such that corrosion or binding due to friction shall be eliminated as far as practical.

(g) be such that opening may not take place when the pressure is not equal on both sides.

(h) take into account dynamic movements and loads on door and hatch operating and hinge mechanisms to verify the structural adequacy and seal tolerance.

(i) provide a means for securing any hinged door or hatch in the fully open position.

(j) preclude unintentional operation of the door or hatch when springs or mechanisms are used to assist in the operation.

(k) ensure that if fluids are used in door or hatch assist mechanisms, they are compatible with the environment.

(l) have a safety interlock system if pressure acts to open or unseat the door or hatch. The safety interlock system shall not permit pressurization of the door or hatch unless the door/hatch closure is fully engaged.

SDC (diving bell) lockout hatches shall be sized to facilitate recovery of a fully dressed and unconscious diver. Larger openings may be necessary to accommodate divers with emergency life-support systems activated. A minimum of 28 in. (711 mm) diameter clear opening is required.

6-3.2 Medical/Service Locks

Medical/service locks shall

(a) be designed, fabricated, inspected, certified, and tested in conformance to this Standard

(b) be sized for the purpose intended (e.g., passing food, medicine, emergency supplies, scrubber canisters, diving helmets, equipment, etc.)

(c) have an external means for monitoring, venting, and equalizing pressure to the compartment being serviced or to atmosphere

(d) be provided with a safety interlock to prevent inadvertent opening of the door, cover, or hatch when the pressure in the medical/service lock acts to open the door, cover, or hatch

6-3.3 Closures

Clamps and closure devices used to couple PVHOs shall

(a) be designed, fabricated, inspected, tested, and certified in accordance with Section 1 of this Standard

(b) be designed for vessel dynamic movements and include sufficient supports to carry the weight of the clamps while in the open position

(c) be fitted as per requirements in para. 6-3.4 where trunks or tunnels are created by use of clamps and closures

(d) be provided with a positive safety interlock in accordance with Section VIII of the Code

(e) incorporate a manual system to allow clamp opening on failure of the primary operating system if the primary system is a powered system

6-3.4 Trunks and Tunnels

Trunks and tunnels incorporated in or created by the coupling of PVHOs shall

(a) be designed, fabricated, inspected, tested, and certified in accordance with Section 1 of this Standard

(b) have a minimum internal diameter of 24 in. (610 mm)

(c) have an external means for monitoring, venting, and equalizing pressure when connected to an adjacent compartment or atmospheric pressure

(d) provide hand and/or footholds in trunks or tunnels exceeding 36 in. (914 mm) in length

6-3.5 Viewports

All viewports shall meet the requirements of Section 2 of this Standard. Viewports shall be provided with protection suitable for the use intended.

6-3.6 Lighting

6-3.6.1 Light Level. Sufficient lighting shall be provided for the safe operation of the PVHO.

6-3.6.2 Lighting Devices. Interior lighting devices shall be rated for the PVHO's MAWP. Exterior light transmitting devices that act as part of the PVHO pressure boundary shall meet the requirements of Section 2 of this Standard.

6-3.7 Service Penetrators

Service penetrators shall

(a) be equipped with valves on both sides of the penetrator and be installed as close to the PVHO hull penetration as possible

(b) have a MAWP equal to or greater than that of the PVHO

(c) be able to withstand maximum internal and external pressures

(d) be compatible with the intended service

(e) be suitable for the effects of chemical reactions

- (f) be suitable for the effects of temperature
- (g) be suitable for the effects of corrosion
- (h) have suitable protection to areas subject to impacts during operation or transportation
- (i) be accessible for inspection

6-3.8 Electrical Penetrators

Electrical service and instrumentation penetrators shall

- (a) be designed for the service intended
- (b) be constructed from materials suitable for the service intended including the effects of corrosion
- (c) have a design pressure and temperature rating equal to or greater than the PVHO MAWP and temperature
- (d) be gas/watertight even in the event of damage to the connecting cable
- (e) be designed for both internal and external pressure when used in PVHOs that are rated for internal and external pressure (e.g., diving bell)

6-3.9 Fiber-Optic Penetrators

Fiber-optic penetrators shall meet the mechanical criteria as described for electrical penetrators.

6-4 SYSTEMS

6-4.1 Handling Systems

6-4.1.1 General. This section provides the additional requirements for the handling, deployment, and emergency recovery of diving bells, which are also known as personnel transfer capsules (PTCs).

Handling systems for diving bells shall comply with at least one of the codes and standards required by an International Association of Classification Societies (IACS) member classification society and the applicable organization(s) having regulatory and jurisdictional authority.

Ropes and loose gear items (blocks, sheaves, shackles, etc.) used on handling systems shall comply with the codes and standards recognized by the applicable organization(s) having regulatory and/or jurisdictional authority.

6-4.1.2 Design. Diving systems shall be provided with a handling system as defined. The handling system shall be capable of safely moving the diving bell and its occupants (divers) between the work location and surface compression chamber(s).

The handling system shall comply with the handling system rated load/safe working load requirements as defined and meet the performance criteria given in the User's Design Specification.

The handling system shall comply with the handling system design load requirements as defined in para. 6-2.2 and meet the performance criteria given in the User's Design Specification.

For the eventuality of a single component failure in the main handling system, a secondary system shall be provided to enable the divers to be brought back to the surface compression chamber. This secondary system shall be powered independently from the main handling system.

Handling system winches shall be provided with two independent braking mechanisms. The braking mechanisms shall be designed to hold 100% of the design load of the handling system. Braking mechanisms shall be designed to fail-to-safety and set automatically upon loss of power to the winch.

Lowering of loads shall be controlled by powered drives independent of the braking mechanisms. Powered drives shall be designed to handle 100% of the design load of the handling system.

The handling system shall be provided with the means to stabilize the diving bell and prevent excessive rotation during ascent/descent through the water column.

The handling system shall be provided with the means to prevent the diving bell from contacting the vessel's hull or any elements of the handling system during handling operations between the surface compression chambers and keel depth of the vessel.

6-4.1.3 Test and Trials. The fully assembled handling system shall be statically load tested to 100% of the design load of the handling system.

After installation on board the vessel, the handling system shall be functionally tested at the maximum rated speed of the system. Satisfactory operation of the complete handling system, including the powered drives and brakes, shall be demonstrated and shown to meet the requirements of para. 6-4.1.2.

6-4.2 Communication Systems

6-4.2.1 All diving PVHOs shall be equipped with communications between the PVHO operator(s) and internal occupants. Communication systems shall consist of both a primary and secondary system. The secondary system shall consist of a sound-powered telephone or other methods that operate in the event of power loss. Communication systems shall be included in each occupiable lock of the PVHO. In the event the control operator or the occupant(s) do not have direct visual contact, the secondary system shall be equipped with a signal device, such as an audible annunciator, to alert the operator or the occupant(s).

6-4.2.2 When helium mixtures are used in the breathing medium, a helium unscrambler shall be used.

6-4.2.3 Diving bells shall be equipped with a through-water communications system rated for the maximum operational distance from the PVHO operator(s).

6-4.3 Sanitary Systems

6-4.3.1 All diving PVHO systems designed for extended occupancy shall be outfitted with the following system capable of supporting the sanitary needs of the occupants:

(a) Chambers designed for occupancy not exceeding 24 hr shall have provisions for handling sanitary waste and hand-washing facilities.

(b) Chambers designed for occupancy in excess of 24 hr, except those used exclusively for hyperbaric rescue, shall incorporate a flushing toilet, hand-washing sink, and shower with running water and drain facilities.

6-4.3.2 The flushing toilet shall be provided with the following:

(a) a source of water capable of being delivered at a pressure adequate to ensure sufficient flow into the chamber at its maximum operating pressure

(b) interlock(s) to prevent actuation while the occupant is seated

(c) an actuation that shall require at least two distinct and separate sequential actions by the occupant

(d) a flushing system that shall be designed to limit the volume of gas exhausted with each actuation

(e) an effluent drain that shall be routed to an external holding tank

(f) a toilet seat that must include a stand-off to ensure that a complete seal between the toilet bowl and user cannot be achieved

6-4.3.3 The hand-washing sink and shower system shall be provided with the following:

(a) a source of water capable of being delivered at a pressure adequate to ensure sufficient flow into the chamber at its maximum working pressure

(b) a water drain that shall be routed to an external holding tank

(c) a drain that may be manual or automatic

(d) a drain system that shall include a stand-off that ensures that a complete seal between the drain and user cannot occur

6-4.3.4 The holding tank shall be provided with the following:

(a) pilot and vent valves to ensure it cannot exceed chamber pressure during system actuation or chamber decompression.

(b) a pressure gauge indicating tank pressure.

(c) a level-indicating device and normally closed fail-to-safety actuating drain valve.

(d) a drain line connecting the holding tank with the appropriate system on the vessel or land-based facility sewerage system. This external drain shall be designed to prevent nonpermissible pressurization of the external drainage system.

6-4.4 Electrical Systems

(16)

6-4.4.1 General. Electrical systems, including power supply arrangements, shall be designed for the environment in which they will operate in order to minimize the risk of fires, explosions, electrical shocks, emission of toxic gases, and galvanic action on the PVHOs. For electrical equipment exposed to diving conditions, the designer shall consider pressure and pressure cycling, humidity, moisture, temperature, oxygen concentration, hydrogen concentration, and cable flammability.

Electrical systems installed within PVHOs shall be limited to those necessary for the safe operation of the PVHO and the monitoring of its occupants.

6-4.4.2 Power Supplies

6-4.4.2.1 General. Diving systems shall be provided with independent main and emergency sources of electrical power.

6-4.4.2.2 Main Power. The main source of electrical power shall have sufficient capacity for all anticipated diving operations.

6-4.4.2.3 Emergency Power. The emergency source of power shall have sufficient capacity to supply the applicable emergency electrical loads for the safe termination of the diving operations. The emergency source of electrical power shall be located so as to ensure its functioning in the event of failure of the main source of power.

6-4.4.2.4 Reserve Power. In addition to the main and emergency sources of power, diving bells/personnel transfer capsules and hyperbaric rescue chambers/lifeboats shall be provided with a suitable on-board reserve source of power. This on-board source of power shall be capable of feeding the applicable emergency equipment such as the emergency life-support equipment, communication equipment, and internal lighting. For diving bells/personnel transfer capsules, the on-board source of power shall have sufficient capacity to supply power for at least 24 hr. For hyperbaric rescue chambers/lifeboats, the on-board source of power shall have sufficient capacity to supply power for at least 72 hr.

6-4.4.3 Distribution

6-4.4.3.1 General. The pressure boundary of PVHOs shall not be used as a current-carrying conductor. All electrical power distribution systems shall be ungrounded and insulated to minimize the occurrence of faults and stray currents that may create galvanic corrosion.

6-4.4.3.2 Voltage. The maximum voltages for PVHOs shall not exceed those specified below.

Application	Maximum Voltage	Nominal Voltage
AC with circuit protection device	250	220
AC without circuit protection device	7.5	6
DC with circuit protection device	285	250
DC without circuit protection device	30	24

6-4.4.3.3 Ground Detectors. Ground detectors or interrupters shall be provided for systems with a line voltage above 7.5 V AC or 30 V DC.

6-4.4.3.4 Cables and Wiring. Cables and wiring shall meet a recognized national or international electrical standard (such as IEC Standards or IEEE Standard 45). They shall be flame retardant and shall comply with the flammability criteria of a recognized national or international standard. Cables and wiring within the pressure boundary of PVHOs shall be of the low-smoke, low/zero-halogen type.

6-4.4.3.5 Cable Separation. Cables and wiring of circuits supplied by different voltages and by main and emergency circuits shall be effectively separated from each other.

6-4.4.3.6 Positive and Negative Conductors. The positive and negative conductors from the main or emergency power source shall be spaced sufficiently to prevent damaging currents and shall not pass through the same penetrator or connection in a pressure boundary unless

(a) it can be shown that there is little risk of short circuiting or tracking between the conductors

(b) the voltages and currents are of such an order that, in the event of failure in any way of the conductor insulation, the penetrating device's gas- and watertight integrity is maintained

6-4.4.3.7 Cables Subjected to External Pressure. Materials for uncompensated cable and wiring insulation subjected to external pressure shall be capable of withstanding a hydrostatic pressure of 1.5 times the design pressure of the diving system. Submerged cable assemblies shall be tested by the continuous application of an alternating current voltage of at least 500 V for 1 min. This shall be performed with the jacket exposed to seawater. The quality of the assembly should be such that the leakage current will neither prevent proper operation of the systems nor expose personnel to unsafe voltages.

6-4.4.4 Circuit Protection

6-4.4.4.1 Circuit Protection Devices. Power cables shall be protected from overloads and short circuits by protective devices that isolate all conductors in the overloaded circuit. Circuit protection devices shall meet a recognized national or international electrical standard.

Fuses and thermal circuit breakers are not permitted in a helium-oxygen environment.

6-4.4.4.2 Pressure Boundary Power Penetrations.

All power cables passing through the pressure boundaries of PVHOs shall be adequately protected by circuit breakers or fuses against overload and short circuit. The circuit breakers or fuses shall be located on the power source side of the pressure boundaries and shall have the ability to open the circuits quickly to prevent damage to the gas/watertight integrity of the electrical penetrators.

6-4.4.5 Battery Compartments

6-4.4.5.1 Sources of Ignition. Design and procedural precautions shall be taken to eliminate all potential sources of ignition within battery compartments.

6-4.4.5.2 Hydrogen Levels. For batteries capable of generating hydrogen gas, design features shall be in place to avoid the potential hazards arising from hydrogen accumulation. Protective devices located in battery compartments containing these batteries shall not provide an ignition source for the hydrogen gas.

6-4.4.5.3 Electrical Equipment. All electrical equipment in battery compartments containing batteries capable of generating hydrogen gas shall be of the explosion-proof or intrinsically safe type.

6-4.5 Emergency Evacuation Systems

(16)

6-4.5.1 General. All diving systems used to support saturation diving operations shall be equipped with an emergency evacuation system (EES) capable of providing a means of evacuation for the maximum number of divers in the diving system. The EES shall be capable of operating at the maximum operating pressure of the diving system as set forth in the User's Design Specification in accordance with subsection 1-4. Emergency evacuation systems include, but are not limited to, hyperbaric lifeboats, hyperbaric rescue chambers, and flyaway chambers, but for the purposes of this section of the Standard shall include any system intended for the emergency evacuation of saturation divers under pressure. Diving bell(s) used for normal operations and one- or two-man transportable chambers shall not be considered as part of the emergency evacuation system.

6-4.5.2 Emergency Evacuation System User Requirements

6-4.5.2.1 There are two forms of hyperbaric evacuation system

(a) a PVHO that has been specifically designed and outfitted with the equipment and life-support systems necessary to evacuate divers from a ship, barge, semi-submersible, or fixed offshore structure, and maintain life-supporting conditions for the maximum number of occupants at the maximum operating pressure of the diving system for a period of not less than 72 hr

(b) a PVHO integrated into or forming part of a purpose-built, SOLAS¹-compliant self-propelled lifeboat outfitted with the equipment and life-support systems necessary to evacuate divers and maintain life-supporting conditions for the maximum number of occupants at the maximum operating pressure of the diving system for a period of not less than 72 hr

6-4.5.2.2 The EES shall be fitted with and/or carry on-board the following:

(a) Individual seats for each occupant shall be outfitted with a positive means to prevent injury to the occupants during launch and recovery and in rough weather conditions.

(b) A clearly written operation procedure manual detailing preparation for evacuation, the setup and operation of the environmental control equipment, and all other life-support equipment and systems.

(c) A list of tapping codes for nonverbal communication with personnel outside the evacuation chamber in the absence or failure of two-way radio communications.

(d) On-board oxygen to support the metabolic oxygen requirements of the maximum number of occupants for a period of 72 hr based on a minimum flow of 0.017 standard ft³/min (0.48 standard L/min) per occupant. Special care shall be taken to ensure adequate distribution and mixing of metabolic oxygen within the chamber.

(e) A primary and secondary means of removing carbon dioxide (CO₂) from the atmosphere including, but not limited to, battery- and lung-powered systems with absorbent chemicals sufficient to remove the CO₂ output from the maximum number of occupants for a period of 72 hr.

(f) A primary and secondary means of chamber lighting. The primary lighting power source shall be sufficient to maintain primary lighting for a period of 72 hr. If the secondary means of lighting is powered, then it too shall be sufficient for 72 hr.

(g) A toolkit shall be provided that is capable of supporting minor repairs and maintenance inside the chamber. The toolkit shall be clearly marked and located to be easily accessible. For self-propelled lifeboats, an additional external toolkit shall be provided.

(h) A means of monitoring the chamber environment including pressure, temperature, humidity, oxygen (O₂), and carbon dioxide (CO₂). Independent backup for O₂ and CO₂ monitoring shall be provided.

(i) A system for heating/cooling the PVHO to maintain physiologically acceptable conditions throughout the operating range of the evacuation system. Thermally protective clothing may also be provided as a passive backup system to the heating system.

(j) Power sufficient to support all life-critical powered systems for a period of 72 hr.

(k) A medical kit shall be provided that is suitable for at least minor injuries, with sick bags and medications for motion sickness. The kit shall be stored in a suitable container, clearly marked and located to be easily accessible.

(l) A means of transferring equipment and supplies into and out of the chamber under pressure.

(m) Meals that use exothermic chemical means, flames, electrical resistance, or any other heating means that is not approved for use in pressurized, oxygen-enriched environments shall not be used. Each meal shall provide a minimum equivalent of 800 calories per 24-hr period per occupant. There shall be meals for the maximum number of occupants for a period of 72 hr stored in a clearly marked, easily accessible location.

(n) A minimum of 6 pints (3 L) of drinking water per 24-hr period per occupant for the maximum number of occupants for a period of 72 hr shall be carried on board. The water shall be stored in a secure, clearly marked, easily accessible location.

(o) A means of managing human waste. The system shall be capable of preventing accidental spillage during launch or recovery or in rough weather conditions.

(p) An internationally recognized marine emergency position-indicating radio beacon (EPIRB).

(q) The external surfaces of the emergency evacuation system shall be colored international orange.

(r) Signs indicating DIVERS IN DISTRESS shall be located on the top and sides in three places and sized and marked in accordance with the International Maritime Organization (IMO) guidelines A692 (17) (Fig. 6-4.5.2.2-1).

(s) Warning information shall be located on the sides at or above the waterline in accordance with the IMO guidelines A692 (17) as shown in Fig. 6-4.5.2.2-2.

(t) A radar reflector, reflective tape, and a strobe light shall be installed to facilitate system location.

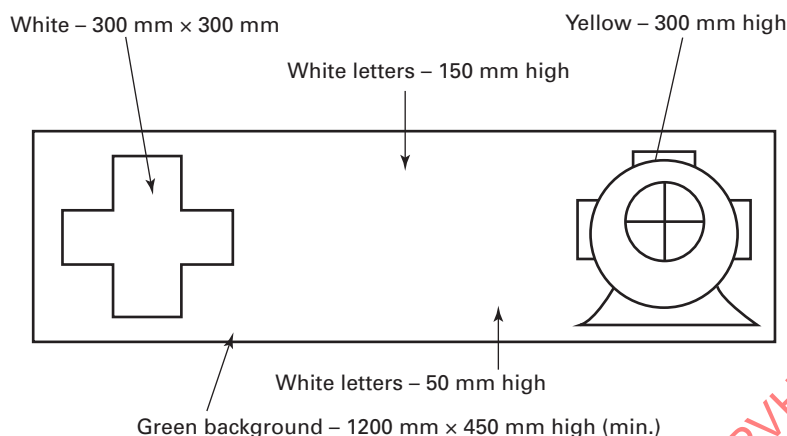
(u) Lifting slings and towing bridles shall be provided, securely stowed, and labeled. The total in air weight of the evacuation system including personnel and equipment shall be prominently displayed. In addition, each lifting point shall be clearly marked with its safe working load.

(v) A communication system capable of permitting two-way voice communication between the chamber occupants and outside attendants.

(w) A sound-powered phone secondary communication system.

(x) A waterproof emergency services interface point protected from damage by a reinforced cover. This interface shall contain connection points for power, gas/oxygen, and the internal chamber two-way voice communication system, a sound-powered phone, a copy of the operation procedure manual, a set of the tapping codes, and a complete inventory of supplies. Consideration shall be given to providing a waterproof handheld VHF radio for use by rescuing personnel.

¹ SOLAS = safety of life at sea.

Fig. 6-4.5.2.2-1 Placement and Design of Markings of Hyperbaric Rescue Systems Designed to Float in Water (16)

GENERAL NOTE: From IMO A692(17).

Fig. 6-4.5.2.2-2 Markings of Hyperbaric Rescue Systems Designed to Float in Water (16)

UNLESS SPECIALIZED DIVING ASSISTANCE IS AVAILABLE:

DO NOT touch any valves or other controls

DO NOT take in tow unless in imminent danger

DO NOT try to get the occupants out

DO NOT connect any gas, air, water, or other supplies

DO NOT attempt to give food, drinks, or medical supplies to the occupants

DO NOT open any hatches

GENERAL NOTE: From IMO A692(17).

(y) The hyperbaric evacuation chamber shall have at least one viewport that provides visual access to the occupants.

6-4.5.3 Emergency Evacuation Life-Support Control System. Each hyperbaric evacuation system shall have a separate, portable life-support control system that provides all interfaces and services necessary to maintain, monitor, and control the chamber environment and conduct safe decompression of the evacuated divers.

6-4.5.4 Testing

6-4.5.4.1 A test shall be carried out to demonstrate the mating, detachment, and deployment of the emergency system from the parent diving system. The chamber shall be weighted to simulate the maximum load condition and verify the launch system meets design load requirements and the emergency evacuation system remains upright and positively buoyant following release.

6-4.5.4.2 A test shall be carried out to demonstrate that with the emergency evacuation system weighted to simulate maximum load conditions, the lifting points are adequate for recovery.

6-4.5.4.3 A test shall be carried out to demonstrate the capacity of the heating/cooling system to maintain thermal balance over the range of environmental conditions as defined in the User's Design Specification.

6-4.5.4.4 A test shall be carried out to demonstrate the capacity of the O₂ makeup system to compensate for the metabolic oxygen consumption of the maximum number of occupants for which the system is rated.

6-4.5.4.5 A test shall be carried out to demonstrate the capacity of the primary CO₂ removal system to remove the total metabolic CO₂ output of the maximum

number of chamber occupants for which the system is rated.

6-4.5.4.6 A test shall be carried out to demonstrate that the emergency evacuation life-support control system is able to be attached and used to maintain, monitor, and control the functional operation of the chamber including decompression.

6-4.5.4.7 Testing shall be witnessed and documented in accordance with the User's Design Specification.

(16) 6-4.6 Emergency Recovery of Diving Bells

6-4.6.1 General. This section addresses the design, construction, and testing of emergency recovery equipment on diving bells.

6-4.6.2 Design. Diving bells shall be outfitted with a means of emergency recovery depending on whether they have been designed to remain negatively buoyant or become positively buoyant.

All diving bells shall be equipped with a secondary lifting point, meeting the same requirements as the primary lifting point, to facilitate the attachment of an emergency lifting wire.

Consideration shall be given to the clearance necessary between the bottom door and the seabed to ensure safe ingress or egress of divers under emergency conditions.

6-4.6.3 Negative Buoyancy Diving Bells. Guide wires and clump weight(s) shall be designed to permit the diving bell to be recovered from the maximum operating depth when loaded to the maximum service weight, with trunk(s) flooded, and the maximum deployable length of umbilical and lifting wire attached to the bell and severed at the surface.

6-4.6.4 Positive Buoyancy Diving Bells. The diving bell shall be equipped with devices for releasing the main lifting wire, guide wires, and the umbilical and ballast weight(s). The operation of each emergency release device shall require at least two mutually independent actions to release.

Release devices shall be designed to prevent accidental actuation. Consideration shall be given to environmental factors, such as exposure to ambient temperatures and pressures. The design should facilitate regular testing and maintenance.

After the release of the main bell wire, guide wires, and umbilical and ballast weight(s), the diving bell shall exhibit positive buoyancy when loaded to the maximum service weight and with trunk(s) flooded. Under these circumstances, the diving bell shall have sufficient stability to remain upright. Consideration shall be given during the risk assessment as required in subsection 1-11 to the ascent rate and impact on surface vessels and structures.

6-4.6.5 Functional Testing. Functional testing shall be carried out to demonstrate and document proper operation of all emergency recovery functions.

6-5 TESTING

All diving PVHOs shall be functionally and physically tested prior to operational service. Testing shall be conducted on all parts, components, and systems for a fully functional and operational diving system. As a minimum, the following tests shall be performed:

(a) internal/external pressurization test to full operational pressure (External pressure test may be included on functional testing during sea trials.)

(b) pressure test of all hatches and sealing surfaces at maximum and minimum pressures

(c) pressurization/leak test of internal and external pressure-retaining components

(d) operational test of electrical and mechanical systems to ensure proper function and the absence of unacceptable hazards as required in subsection 1-11

(e) other tests as required

Trained and qualified personnel shall perform tests in accordance with written instructions stipulating acceptance criteria. All test results shall be documented and retained by the manufacturer.

6-6 QUICK-ACTING CLOSURES FOR DIVING BELLS AND EMERGENCY EVACUATION SYSTEMS (16)

6-6.1 General

These requirements are applicable to quick-acting closures that facilitate the connection and disconnection of diving bells and evacuation systems to and from a main diving system for the purpose of diver transfer under pressure.

6-6.2 Design

(a) The quick-acting closure shall be designed to connect and disconnect the diving bell and emergency evacuation system under all operational conditions as detailed in the User's Design Specification.

(b) The quick-acting closure shall be provided with a safety interlock to prevent accidental opening in accordance with ASME BPVC Section VIII, Division 1 UG-35.2.

(c) The quick-acting closure safety interlock shall also prevent pressurization until the closure mechanism is fully engaged.

(d) When power-actuating systems are used for mating operations, a manual backup actuation system shall be provided for use in the event of a system power or switching failure. The manual backup system shall require two mutually independent actions for operation.

(e) An interlock system with visual indicator shall be provided to prevent operation of the handling system

while mated. The interlock system shall prevent activation of the handling system until the quick-acting closure is in the fully open position.

6-6.3 Testing

(a) Testing shall be carried out to demonstrate the function and structural integrity of all quick-acting closures under all operational conditions.

(b) Testing shall be witnessed and documented by an independent qualified third party.

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Section 7

Submersibles

7-1 GENERAL

7-1.1 Scope

This Section, along with Sections 1 through 4 of this Standard, provides the requirements for the design, assembly, inspection, testing, and certification of PVHOs used in manned submersibles including tourist submersibles. For diver lockout chambers, see Section 6.

7-1.2 General Requirements

The PVHO shall be designed, fabricated, assembled, inspected, tested, and certified in accordance with this Section and Sections 1 through 4 of this Standard.

7-1.2.1 Single Failure. The basic requirement for a submersible craft design is that, in the event of any single failure, the craft can return to the surface without external assistance. Appropriate backup systems and equipment shall be incorporated to meet this general design requirement.

7-1.2.2 Operating Conditions. The submersible shall be designed for and be capable of operating in the service conditions and temperature ranges envisaged both on the surface and under water.

The design criteria provided herein apply to submersibles operating in waters with a seabed depth not greater than the craft's rated depth. Consideration may be given for operations in areas with a greater seabed depth on the basis of safety evaluations demonstrating the adequacy of provisions and/or procedures.

7-1.3 User's Design Specification

The user, agent on his/her behalf, designer, or the manufacturer shall provide or cause to be written a User's Design Specification. This specification shall set forth the requirements as to the intended use of the submersible and operating and environmental conditions in such detail as to constitute an adequate basis for designing, fabricating, inspecting, and testing the system as necessary to comply with this Standard. The User's Design Specification shall include, as a minimum, the following:

- (a) maximum operating depth
- (b) maximum operating sea state
- (c) maximum operating current
- (d) normal and maximum speed while surfaced and submerged
- (e) minimum and maximum allowable operating temperatures (internal and external)

- (f) minimum and maximum onboard personnel
- (g) maximum mission time
- (h) maximum lifting weight
- (i) payload
- (j) maximum towing speed
- (k) normal, reserve, and emergency power capacities
- (l) normal, reserve, and emergency life-support capacities

7-1.4 Design Certification

Conformance of the completed PVHO to the requirements of this Section of the Standard and the User's Design Specification shall be established by one of the following procedures:

(a) *Professional Engineer Certification.* A Professional Engineer, registered in one or more of the U.S. states or the provinces of Canada, or the equivalent in other countries, experienced in the design of submarines, shall certify that the PVHO was designed either by him or under his supervision, or that he has thoroughly reviewed a design prepared by others, and that to the best of his knowledge, within the User's Design Specification, the PVHO design complies with this Section of the Standard.

(b) *Independent Third-Party Certification.* The PVHO shall be reviewed by an independent classification society competent in pressure vessels for human occupancy,¹ and such organization shall provide a certification that, within the User's Design Specification, the PVHO design complies with this Section of the Standard.

7-1.5 Documentation

The manufacturer shall retain a copy of the User's Design Specification, the Design Certification, and supporting data (test data and material test reports as required by the User's Design Specification, window certificates) for at least 5 yr.

A copy of the following shall be provided to the user:

- (a) User's Design Specification
- (b) window certificates
- (c) any classification society certifications
- (d) vessel drawings necessary for the maintenance, inspection, and repair of the PVHO
- (e) operations manual

¹ Systems and manned submersibles.

7-1.6 Operations Manual

An operations manual describing normal and emergency operational procedures shall be provided. In addition to items listed in para. 7-1.3, the manual shall include

- (a) systems description
- (b) operational check-off list (list shall include equipment requiring operational status verification or inspection prior to each dive/operation)
- (c) special restrictions based on uniqueness of the design and operating conditions
- (d) life-support systems descriptions including capacities
- (e) electrical system description
- (f) ballast system description
- (g) fire-suppression system description
- (h) launch and recovery operation procedures
- (i) normal and emergency communications procedures
- (j) emergency rescue plan
- (k) emergency procedures for situations including, but not limited to, the following:
 - (1) power failure
 - (2) break in umbilical cord (if applicable)
 - (3) deballasting/jettisoning
 - (4) loss of communications
 - (5) life-support system malfunction
 - (6) fire
 - (7) entanglement
 - (8) high hydrogen level (if applicable)
 - (9) high oxygen level
 - (10) high carbon dioxide (CO₂) level
 - (11) internal and external oxygen leaks
 - (12) being stranded on the bottom
 - (13) minor flooding
 - (14) specific emergency conditions (characteristic of special types of systems)
 - (15) loss of propulsion
 - (16) deteriorated surface conditions during a dive

7-2 PRESSURE BOUNDARY

7-2.1 General

The pressure boundary of submersibles built to this Section of the Standard shall be designed and constructed in accordance with Section 1 of this Standard. Other recognized industry standards for the design, construction, and testing of manned submersibles that have been validated through testing and service and that are suitable for the intended service and acceptable to the jurisdiction may also be used where Section 1 of this Standard does not address industry-specific issues for the design of submersibles.

Testing of the PVHO shall be in accordance with the recognized engineering methods used. As a minimum

requirement, such testing shall be 1.25 times the design pressure. The designer is cautioned that specific design requirements may be driven by depth, service, and environment. It is the designer's responsibility to provide a safe design.

7-2.2 Hatches

7-2.2.1 Number, Size, and Location. The following shall be considered when determining the number, size, and location of access hatches:

- (a) evacuation of crew and passengers in an emergency situation
 - (b) risks such as fire, smoke, stability of the craft, and possible down flooding due to adverse sea state
- The number of hatches shall not be unnecessarily increased beyond the safe minimum as determined in (a) and (b) above.

7-2.2.2 Opening, Closing, and Securing. Opening and closing of hatches shall be possible by a single person, in all anticipated operating conditions.

Provisions shall be made for opening/closing hatches from both sides.

Two means, one of which should be visual, shall be available to ensure that hatches are closed and secured prior to diving.

Hatches shall have a means for securing them in the open and closed positions.

7-2.2.3 Equalization. Means shall be available to ensure that pressures on either side of the hatch are equalized prior to opening.

7-2.3 Viewports

Viewports shall comply with Section 2 of this Standard.

7-2.4 Penetrators

7-2.4.1 Mechanical Penetrators. Mechanical penetrators shall be designed such that in the event of failure, the penetrator remains intact and does not allow leakage into the pressure hull.

7-2.4.2 Hull Shut-Off Valves. Any piping systems penetrating the pressure hull shall be equipped with a valve that can be operated manually. These valves shall be mounted directly on the inner side of the hull or on short and strong stub pieces (capable of withstanding anticipated mechanical and pressure loads) fitted between the valve and hull.

7-2.4.3 Testing Electrical Penetrators. Samples of penetrating devices conveying electricity through pressure boundaries shall be tested as indicated below, in the listed sequence of tests. Where applicable, penetrators shall be tested assembled with a length of cable of the type that will be used in the installation. The cable

and penetrator assemblies are to show no sign of deficiency during or after the test.

(a) voltage test by separately applying 1 kV plus twice the design voltage for 1 min across each conductor and armor separately under the most unfavorable environmental condition they will be subjected to during service.

(b) hydrostatic test to a pressure of 1.5 times the design pressure repeated six times. The pressure shall be applied to the side that will be under pressure in the actual application and shall be maintained for 20 min after the last cycle.

(c) gas leakage test with cable cut open using air to twice the design pressure or helium to 1.5 times the design pressure.

(d) insulation test to 5 MO at design pressure applying salt water. Tests shall be made between each conductor and armor.

Electrical conductors within the penetrating device shall be of solid material.

7-2.4.4 Electrical Penetrators. The positive and negative conductors from a power source shall not pass through the same penetrating device unless

(a) it can be shown that there is little risk of short circuiting or tracking between conductors

(b) the voltages and currents are of such an order that, in the event of failure in any way of the conductor insulation, the integrity of the penetrating device's water block is maintained

Electrical penetrating devices shall not have any pipes or other system passing through them. Different types of penetrating devices passing through a common plate are acceptable.

7-3 PIPING

7-3.1 Exceptions and Alternatives

7-3.1.1 Relieving Devices. In lieu of subsection 1-8, for PVHOs not internally pressurized, the following shall apply:

(a) A pressure-relieving device shall be used to ensure the internal pressure does not exceed that specified by the designer.

(b) A shutoff valve shall be installed upstream of the pressure-relieving device and shall be accessible to the attendant/pilot monitoring the operation of the PVHO.

(c) Rupture disks shall not be used.

7-3.1.2 User's Design Specification. In lieu of para. 4-1.2, the following information shall be documented on the system assembly drawing, in the operations manual, and/or in the User's Design Specification:

(a) the system maximum allowable working pressure (MAWP)

(b) conditions affecting the requirements for and amounts of stored gas reserves

7-3.1.3 Marking. Compliance with para. 4-2.4.4 is required with the exception that the hoses do not have to be tagged or marked with the test pressure or test dates. Hose assemblies shall be tested in accordance with para. 4-2.4.5. Hose testing shall be documented. (16)

7-3.2 Internal and External Pressures

Systems, fittings, and equipment subject to internal or external pressure or a combination of both shall be designed for the worst combination(s) of the above (e.g., external oxygen systems).

7-3.3 Ambient Pressure

Systems, piping, and equipment exposed to ambient sea pressure shall be suitable for the intended service and capable of withstanding all anticipated pressure differentials.

7-3.4 Inaccessible Spaces

Piping passing through spaces inaccessible for maintenance shall be of continuous pipe.

7-3.5 Hull Valves

For piping systems penetrating the occupied pressure hull and open to the sea, a nonreturn valve or shutoff valve shall be provided in addition to that provided in accordance with para. 7-2.4.2.

7-3.6 Plug Valves

Plug valves shall not be used.

7-3.7 Pressure Containers

The volume of a single internal gas source shall be limited in such a way that complete release of its contents will not increase the pressure beyond the safe limit for the craft and its occupants.

Cylinders and pressure vessels mounted externally, which may be depleted while at depth, shall be designed to withstand external pressures equal to the design depth of the submersible.

7-4 ELECTRICAL SYSTEMS

7-4.1 General

All power sources and electrical equipment shall be designed for the environment in which they will operate to minimize the risk of fire, explosion, electrical shock, and emission of toxic gases to personnel and passengers, and galvanic action of the submersible.

The designer shall consider pressure and pressure cycling, humidity, moisture, temperature, oxygen concentration, hydrogen concentration, and cable combustibility.

7-4.2 Power Supplies

7-4.2.1 General. The submersible shall have a separate main and an onboard emergency source of electrical power.

7-4.2.2 Main Power. The main source of electrical power shall have a reserve capacity beyond the normal mission time to supply, where and as appropriate, the following systems for a period of time consistent with the plan to rescue the submarine from its rated depth. The period of time shall in no case be less than 24 hr.

- (a) emergency lighting
- (b) communication equipment
- (c) life-support systems
- (d) environmental monitoring equipment
- (e) essential control systems
- (f) other equipment necessary to sustain life

7-4.2.3 Emergency Power. The emergency source of electrical power shall be located so as to ensure its functioning in the event of fire or other casualty causing failure to the main electrical power source.

The onboard emergency source of electrical power shall have the capacity to supply the systems listed in paras. 7-4.2.2(a), (b), and (d) through (f), plus the emergency life-support system, if electrically supplied, for 150% of the time normally required to reach the surface or 1 hr, whichever is greater, unless otherwise approved on the basis of special operating conditions.

7-4.3 Electrical Cables

7-4.3.1 Protection. Power cables shall have short circuit and overload protection. The device connected to power cables passing through a pressure boundary shall have response characteristics that ensure watertight integrity of the electrical penetrators. Protection devices located in the battery compartment shall not provide an ignition source for the hydrogen gas.

7-4.3.2 Main and Emergency Cables. Cables and wiring of circuits supplied by different voltages and by main and emergency circuits shall be effectively separated from each other.

7-4.3.3 Positive and Negative Conductors. Positive and negative conductors from power sources shall not pass through the same penetrator or connection in a pressure boundary and shall be spaced sufficiently to prevent damaging currents.

7-4.3.4 Pressure Boundary. The pressure boundary shall not be used as a current-carrying conductor.

7-4.3.5 Grounding. All electrical power distribution systems shall be ungrounded and insulated to minimize the occurrence of faults and stray currents that may create galvanic corrosion.

7-4.3.6 Insulation Material. Materials for uncompensated cable and wiring insulation subjected to external pressure shall be able to withstand a hydrostatic pressure of 1.5 times the design pressure of the submersible. Submerged cable assemblies shall be tested by the continuous application of an alternating current voltage of at least 500 V for 1 min. This shall be performed with the jacket exposed to seawater. The quality of the assembly shall be such that the leakage current will neither prevent proper operation of the systems nor expose personnel to unsafe voltages.

7-4.4 Battery Compartments

7-4.4.1 Sources of Ignition. Design or procedural precautions shall be taken to eliminate all potential sources of ignition within battery compartments.

7-4.4.2 Hydrogen Levels. Design features shall be in place to avoid the potential hazards arising from hydrogen accumulation.

For batteries located within the occupied pressure boundary, hydrogen gas concentrations shall be monitored and maintained at a level below the lower explosive limit.

7-4.5 Emergency Lighting

Internal emergency lighting that is switched on automatically if the main power supply fails shall be installed.

7-5 LIFE SUPPORT

7-5.1 General

The submersible shall be provided with systems and equipment necessary to ensure adequate life-support services during normal and emergency conditions.

A separate main and an onboard emergency life-support system shall be provided for maintaining the oxygen content of the breathing gas between 18% and 23% by volume and the concentration of carbon dioxide (CO₂) below 0.5% by volume under normal conditions and 1.5% by volume under emergency conditions.

7-5.2 Main Life Support

The main life-support system shall have sufficient capacity for the design mission time plus a period of time consistent with the plan to rescue the submarine from its rated depth. This period of time shall in no case be less than 24 hr and shall be consistent with the requirements of para. 7-4.2.2.

7-5.3 Emergency Life Support

The capacity of the onboard emergency life-support system shall be sufficient for 150% of the time normally required to reach the surface or 1 hr, whichever is greater, unless otherwise approved on the basis of special

operating conditions, and shall be consistent with the requirements of para. 7-4.2.3.

(a) Emergency breathing gas shall be supplied through full-face masks, oral-nasal masks, self-contained rebreathers, or other means suitable for supporting life in a contaminated environment, including the by-products of an onboard fire. One mask per person shall be provided.

(b) The emergency life-support system shall be independent of any surface support systems and independent of the main life-support systems.

(c) Where open-circuit systems are used, the effects of increased compartment pressure shall be considered.

7-5.4 Consumption Rates

For calculating the required capacities of main and emergency life-support systems, the consumption of oxygen shall be at a rate of 1 ft³ (28.3 L) per hr per person and a carbon dioxide (CO₂) production rate of 0.115 lb (0.0523 kg) per hr per person, at 1 atm.

7-5.5 Oxygen Systems and Storage

(a) When oxygen storage containers are located inside the pressure hull, the volume of a single container shall be limited such that the release of its contents shall not increase the pressure in the occupied PVHO by more than 1 atm or raise the oxygen level above 25% by volume. The designer, as may be required by other constraints, shall limit the allowable pressure increase.

(b) When oxygen storage containers are stored outside the pressure hull, they shall be arranged in at least two banks with separate penetrations entering the submersible. The pressure containers shall be designed for an external pressure differential of not less than the rated depth of the submersible.

(c) In view of the hazards associated with oxygen systems, consideration shall be given to the selection of materials, equipment, installation, cleaning, and testing procedures.

7-5.6 Monitoring

Capability shall be available to the pilot for monitoring oxygen (O₂) levels, carbon dioxide (CO₂) concentrations, humidity, temperature, and pressure of all occupied spaces.

Means shall be provided, and/or operational procedures implemented, to notify of a malfunction of the life-support systems.

7-6 FIRE PROTECTION

7-6.1 Materials

The construction of the submersible shall minimize hazards of smoke and fire. All materials and equipment within the craft shall be nonflammable within the range of oxygen (O₂) levels envisaged.

7-6.2 Toxicity

Toxicity of burning materials and low flame-spread characteristics shall be taken into consideration.

7-6.3 Smoke Detectors

The designer shall consider the size of the submersible, usage of unoccupied spaces, and the ability of occupants to detect fire/smoke, in advance of an onboard detector, in determining the location and quantity of smoke detectors.

7-6.4 Extinguishers

All submersibles shall be equipped with a suitable means of fire extinguishing. This may consist of a permanently installed system and/or portable extinguishers. The design of the system and selection of the extinguishing medium shall consider type and location of fire anticipated, hazards to human health, and the effects of increased pressure. Carbon dioxide and seawater are considered unsuitable.

7-7 NAVIGATION

7-7.1 General

Submersible craft shall be provided with navigational equipment to enable safe operation under all design conditions. Equipment shall include, but not be limited to, the following:

- (a) directional indicator
- (b) depth indicator
- (c) depth sounder
- (d) clock
- (e) trim and heel indicator
- (f) underwater location device

7-7.2 Propulsion

Submersibles equipped with propulsion systems shall be provided with adequate controls and indicators to enable safe operation under all design conditions.

7-7.3 Depth Gauges

Two independent instruments for registration of depth shall be provided. At least one of these instruments shall be a pressure gauge capable of functioning in an emergency situation. If both are pressure gauges, they shall not have a common inlet.

7-7.4 Depth Alarm

Submersibles operating in water where the seabed depth is greater than the rated depth of the submersible shall have a depth alarm set at no greater than the rated depth of the craft.

7-7.5 Obstacle Avoidance

Operational procedures and/or onboard equipment shall be used to provide adequate means of avoiding obstacles under all anticipated operational conditions.

7-7.6 Surfaced Detection

Means shall be provided to render the submersible, while on the surface, readily visible to other vessels.

7-7.7 Submerged Detection

Means shall be provided to indicate the submersible's location while it is submerged.

Where a releasable location system is used, the release arrangement may be manual or hand-hydraulic. It shall not depend on electrical power for its operation and shall be able to operate at all anticipated angles of heel and trim. The size of the float and length of line shall be such that expected current action on the line does not prevent the float from coming to the surface.

7-8 COMMUNICATIONS

7-8.1 General

Each submersible shall be fitted with such equipment as is necessary for the crew to communicate with personnel at the support facility when on the surface and when submerged.

7-8.2 VHF Radio

Each submersible shall be equipped with at least one two-channel transmitter/receiver, one of the channels of which shall operate on safety channel 16-VHF, while the other is used as a "working channel" for communication between the submersible craft and its support facility.

7-8.3 Underwater Telephone (UWT)

Each submersible shall be equipped with at least one dual-channel underwater telephone system. This system shall enable two-way communications to be maintained with the support facility.

7-8.4 Pinger

In addition to the requirements of para. 7-7.7, each submersible shall be fitted with an acoustic underwater pinger, compatible with equipment available for executing an underwater search and rescue. The pinger shall remain operational in the event of loss of main power.

7-9 INSTRUMENTATION

7-9.1 General

The pilot shall be able to monitor the conditions affecting the safety of the submersible craft and its occupants.

7-9.2 Water Intrusion

An audio alarm indicating water leakage into the main pressure hull, battery pods, and other compartments, as may be deemed necessary, shall be incorporated into the design.

7-9.3 Power Levels

Visual indications of available power (fuel, electrical, etc.) shall be provided.

7-9.4 Voltage and Current Meters

Voltage of, and current from, each electrical source of power shall be provided.

7-9.5 Ground Faults

A ground/earth fault monitoring system shall be provided.

7-9.6 Ballast Water

Where water ballast systems are used, a visual display showing the quantities of ballast water onboard shall be provided.

7-10 BUOYANCY, STABILITY, EMERGENCY ASCENT, AND ENTANGLEMENT

7-10.1 General

Submersibles shall be able to ascend/descend in a safe and controlled manner throughout the craft's depth of operations.

Submersibles shall be able to maintain an acceptable stability and trim during ascent and descent, while submerged, and on the surface. Acceptable stability and trim shall be maintained during transit from a submerged to a surfaced condition, and vice versa. The submersible craft shall be capable of remaining on the surface with the hatch(es) open during all anticipated design environmental and operating conditions without down flooding.

The arrangements for blowing ballast tanks shall be such that overpressurization is not possible.

7-10.2 Underwater Operation

The submarine shall, under all conditions of loading and ballast, remain stable and in the upright condition with the center of gravity remaining below the center of buoyancy. The distance between the center of gravity and the center of buoyancy (GB), under all normal operating conditions, is the greater of 1.5 in. (38 mm) or as determined by the following:

$$GB = nwNd / W \tan \alpha$$

where

d = the interior distance within the main cabin accessible to onboard personnel, in. (mm)

N = total number of persons onboard the submarine

n = 0.1 (10% of the people aboard moving simultaneously)

W = the total weight of the fully loaded submarine, lb (kg)

w = 175 lb (79.5 kg) per person

$\alpha = 25$ deg or less if required by other design features including battery spillage or malfunction of essential equipment

7-10.3 Surfacing

(a) A pilot-operated means that is independent of the jettison system required in para. 7-10.4 shall be provided to bring the submersible to the surface in a stable condition.

(b) The submersible shall be equipped with at least two lifting points to which attachments may be secured to raise the vehicle to the surface in an emergency. The lugs and their connection to the vehicle structure shall be designed taking into account loads generated by forces of 2g vertical (1g static plus 1g dynamic), 1g transverse, and 1g longitudinal acting simultaneously under the most severe condition, or the submersible craft shall be provided with means of externally bringing the craft to the surface, in all anticipated operating and emergency conditions, without assistance from personnel inside of the submersible.

7-10.4 Jettisoning System

(a) Submersibles shall be provided with a means to jettison sufficient mass such that if the largest single floodable volume, other than personnel compartments, is flooded, an ascent rate approximating the normal ascent rate can be achieved. The jettisoned mass may consist of a drop weight, appendages subject to entanglement, or a combination of both. Alternatively, the passenger compartment may be provided with a means of separating it from all other parts of the system, including appendages, provided the personnel compartment is positively buoyant when released.

(b) Consideration shall be given to the jettisoning of appendages subject to entanglement including, but not limited to, thrusters, manipulators, cameras, and pan and tilt systems.

(c) Jettison systems shall require at least two positive manual actions and shall be independent of electric power.

(d) Submersibles shall have stability under any combination of jettisoned masses to provide safe recovery of personnel.

7-10.5 Entanglement

The possibility of entanglements shall be considered in the design of submersible craft. Design features, operational and emergency procedures, and/or means of jettisoning may be necessary.

7-11 EMERGENCY EQUIPMENT

7-11.1 Life Jackets

Life jackets shall be provided for, and accessible to, each person on the submersible. Personnel shall be able to disembark with a donned life jacket. Inflatable-type life jackets should be considered to facilitate disembarkation.

7-11.2 First Aid Kit

Submersibles shall be provided with a first aid kit appropriate for the environment and intended needs.

7-11.3 Thermal Protection

Submersibles operating in cold waters shall be equipped with sufficient emergency thermal protection for all occupants in consideration of the duration of onboard life-support systems.

7-11.4 Rations

Sufficient food and water rations shall be provided for each person onboard as may be required for normal and emergency operations.

7-11.5 Tow Point

An accessible towing point shall be provided.

MANDATORY APPENDIX I

REFERENCE CODES, STANDARDS, AND SPECIFICATIONS

Codes, standards, and specifications incorporated in this Standard by reference, and the names and addresses of the sponsoring organizations, are shown below. The most current edition, including addenda, of referenced codes, standards, and specifications shall be used.

21 CFR 820, Food and Drugs, Quality System Regulation
29 CFR 1910, Occupational Safety and Health Standards

Publisher: U.S. Government Publishing Office (GPO),
732 N. Capitol Street, NW, Washington, DC 20401
(www.gpo.gov)

ANSI/FCI 70-2, American National Standard for
Control Valve Seat Leakage

Publisher: Fluid Controls Institute (FCI), 1300 Sumner
Avenue, Cleveland, OH 44115
(www.fluidcontrolsintstitute.org)

ASME B1.20.1, Pipe Threads, General Purpose (Inch)
ASME B31.1, Power Piping
ASME B36.10M, Welded and Seamless Wrought Steel
Pipe

ASME B36.19M, Stainless Steel Pipe

ASME Boiler and Pressure Vessel Code

ASME PVHO-2, Safety Standard for Pressure Vessels for
Human Occupancy: In-Service Guidelines

Publisher: The American Society of Mechanical
Engineers (ASME), Two Park Avenue, New York, NY
10016-5990 (www.asme.org)

ASTM B88, Specification for Seamless Copper Water
Tube

ASTM B154, Method of Mercurous Nitrate Test for
Copper and Copper Alloys

ASTM D256, Test Methods for Impact Resistance of
Plastics and Electrical Insulating Materials

ASTM D542, Test Methods for Index of Refraction of
Transparent Organic Plastics

ASTM D570, Test Method for Water Absorption of
Plastics

ASTM D638, Test Method for Tensile Properties of
Plastics

ASTM D648, Test Method for Deflection Temperature
of Plastics Under Flexural Load

ASTM D695, Test Method for Compressive Properties
of Rigid Plastics

ASTM D696, Test Method for Coefficient of Linear
Thermal Expansion of Plastics

ASTM D732, Test Method for Shear Strength of Plastics
by Punch Tool

ASTM D785, Test Method for Rockwell Hardness of
Plastics and Electrical Insulating Materials

ASTM D790, Test Methods for Flexural Properties of
Unreinforced and Reinforced Plastics and Electrical
Insulating Materials

ASTM D792, Test Method for Specific Gravity (Relative
Density) and Density of Plastics by Displacement

ASTM E208, Method for Conducting Drop-Weight Test
to Determine Nil-Ductility Transition Temperature of
Ferritic Steels

ASTM E308, Method for Computing the Colors of
Objects by Using the CIE System

ASTM G63, Standard Guide for Evaluating Nonmetallic
Materials for Oxygen Service

ASTM G88, Standard Guide for Designing Systems for
Oxygen Service

ASTM Manual 36, Safe Use of Oxygen and Oxygen
Systems: Guidelines for Oxygen System Design,
Materials Selection, Operations, Storage, and
Transportation

Publisher: American Society for Testing and Materials
(ASTM International), 100 Barr Harbor Drive, P.O. Box
C700, West Conshohocken, PA 19428-2959
(www.astm.org)

CGA G-4.4, Oxygen Pipeline Systems

Publisher: Compressed Gas Association (CGA), 14501
George Carter Way, Suite 103, Chantilly, VA 20151
(www.cganet.com)

ISO 9001, Quality management systems —
Requirements¹

ISO 13485, Medical devices — Quality management sys-
tems — Requirements for regulatory purposes¹

Publisher: International Organization for
Standardization (ISO), Central Secretariat, Chemin de
Blandonnet 8, Case postale 401, 1214 Vernier, Geneva,
Switzerland (www.iso.org)

NASA Technical Manual TMX 64711, Compatibility of
Materials with Liquid Oxygen, October 1, 1972

¹ May also be obtained from the American National Standards
Institute (ANSI), 25 West 43rd Street, New York, NY 10036
(www.ansi.org).

Publisher: Marshall Space Flight Center, Building 4200,
Room 120, MSFC, Huntsville, AL 35812
(www.msfc.nasa.gov)

Naval Ships' Technical Manual NAVSEA S9086-H7-
STM-010/CH-262R6, Chapter 262, Lubricating Oils,
Greases, Specialty Lubricants, and Lubrication
Systems

Publisher: Commander Naval Sea Systems Command,
1333 Isaac Hull Avenue, SE, Washington Navy Yard,
DC 20376-1080 (www.navsea.navy.mil)

NFPA 99, Standards for Health Care Facilities

Publisher: National Fire Protection Association (NFPA),
1 Batterymarch Park, Quincy, MA 02169
(www.nfpa.org)

Threshold Limit Values for Chemical Substances

Publisher: American Conference of Governmental
Industrial Hygienists (ACGIH), 1330 Kemper
Meadow Drive, Cincinnati, OH 45240
(www.acgih.org)

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MANDATORY APPENDIX II

DEFINITIONS

(16)

ACGIH: American Conference of Governmental Industrial Hygienists.

acrylic: methyl methacrylate polymer possessing physical and mechanical properties shown in Tables 2-3.4-1 and 2-3.4-2 of this Standard.

ballast tank: a compartment/tank used to control the buoyancy of a submersible PVHO.

brazed fitting (tube): any tube or pipe fitting that is attached to the pipe or tube by means of a brazing process.

breathing device: the appliance used to deliver a breathing gas to a PVHO occupant. The gas may be different from the chamber atmosphere.

breathing gas: any gas intended for use as a respirable gas.

breathing gas service: any line that carries gas that is intended for use as a respirable environmental gas in an occupied space or is intended for use in some type of breathing apparatus is considered to be in breathing gas service.

breathing gas system: any system that is used to handle gas (including air) intended for human respiration. All oxygen systems are considered breathing gas systems.

chamber: a pressure vessel intended for occupancy by humans.

chamber system: one or more chambers intended to function as an operational unit.

chip: a small fracture flaw in the window surface (most typically, the result of impact with a hard object).

closure: a mechanism that allows opening and/or closing for attachment or disconnection of an associated PVHO, hatch, or door. Includes both fixed clamps and quick-opening clamps.

clump weight: the weight attached to and deployed by the guide wire system.

component: consists of, but not limited to, items such as pipe, piping subassemblies, parts, valves, strainers, relief devices, and fittings.

compression fitting (tube): any tube fitting that grips the tube by means of one or more ferrules that compress or swage the end of the tube without creating a definite notch in the tube wall.

conical frustum window: a flat, circular window geometry with a conic section bearing edge.

contamination (window): a noticeable local discoloration or opaqueness without well-defined boundaries on the surface or body of the acrylic window.

conversion factor (CF) (window): an empirical ratio of short-term critical pressure to design pressure for a given temperature.

crack (window): a discontinuity in the acrylic indicating local failure of the acrylic window. A crack is characterized by its length and depth.

crazing (window): a haze on the surface of the window made up of a multitude of very fine, hair-like straight or randomly oriented cracks that become clearly visible if illuminated at an angle by a bright light. Crazing is an indication of surface degradation that may be thermally, mechanically, radiation, or chemically induced.

critical density of population: number of significant inclusions or scratches per specified contiguous area or volume of window that cannot be exceeded in a finished window.

critical dimension (window): the maximum dimension of discontinuity on the surface or in the body of an acrylic window. For inclusions, it is the effective diameter, whereas for scratches, it is the depth.

critical locations (window): locations on the surface or interior of the window where no discontinuities or artifacts are permitted.

critical pressure (window): pressure that, acting on one side of the window, causes it to lose structural integrity.

critical size of population (window): total number of inclusions or total length of scratches with significant dimensions that cannot be exceeded in a finished window.

critical spacing (window): the minimum allowable spacing between peripheries of inclusions or scratches with significant dimensions in a finished window.

custom casting (window): a casting of any shape that is not carried as a standard production item.

cyclic design life (window): the number of pressure cycles that a window is projected to withstand without catastrophic failure when pressure cycled, at 4 hr per cycle, to design pressure at design temperature.

cyclic proof pressure (CPP) (window): the pressure that a window shall withstand without cracking under intermittent pressurization.

cylindrical window: a window consisting of a tube with circular cross section.

deck decompression chamber: a PVHO used for operational recompression, barotrauma treatment, and decompression of divers.

design cycle (windows): the design cycle is used as the basis for the development of the conversion factors used herein. For the purpose of this Standard, it is a pressure excursion at design temperature to the design pressure and returning to ambient. Pressure is held for 4 hr at both the design and ambient pressures.

design depth: the maximum depth to which the submersible PVHO is designed to operate.

design life (windows): the period of time and/or number of design cycles assumed for a window complying with this Standard. The window design life may be different for different types of windows. The design life has three aspects: total time under pressure, cyclic design life, and total chronological time from the date of initial manufacture.

design pressure: the highest pressure that shall be reached in the pressure vessel including coincident static head in the operating position and at the most severe combination of pressure and temperature expected in normal operations. For this condition the maximum differences in pressure between the inside and outside of a pressure vessel, or between any two chambers or a combination unit, shall be considered.

design qualification (window): an experimental procedure for verifying the conformance of a nonstandard window design to mandatory structural requirements of this Standard.

design temperature: maximum and minimum temperatures for which a pressure component is designed.

ding (window): a crater-like, shallow, crack-free indentation in the window surface resulting from impact. The depth of the indentation is typically less than the diameter of the crater at the window surface.

diving system: a PVHO system that is used for diving, support of diving operations, or diving training.

drop weight: a releasable weight(s) attached to the diving bell.

elastomer: a natural or synthetic material that is elastic or resilient and in general resembles rubber in its deformation under tensile or compressive stresses (i.e., at least 50% elastic compression and 70% elastic extension).

examination: the process of determining the condition of an area of interest by nondestructive means measured against established acceptance or rejection criteria. Examination is generally performed using nondestructive examination (NDE) methods, such as visual, liquid penetrant, radiography, ultrasonic, etc.

fabricator of windows: the party who fabricates finished acrylic windows from castings, marks them with identification, and provides fabrication certification.

fiber (window inclusion): a nonmetallic fiber in an acrylic casting (e.g., individual hair or fiber of cotton, polyester, nylon, etc.) with diameter <0.005 in. (0.125 mm).

flammable: a material capable, when ignited, of maintaining combustion under specific environmental conditions.

flare fitting (tube): any tube fitting that grips the tube by means of a flare that is applied to the end of the tube by mechanical means.

flat disk window: a plane, circular window geometry.

Fp: adjustment factor to be multiplied by the ACGIH TLV when the anticipated duration of manned occupation is in excess of 8 hr.

full-scale window: a window whose dimensions are identical to the window in actual service.

gas chromatography/mass spectrometry (GC/MS): method of identifying and quantifying volatile hydrocarbons using a combination of gas chromatography and mass spectrometry.

gas container: a pressure vessel for the storage and transport of gases under pressure.

gouge (window): a wide, V-shaped, crack-free discontinuity in the window surface resulting from the movement of a rough, hard object across the surface of the window. The depth of the gouge is typically less than or equal to the width of the discontinuity.

guide wire(s): an independent system of wires used to deploy a clump weight that provides vertical and rotational stability to the diving bell. These are typically connected at two or four points on the diving bell protection frame. Connection is by means of special clamps designed to allow the diving bell to run freely up and down the guide wires.

handling system: a system to support the launch, recovery, and other handling operations of diving bells and may include cranes, booms, masts, frames, winches, and associated hydraulic and electrical systems as necessary for the intended operations.

handling system design load: the design load is the maximum expected load on the handling system and consists of a combination of the rated load; the dynamic effects of pitch, roll, and heave; the weight of the rigging (hooks, blocks, deployed rope, etc.); and other applicable loads, such as wind load, drag, added mass effect, and weight of entrained mud and water.

handling system rated load/safe working load: the rated load or safe working load is the maximum load that the assembled handling system is certified to lift at its maximum rated speed when the outermost layer of rope or

umbilical is being wound on the winch drum, under the parameters specified in the User's Design Specification (e.g., hydraulic pressures, electrical currents/voltages, etc.).

harmful chemicals (window): liquid, solid, or gaseous substances that, upon contact with surfaces of stressed acrylic windows, initiate crazing (e.g., alcohols, acetone, ether, methyl ethyl ketone, adhesive tapes, etc.).

helium service: any portion of a piping system that may contain gases containing helium shall be considered to be in helium service.

hemispherical window: a geometry that depicts a half-spherical window shape.

high-pressure face (window): viewing surface of the window that in service is acted upon by the pressure loading on the window.

hydrocarbon: all organic compounds detectable by a total hydrocarbon analyzer.

hyperbaric stretcher: a portable monoplace PVHO approved for transfer under pressure.

hyperhemispherical window: a spherical acrylic shell having an included angle greater than 180 deg, a single penetration, and a conical bearing surface.

inclusion-fiber (window): a nonmetallic fiber in an acrylic casting (e.g., individual hair or fiber of cotton, polyester, nylon, etc.) with diameter <0.005 in. (0.125 mm).

inclusion (window): a foreign substance or void in the body of acrylic with a dimension measured as the diameter of a sphere having an equivalent volume of the inclusion.

inspection: activities performed to verify that materials, fabrication, construction, examinations, testing, repairs, etc., conform to applicable code, engineering, and/or owner's written procedure requirements.

inventory control identification (window): identification assigned to a single sheet or custom casting by the fabricator of windows when lot identification is not provided by the manufacturer of plastic.

life-sensitive system: any system where an interruption of service represents a hazard to the health and well-being of the chamber occupants.

life-support system: the equipment and systems required to maintain a habitable atmosphere in the PVHO in all anticipated operating conditions.

lock: a chamber compartment that can be maintained at a pressure different from other connected compartments (e.g., inner lock, outer lock, entry lock, med/service lock).

long-term proof pressure (LTPP): pressure that a window shall withstand without catastrophic failure under sustained pressurization of 80,000-hr duration in design temperature ambient environment. This Standard

defines long-term proof pressure as equal to design pressure.

lot identification (window): identification affixed by the manufacturer of plastic to all castings constituting a lot of material.

lot of material (window): a unit of manufacture consisting of a single production run poured from the same mix of monometric material and made at the same time, undergoing identical processing from monomer to polymer.

low-pressure face (window): viewing surface of the window that while in-service is not acted upon by the pressure applied to the window.

manufacturer (component): individual or organization that fabricates components used in PVHO systems.

manufacturer of plastic (window): the party who converts methyl methacrylate resin into acrylic castings, provides Material Manufacturer's Certification for Acrylic (PVHO-1 Form VP-3), and may also provide Material Testing Certification for Acrylic (PVHO-1 Form VP-4).

manufacturer (PVHO): individual or organization that fabricates or assembles PVHO systems and provides the customer with the Manufacturer's Data Report and associated documentation required by this Standard.

marine system: a chamber or chamber system that is to be used in a marine environment. For the purposes of this Standard, all chambers and chamber systems that are not exclusively land-based are considered marine systems.

marking (window): identification on the window's bearing surface or edge denoting that the window met the PVHO-1 Standard requirements for the specified design temperature and pressure. The fabricator's identification symbol, serial number, and year of fabrication are also part of the marking.

material specification: a description of the identifying characteristics of a material (product, form, ranges of composition, mechanical properties, methods of production, etc.) together with sampling, testing, and examination procedures to be applied to production lots of such material to verify acceptable conformance to the intended characteristics.

material testing laboratory (window): the party who tests material specimens cut from plastic casting and provides Material Testing Certification for Acrylic (PVHO-1 Form VP-4).

maximum allowable working pressure (MAWP): maximum rated pressure for a component.

maximum operating pressure: the maximum pressure in which a system (pressure vessel, supporting controls, and instrumentation) shall be operated.

medical chamber: a chamber or chamber system that is intended for use as part of a clinical setting for administering hyperbaric oxygen therapy or other hyperbaric medical treatments.

medical lock: a small compartment that penetrates the pressure hull of the PVHO, allowing items to be transferred into and out of a PVHO under pressure.

megapascal (MPa): the metric unit of pressure equal to 10 bar, or 145 psi.

model-scale window: a window whose dimensions are all scaled down linearly from the window in actual service.

monoplace chamber: a PVHO designed to accommodate a single person.

multiplace chamber: a PVHO designed to accommodate two or more people.

NEMO window: a spherical acrylic shell with two or more conical penetrations whose edges are supported by inserts with conical edges.

nominal values: specified dimensions or angles for components of a chamber to which dimensional tolerances are subsequently applied on fabrication drawings.

nonstandard window geometry: unproven window geometry that must be, first, experimentally qualified for the intended design pressure and temperatures.

operating pressure: the pressure at which the PVHO and its subsystems are designed to operate. This shall not exceed the maximum allowable working pressure (as defined in the current edition of ASME BPVC and ASME B31.1) of the PVHO or any of its subsystems. The operating pressure is usually kept at a suitable level below the setting of the pressure relief device(s) to prevent their frequent opening.

operational temperature range: the range of ambient temperatures to which the chamber can be subjected while pressurized.

oxygen service (piping): any portion of a piping system internally pressurized with a gas containing more than 25% oxygen by volume.

payload: the weight the submersible PVHO is capable of carrying in addition to its permanently fitted equipment.

permissible exposure limit (PEL): nomenclature used by the Occupational Safety and Health Administration (OSHA) to express allowable airborne concentration for a conventional 8-hr workday and a 40-hr workweek.

pilot: a person appointed and trained to command a submersible PVHO.

pipe: a tube with a circular cross section conforming to the dimensional requirements for nominal pipe size as tabulated in ASME B36.10M, Table 1 and ASME B36.19M, Table 1. For special pipe having a diameter not listed in these tables, and also for round tube, the

nominal diameter corresponds with the outside diameter. The fundamental difference between pipe and tube is the dimensional standard to which each is manufactured.

piping: refers to all circular cross-section conduits and is used generically to include both pipe and tube used for the transmission of fluids. The use of noncircular tubing for pressure piping within the scope of this Standard is not permitted.

piping system: the assembly of piping and components required to form a functional system.

ppm: concentration in air expressed as parts per million, on a volumetric basis.

pressure control valve: a valve used to reduce or maintain the pressure in a piping system by admitting or releasing fluid pressure, as required, to maintain pressure at or near a designated setpoint. Other commonly used terms include pressure-reducing valve, pressure regulator, and back pressure regulator.

pressure testing certification (window): certification that the newly manufactured window has successfully met the mandatory requirements of PVHO-1.

pressure testing laboratory (window): the party who pressure tests windows installed in viewport flanges and provides pressure testing certification.

pressure vessel for human occupancy (PVHO): a chamber that encloses a human being within its pressure boundary while it is under internal or external pressure.

PVHO manufacturer: person, group, or corporate entity that constructs or assembles a pressure vessel for human occupancy in accordance with the provisions of ASME PVHO-1 and the User's Design Specification.

qualified person: someone who, by possession of a recognized degree, certificate, or professional standing, or who, by knowledge, training, and experience, has successfully demonstrated the ability to perform the assigned duties.

quality assurance program: documented systematic organization of policies and procedures to ensure that the product or service delivered meets all customer and design specifications.

rated depth: the maximum depth to which the submersible craft is certified to operate.

risk: the combination of the probability of occurrence of harm and the severity of that harm.

risk analysis: the systematic use of available information to identify hazards and to eliminate the risk.

saturation diving: a diving procedure by which the diver is continuously subjected to a pressure greater than atmospheric so that his body tissue and blood become saturated with the inert element of the breathing gas at the elevated ambient pressure.

scratch (window): a crack-free discontinuity on the surface of the acrylic window that is the result of foreign objects coming in contact with the acrylic surface. For the purpose of evaluation, gouges and dings shall be considered scratches. The dimension of a scratch is the depth of the sharp surface discontinuity measured from the window surface to the bottom of the scratch.

service life (window): the period of time and/or number of cycles that a window may be permitted to remain in service. The window service life may be shorter or longer than the window design life due to variations in the conditions of service, latent manufacturing defects, or other factors. (For additional information regarding the service life of windows, see ASME PVHO-2.)

service locks (other than human occupancy): compartments for transferring supplies and materials into and out of a PVHO while the occupants remain under pressure.

shall: *shall* or *shall not* is used to indicate that a provision is mandatory.

sheet castings: sheets of plastic cast on a production line basis and carried as a standard production item in a manufacturer's sales catalog.

short-term critical pressure (STCP) (window): the pressure required to catastrophically fail a window at a 650-psi/min (4.5-MPa/min) rate in design temperature ambient environment.

short-term proof pressure (STPP): the pressure that a window shall withstand without catastrophic failure under short-term pressurization at 650 psi/min (4.5 MPa/min) in design temperature ambient environment. This Standard defines short-term proof pressure as equal to 4 times the design pressure.

should: *should* or *it is recommended* is used to indicate that a provision is not mandatory but is recommended as good practice.

significant dimension (window): when the dimension of an inclusion or a scratch exceeds a specified value and is considered as being present in the window for inspection purposes.

soft goods: O-rings, gaskets, seals, and other polymer or elastomer components used in a PVHO system.

spherical sector window: a geometry that depicts a spherical window shape.

standard temperature: the range of material temperatures from 70°F to 75°F (21°C to 24°C) at which all the dimensions in this Standard are specified.

standard window geometry: proven window geometry that, because of its safe service record, has been incorporated in this Standard. Windows with standard geometries may be used in pressure vessels for human occupancy without having to undergo experimental design qualification.

submersible: a manned, self-contained, mobile vessel that primarily operates under water and relies on surface support (e.g., a surface ship or shore-based facilities) for monitoring and for one or more of the following:

- (a) recharging of power supply
- (b) recharging high-pressure air
- (c) recharging life support

submersible diving chamber (SDC): commonly called a diving bell, used to transport divers under pressure to a work site.

supplier (windows): the party who supplies finished windows with all required certifications to the chamber manufacturer (original equipment) or user (replacement). There is nothing in this Standard prohibiting the supplier from performing the functions of plastic manufacturer, material testing laboratory, window designer, window fabricator, and pressure testing laboratory, provided that these functions generate the required certifications.

support facility: a surface craft or shore-based facility providing support to the submersible PVHO.

testing: within this Standard, testing generally refers to either pressure testing, whether performed hydrostatically, pneumatically, or a combination hydrostatic pneumatic, or mechanical testing to determine such data as material hardness, strength, and notch toughness. Testing, however, does not refer to NDE using methods such as liquid penetrant, radiography, etc. See *examination*.

thickness of a vessel wall

design thickness: the sum of the required thickness and the corrosion allowance.

nominal thickness: the thickness selected as commercially available and supplied to the manufacturer. For plate material used in formed shapes, the nominal thickness shall be, at the manufacturer's option, either the thickness shown on the Material Test Report before forming or the thickness of the plate at the joint or location under consideration.

required thickness: that thickness computed from the maximum design pressure and other loading criteria prior to the corrosion allowance being applied.

third-party inspection agency: an individual or organization, independent of the designer, fabricator, and user, who is qualified through education, test, or experience to perform the inspection.

threshold limit values (TLV): nomenclature used by the American Conference of Governmental Industrial Hygienists (ACGIH) to express allowable airborne concentration for a conventional 8-hr workday and a 40-hr workweek.

total hydrocarbon analyzer: any suitable process analyzer employing a hydrogen flame ionization detector (FID)

having a range of 0 mg/m³ to at least 1 000 mg/m³ methane equivalents.

trunk/tunnel: any void that creates a volume between two or more doors or hatches is considered to be either a trunk or a tunnel.

tube: a hollow product of circular or any other cross section having a continuous periphery. Circular tube size may be specified with respect to any two, but not all three, of the following: outside diameter, inside diameter, wall thickness; types K, L, and M copper tube may also be specified by nominal size and type only. Dimensions and permissible variations (tolerances) are specified in the appropriate ASTM or ASME standard specifications.

tube or pipe fitting, bite-type fitting: any tube fitting that grips the tube by means of one or more teeth that bite

or dig into the outside diameter of the tube creating a definite notch.

viewport (window): a penetration in the pressure vessel including the window, flange, retaining rings, and seals.

void (window): hollow cavity in the body of the acrylic casting.

welded fitting: any tube or pipe fitting that is attached to the tube or pipe by means of a welding process.

window: a transparent, impermeable, and pressure-resistant insert in the viewport.

window fabricator: person, group, or corporate entity that fabricates PVHO windows in accordance with the requirements of ASME PVHO-1 and the User's Design Specification.

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NONMANDATORY APPENDIX A

DESIGN OF SUPPORTS AND LIFTING ATTACHMENTS

The designer should consider using the provisions of the following studies, which appear in *Pressure Vessels and Piping: Design and Analysis, Volume Two — Components and Structural Dynamics*, The American Society of Mechanical Engineers, New York, 1972:

- (a) "Local Stresses in Spherical and Cylindrical Shells due to External Loadings," K. R. Wichman, A. G. Hopper, and J. L. Mershon, reprinted from Welding Research Council Bulletin 107, 1965.
- (b) "Stresses in Large Horizontal Cylindrical Pressure Vessels on Two Saddle Supports," L. P. Zick, reprinted from Welding Journal Research Supplement, 1971.

The use of these provisions shall not negate Code requirements.

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NONMANDATORY APPENDIX B

RECOMMENDATIONS FOR THE DESIGN OF THROUGH-PRESSURE BOUNDARY PENETRATIONS

B-1 GENERAL

This Appendix provides several basic designs of through-pressure boundary piping penetration designs that have been found to give good service. Acceptable designs of through-pressure boundary piping systems are not necessarily limited to the designs shown. All pressure boundary penetrations shall meet the reinforcement and weld detail requirements of ASME PVHO-1 and the ASME Boiler and Pressure Vessel Code, Section VIII, Division 1 or Division 2, as appropriate.

B-2 PENETRATOR DESIGNS

Figure B-2-1 shows four basic penetrator designs intended principally for services as follows:

(a) full coupling intended for standard threaded pipe couplings or a special coupling dictated by the User's Design Specification. For most applications, a standard 6,000-psi NPT coupling is acceptable in 316 or 316L stainless steel.

(b) half coupling, full-penetration weld installation. This is generally used for pressure equalization in supply locks and transfer tunnels and can also be used for pressure gauge penetrators.

(c) special forging. This category is intended for fully radiographable penetrators, generally to comply with Section VIII, Division 2 of the Code.

(d) flush-mount coupling. This category is generally a 6,000-psi or special forging type coupling. This configuration is used where a full coupling with internal and external threads is required, or where there are chamber drains and supply lock and tunnel equalizations, or in other applications where a flush internal mount is required.

B-3 COUPLING DETAILS

Figure B-3-1 shows four acceptable coupling details.

B-3.1 Threaded Couplings

(a) *NPT (National Pipe Thread) 6,000-psi Coupling*. For marine systems the coupling material should be a stainless steel per para. B-4. The heavy wall of the 6,000-psi coupling normally permits at least one field rethreading should the original threads be damaged.

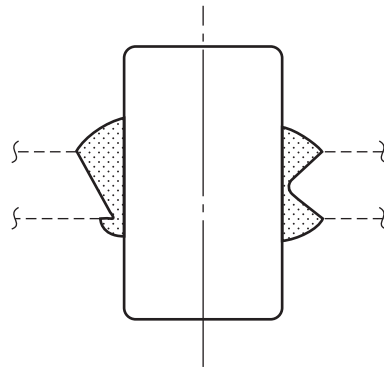
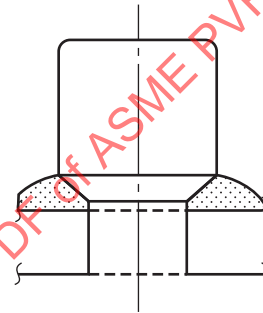
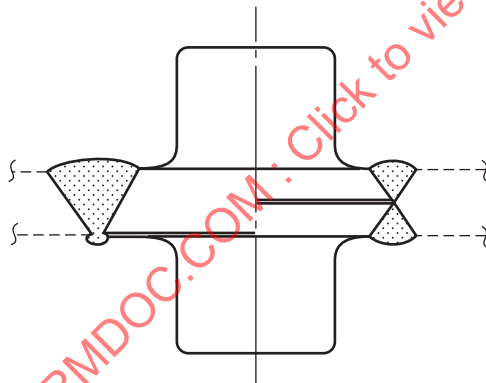
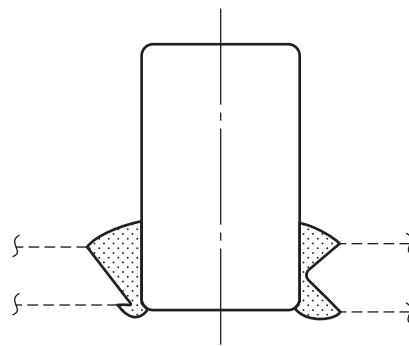
(b) *Special Coupling With an SAE or MS (Military Standard) Straight Thread O-Ring Boss*. This design is recommended over pipe threads when the contained fluid may be helium.

B-3.2 Threaded Insert Couplings

These are generally smooth bore couplings with threaded, flanged inserts with either pipe threads or straight thread O-ring seals. This installation can be sealed and secured with a fillet weld or assembled with a flat washer and locking nut with O-ring seals as shown. The latter installation is preferred but its cost often makes it impractical.

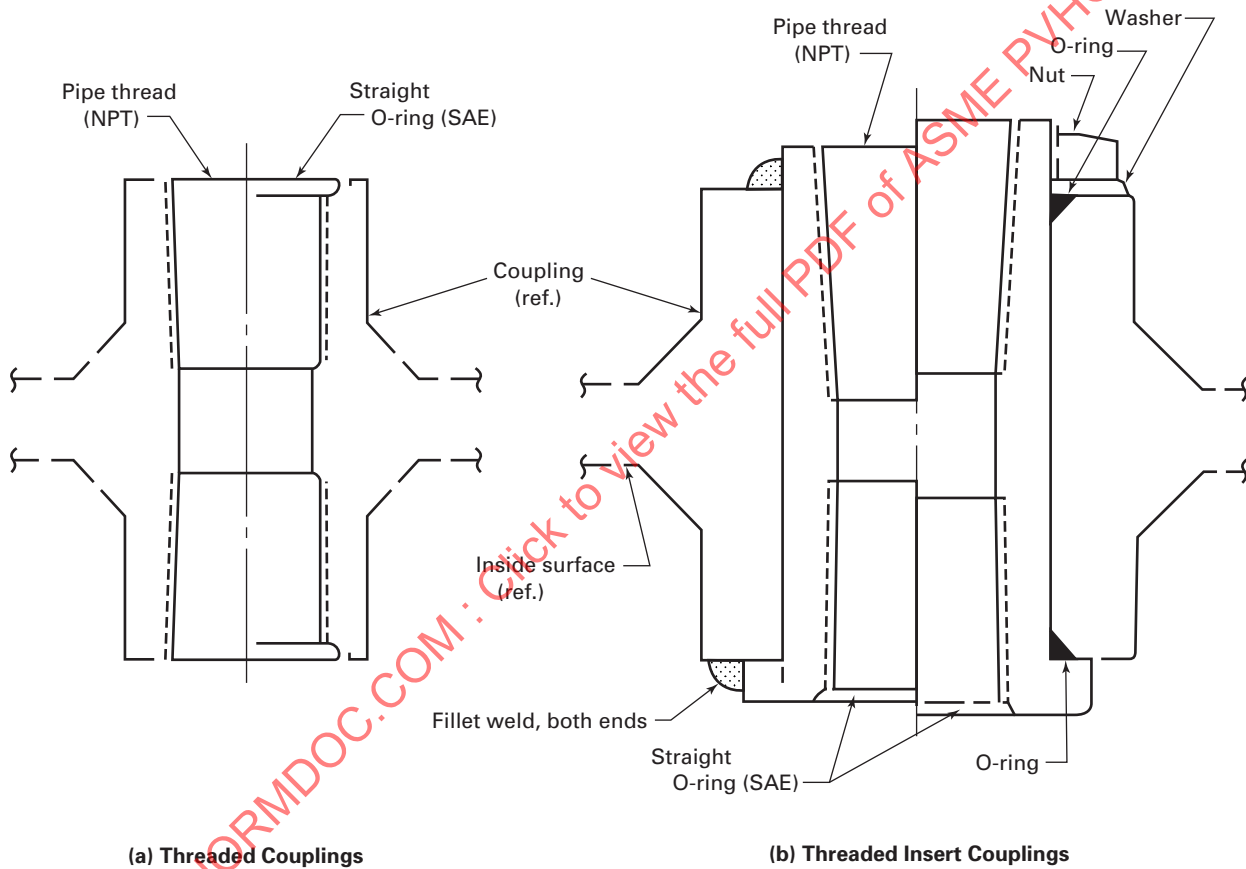
B-4 MATERIALS

Practical experience has shown that unthreaded (i.e., smooth bore) couplings in marine systems may be any Code-approved forged steel while threaded couplings and inserts should be of approved stainless steel (316 or 316L), brass, or bronze. Corrosion-resistant alloys are strongly recommended to eliminate cleaning, maintenance, and material compatibility problems. Threaded couplings and inserts in land-based chambers may be of any Code-approved material.

Fig. B-2-1 Acceptable Weld Nozzle Penetrators**(a) Full Coupling****(b) Half Coupling****(c) Special Forging****(d) Flush-Mount Coupling**

GENERAL NOTE: This figure refers to pipes 2 in. (50 mm) and under.

Fig. B-3-1 Acceptable Threads and Inserts



NONMANDATORY APPENDIX C RECOMMENDED PRACTICES FOR COLOR CODING AND LABELING

All piping and gas storage bottles should be colored and labeled to indicate content, maximum allowable working pressure, and direction of flow. Except for certain pipe materials such as stainless steel, the color should be a continuous coat of paint. For stainless steel and similar corrosion-resistant materials, color coding may be a 1-in. (25-mm) band of paint or tape. Bands should be applied at every bend and intersection, and at each side of obstructions. To aid in tracing the pipe, a minimum of three bands should be visible at any

location. In addition to color coding, piping should be labeled with the name and/or symbol of its contents, direction of flow, and maximum allowable working pressure. This labeling should be applied at every intersection and at each side of obstructions. For labeling, a color that contrasts with that of the pipe should be used. Tables C-1 and C-2 give the color codes required by the U.S. Navy and the International Maritime Organization (IMO), respectively. Other color codes may also be used.

Table C-1 U.S. Navy Color Codes

Name	Designation	Color
Oxygen	O ₂	Green
Nitrogen	N	Light gray
Air (low pressure)	ALP	Black
Air (high pressure)	AHP	Black
Helium	He	Buff
Helium-oxygen mix	He-O ₂	Buff and green

GENERAL NOTE: Adapted from *U.S. Navy Diving Manual NAVSHIPS 0994-001-9010*.

Table C-2 IMO Color Codes

Name	Symbol	Color
Oxygen	O ₂	White
Nitrogen	N ₂	Black
Air	Air	White and black
Carbon dioxide	CO ₂	Gray
Helium	He	Brown
Oxygen-helium mix	O ₂ -He	White and brown

GENERAL NOTE: Adapted from *IMO Resolution A536, "Code of Safety for Diving Systems."*

NONMANDATORY APPENDIX D

GUIDELINES FOR THE SUBMISSION OF A PVHO CASE FOR THE USE OF NONSTANDARD DESIGNS, MATERIALS, AND CONSTRUCTION

PVHO chambers using nonstandard materials, design, and/or construction techniques may be constructed under the requirements of PVHO-1 if a Case describing all exceptions and additions to PVHO-1 has been reviewed and approved by the PVHO Consensus Committee (hereinafter referred to as the Committee) in accordance with Committee Procedures. The following provides a general outline of the information and format that should be included in the proposed Case inquiry (hereinafter referred to as the Case).

The issuance of a PVHO Case should not be construed as approval of a specific design. It is the intent of the Committee to provide performance-based criteria that are applicable to similar nonstandard features. The Case method permits the Committee to assess the inherent safety of the nonstandard feature prior to adoption into PVHO-1. It is the Committee's objective to ensure that a nonstandard PVHO provides equivalent safety as a standard PVHO.

D-1 INTRODUCTION

The intention of a Case is to ensure that alternative approaches are implemented with design margins and quality assurance commensurate with those set forth for recognized materials and established geometry. Minor changes to the requirements in PVHO-1 may not require the extensive analysis and testing described below. Radically different designs may require additional considerations. For this reason, the applicant is cautioned not to fabricate and test a PVHO in accordance with these guidelines and then submit the results with a request for review. Rather, submittal of the Case in the format recommended provides a baseline for the Committee to make an initial assessment of the inherent technical merit and, if warranted, offer appropriate recommendations regarding revision. Should the applicant wish to conduct testing prior to submitting a Case, the Committee reserves the right to require additional tests.

Once a Case is published, it may then be used in accordance with the provisions and limitations defined in the Case.

A Case is normally issued for a limited period of time, after which it may be reaffirmed, incorporated into the Standard, revised, or allowed to expire. The Committee

may also act to revoke a Case prior to its normally scheduled expiration, if deemed necessary.

D-2 GENERAL

The formal written inquiry to the Committee should provide background information describing the new or novel design and/or material being proposed for consideration. An explanation of what is being proposed, why this proposal is being presented for consideration, and how the new design and/or material is to be used should be provided.

The applicant should clearly and concisely present all exceptions to PVHO-1 that are being sought. Requirements in addition to those in PVHO-1 that are proposed to ensure that the nonstandard PVHO provides equivalent safety to a standard PVHO should also be stated. The following information shall be provided:

- (a) the maximum allowable working pressure (MAWP)
- (b) a description of the configuration, shape, and dimensions of the vessel complete with enclosures, windows, etc.
- (c) the maximum number of occupants
- (d) the design temperature limits
- (e) the design life expectancy of the vessel, yr
- (f) the design number of pressure cycles

D-3 MATERIALS

All materials shall comply with PVHO-1 requirements or a recognized international material standard. Detailed specifications shall be submitted for nonstandard PVHO-1 materials. Supporting information for nonstandard materials, including testing specifications and material properties, operational limitations, and inspection criteria, shall be provided for such materials. The shelf life, cyclic life, temperature limitations, and other relevant critical properties of all nonstandard materials shall be provided.

All materials and material specifications used in the manufacture of the PVHO shall have supporting documentation certifying that each lot used in the manufacture of the PVHO meets PVHO-1 and/or a recognized international materials standard.

As a minimum, the following data shall be provided for proposed alternative materials:

- (a) test data to corroborate the specification data
- (b) strength and elongation data at the maximum and minimum design temperatures, if material properties are temperature dependent
- (c) cyclic life data at the maximum and minimum design temperatures, if material is temperature dependent
- (d) creep and cyclic creep data, if material properties are time dependent
- (e) shelf life, corrosion properties, and any other data that can establish the limitations of the material for the intended use

D-4 DESIGN

For a nonstandard design, the Case submittal shall include a detailed stress analysis performed by a licensed engineer or an independent third-party inspection agency that is experienced in pressure vessel design using the materials proposed.

D-4.1 Design Analysis

The design analysis shall consider the effects of aging and all applicable environmental considerations, both operational and nonoperational. The effects of minimum and maximum temperatures, time under pressure, large displacements associated with deployment (such as collapsible chambers), and long-term storage between usages shall be considered.

D-4.2 Maximum Allowable Working Pressure

The MAWP and associated maximum and minimum design temperatures shall be based upon the results of the prototype testing.

D-4.3 Design Certification

Conformance of the design of the PVHO to the requirements of PVHO-1 shall be established by either of the two following procedures:

- (a) A Professional Engineer registered in one or more of the U.S. states or the provinces of Canada, or licensed by any other country that has equivalent licensing procedures, experienced in relevant pressure vessel design, shall certify that the PVHO was designed either by him/her or under his/her direct supervision, or that he/she has thoroughly reviewed a design prepared by others, and to the best of his/her knowledge, the PVHO complies with PVHO-1 and the Case.
- (b) The design of the PVHO shall be reviewed by an independent third-party agency competent in PVHO systems. A certificate that the PVHO complies with PVHO-1 and the Case shall be provided.

D-4.4 Unusual Design Features

If the proposed PVHO exhibits unusual characteristics for a pressure vessel, these shall be described, and a design criteria shall be proposed.

D-5 TESTING

In lieu of the requirements of PVHO-1, paras. 1-7.7 and 1-7.8, a proposed testing program may be presented with the Case.

All tests shall be witnessed and documented by an independent third-party agency. The inspector shall certify that the test results comply with the testing requirements of the Case.

Testing shall be conducted at the most critical temperature(s) for which the PVHO is designed.

Alternative testing procedures may be proposed that meet the intent of the PVHO Standard and the intended use of the PVHO. These procedures shall be based on statistically significant sampling, recognized engineering practices, or a recognized standard acceptable to the Committee.

Any design changes or fabrication process changes shall require full prototype retesting.

D-5.1 Prototype Testing

PVHOs used for prototype testing cannot be used other than for testing.

D-5.1.1 Proof Pressure Test. Pressure tests shall be conducted on a minimum of three full-scale prototype chambers. These prototype vessels do not have to be completely outfitted. They shall be full size and of identical construction to the end item, with all fabrication completed that in any manner may affect the integrity of the pressure boundary. If desired, prototype chambers that have already been cyclic pressure tested (para. D-5.1.3) may be used.

For materials whose strength is temperature sensitive, the tests shall be performed at the most critical service temperature.

The pressurization rate used for proof pressure and cyclic testing shall be in accordance with that stated in the User's Design Specification. The pressurization rate shall not exceed 650 psi/min (4.5 MPa/min).

Except as permitted by para. D-5.1.5, failure of a vessel shall not occur at a pressure of less than 6 times the rated pressure (MAWP) of the PVHO. The final test pressure shall be held for a minimum of 30 min.

D-5.1.2 Extended-Duration (Creep-Rupture) Testing. For materials that exhibit time-dependent deformation (creep), the long-term strength of the PVHO at maximum design temperature shall be empirically verified using model-scale or full-scale PVHOs.

The use of model-scale PVHOs for extended-duration testing is permitted only if the short-term strength of

the model is equivalent to that obtained for the full-scale PVHO. To verify model-scale equivalence, the proof pressure test in para. D-5.1.1 shall be performed on a model-scale PVHO, and the failure pressure obtained shall lie within the range obtained on the full-scale PVHOs. The same conditions of temperature and rate of pressurization used for full-scale PVHOs shall be applied to the model-scale PVHO. If the model-scale test does not meet these criteria, full-scale PVHOs shall be required for extended-duration tests.

D-5.1.2.1 Extended-duration creep-rupture tests shall be performed as follows:

(a) The PVHOs shall be individually subjected to sustained pressure at the maximum design temperature until catastrophic failure occurs.

(b) Each PVHO shall be subjected to a different hydrostatic pressure with sustained temperature, pressure, and duration being recorded.

(c) At least one data point shall be obtained for each of the following log-time cycles: 1 hr to 10 hr, 10 hr to 100 hr, 100 hr to 1,000 hr, and 1,000 hr to 10,000 hr.

(d) The best-fit straight-line log-log plot of pressure versus time shall be constructed based on all extended-duration test data points.

(e) The extrapolated failure at 80,000 hr continuous sustained loading at maximum design temperature shall be greater than twice the MAWP as obtained per para. D-5.1.1; otherwise MAWP shall be reduced to a value that is 50% of the extrapolated failure pressure at 80,000 hr duration.

D-5.1.2.2 As an alternative, the PVHOs may be subjected to sustained pressure at maximum design temperature for 10,000 hr without failure per any one of the following, where MAWP is determined in accordance with para. D-5.1.1:

- (a) quantity 1 at $3.00 \times \text{MAWP}$
- (b) quantity 2 at $2.75 \times \text{MAWP}$
- (c) quantity 3 at $2.50 \times \text{MAWP}$
- (d) quantity 4 at $2.25 \times \text{MAWP}$
- (e) quantity 5 at $2.00 \times \text{MAWP}$

D-5.1.3 Cyclic Pressure Testing. The maximum permissible number of operational pressurizations shall be determined by cyclic testing of a full-scale PVHO. The pressure test cycles shall be from 1 atm ambient to MAWP and back to ambient. The time at MAWP for each cycle shall not be less than 20 min. If the material strength is temperature sensitive, cycling shall be performed at the most critical service temperature.

The number of approved operational cycles (CA) shall be computed as

$$CA = (CT/2) - 1,000$$

where

CT = total number of test cycles performed

Upon completion of testing, the PVHO shall be visually inspected for cracks. The requirement for acceptance of the cyclic pressure test is that no cracks shall be visibly detectable, using methods that are normally used for visual inspection of the applicable PVHO material.

D-5.1.4 Other Tests. Other testing may be required specific to the intended use of the PVHO. For example, a drop test of portable units or expansion-compression tests of collapsible units may be required.

D-5.1.5 Statistical Analysis. If the applicant desires, statistical analysis may be used in the determination of MAWP.

The test data shall be first checked for normal distribution using Method I of para. D-7.1. If the data passes the normality check, MAWP shall be determined using Method II of para. D-7.2. If the data set does not pass the normality check, MAWP shall be determined using Method III of para. D-7.3. Under no circumstances shall any data points be censored (eliminated from the test database).

If test to failure is not practical (due to economic or other reasons) and the material of construction does not exhibit creep, short-term proof pressure testing of less than failure may be permitted. In such special cases (requiring advance Committee approval), the MAWP shall be determined in accordance with Method IV of section D-7.4.

In all cases, the statistical methods set forth above for determining MAWP are restricted to materials that do not exhibit creep. For materials that do creep, the testing and determination of MAWP shall be performed as set forth in para. D-5.1.2.

D-5.2 Production Proof Pressure Testing

All production units shall be subjected to a hydrostatic or pneumatic test of 1.5 times the MAWP to be held for a minimum of 1 hr. The maximum allowable pressure loss shall not exceed 1% of the rated pressure. Internal and external temperatures shall be measured and recorded at the beginning and end of each test so that compensation can be made for any temperature differences.

Every PVHO shall be examined visually and dimensionally for damage following each test. Any signs of cracks, permanent deformation, or other signs of damage shall be cause for rejection of the PVHO.

Tests shall be witnessed and documented by an independent third-party agency. The inspector shall certify the test results and that they comply with the testing requirements of the Case.

D-6 QUALITY ASSURANCE OVERVIEW BY AN INDEPENDENT THIRD-PARTY AGENT

An independent third-party agency shall be used to ensure that all PVHOs intended to be classified under

PVHO-1 are manufactured and tested to PVHO-1 or the Case submittal.

This shall include, but is not restricted to, the following:

(a) The manufacturer is working to the requirements of the quality assurance systems as described in Section 3 of the Standard.

(b) The materials used in construction of the PVHO comply with approved procedures as required by PVHO-1 or the Case submittal.

(c) All manufacturing operations are conducted in accordance with approved procedures by qualified operators as required in PVHO-1.

(d) All defects are recorded and acceptably repaired and documented.

(e) All prototype and production testing has been performed and witnessed as required by PVHO-1 and the Case.

(f) The PVHO is marked in accordance with PVHO-1 and the Case.

(g) An inspection of the PVHO is conducted to confirm that there are no material defects or dimensional discrepancies.

D-7 STATISTICAL ANALYSIS

D-7.1 Method I: Check of Data Set for Normal Distribution ($3 < n \leq 50$)

The prescribed check is the "W-test," which is mathematically expressed as follows:

$$W = b^2 / \sum_{i=1}^n e_i^2$$

where

$$b = \sum_{i=1}^u a_i [e_{(n-i+1)} - e_i]$$

and

e = residual values = $x - X$ (signed \pm)

n = number of tests to failure

u = largest integer of $n/2$

X = mean value of pressure at failure = $\Sigma(x/n)$

x = pressure values at failure

The a_i values are listed in Table D-7.1-1, and W calculated must be $> W_{\min}$ from Table D-7.1-1. (An example data set is as follows: x values 100, 105, 95, 87, 108; $n = 5$; $X = 99$.)

Step 1: List x values in ascending order, along with e , e^2 , and Σe^2 as follows:

EXAMPLE: x 87 95 100 105 108 ($X=99$)
 e -12 -4 +1 +6 +9 (value $x-X$)
 e^2 144 16 1 36 81 $\Sigma e^2 = 278$

Step 2: Find a -value coefficients from Table D-7.1-1 and compute b -value as follows:

$$b = a_1 (\text{last } e - \text{first } e) \\ + a_2 (\text{second-to-last } e - \text{second } e) + \dots$$

(Note for n odd, there will be a center value of e left over in the expansion.)

EXAMPLE: From Table D-7.1-1 for $n = 5$, $a_1 = 0.665$ and $a_2 = 0.241$ such that

$$b = 0.665 [9 - (-12)] + 0.241 [6 - (-4)] \\ = 0.665 (21) + 0.241 (10) = 16.375$$

Step 3: Compute $W = b^2 / \Sigma e^2$
 EXAMPLE: $W = (16.375)^2 / 278 = 0.9645$

Step 4: Compare to W_{\min} from Table D-7.1-1 (the computed value must be greater).

EXAMPLE: $W_{\min} = 0.762$ vs. 0.9645
 (consider the data set normal)

D-7.2 Method II: MAWP Based on Normally Distributed Proof Test Data

$$s = \text{standard deviation (of sample)} = [\Sigma(x - X)^2 / (n - 1)]^{1/2}$$

Step 1: Compute $X = (\Sigma x)/n$ for each of the following where

95% CI is simply the lower 95% confidence interval

95% CI at 0.9P is the lower 95% confidence interval with a probability of 0.9

95% CI at 0.99P is the lower 95% confidence interval with a probability of 0.99

n	k (95% CI)	k (95% CI at 0.9P)	k (95% CI at 0.99P)
3	2.484	6.155	10.553
4	1.591	4.162	7.042
5	1.241	3.407	5.741
6	1.050	3.006	5.062
7	0.925	2.755	4.642
8	0.836	2.582	4.354
9	0.769	2.454	4.143
10	0.715	2.355	3.981
11	0.664	2.275	3.852
12	0.635	2.210	3.747
13	0.604	2.155	3.659
14	0.577	2.109	3.585
15	0.544	2.068	3.520
>15	eq. (1)	eq. (2)	eq. (3)

$$k \approx 2.35/n^{0.535} \quad (1)$$

$$k \approx 1.282 + e^{(0.958 - 0.520 \ln n + 3.19/n)} \quad (2)$$

$$k \approx 2.326 + e^{(1.34 - 5.22 \ln n + 3.87/n)} \quad (3)$$

(16)

Table D-7.1-1 Tabulated Data for Performance of “W-Test” for Normality of Data Set

n	W_{\min}	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9	a_{10}	a_{11}	a_{12}	a_{13}	a_{14}	a_{15}	a_{16}	a_{17}	a_{18}	a_{19}	a_{20}	a_{21}	a_{22}	a_{23}	a_{24}	a_{25}
3	.767	.707	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
4	.748	.687	.168	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
5	.762	.665	.241	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
6	.788	.643	.281	.088	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
7	.803	.623	.303	.140	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
8	.818	.605	.316	.174	.056	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
9	.829	.589	.324	.198	.095	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
10	.842	.574	.329	.214	.122	.040	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
11	.850	.560	.332	.226	.143	.070	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
12	.859	.548	.332	.235	.159	.092	.030	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
13	.866	.536	.332	.241	.171	.110	.054	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
14	.874	.525	.332	.246	.180	.124	.073	.024	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
15	.881	.515	.331	.250	.188	.135	.088	.043	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
16	.887	.506	.329	.252	.194	.145	.100	.059	.020	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
17	.892	.497	.327	.254	.199	.152	.111	.072	.036	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
18	.897	.489	.325	.255	.203	.159	.120	.084	.050	.016	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
19	.901	.481	.323	.256	.206	.164	.127	.093	.061	.030	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
20	.905	.473	.321	.256	.208	.169	.133	.101	.071	.042	.014	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
21	.908	.464	.318	.258	.212	.174	.140	.109	.080	.053	.026	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
22	.911	.459	.316	.257	.213	.176	.144	.115	.088	.062	.037	.012	...	...	...	...	...	...	...	...	...	...	...	...	...	...
23	.914	.454	.313	.256	.214	.179	.148	.120	.094	.070	.046	.023	...	...	...	...	...	...	...	...	...	...	...	...	...	...
24	.916	.449	.310	.255	.214	.181	.151	.124	.100	.076	.054	.032	.011	...	...	...	...	...	...	...	...	...	...	...	...	...
25	.918	.445	.307	.254	.215	.182	.154	.128	.105	.082	.061	.040	.020	...	...	...	...	...	...	...	...	...	...	...	...	...
30	.927	.425	.294	.249	.215	.187	.163	.142	.122	.104	.086	.070	.054	.038	.023	.008	...	...	...	...	...	...	...	...	...	...
35	.934	.410	.283	.243	.213	.188	.167	.149	.132	.116	.101	.087	.074	.061	.048	.036	.024	.012	...	...	...	...	...	...	...	...
40	.940	.396	.274	.237	.210	.188	.169	.153	.138	.124	.111	.099	.087	.076	.065	.055	.044	.034	.024	.015	.005	...	...	...	...	...
45	.945	.385	.265	.231	.206	.186	.170	.154	.141	.129	.117	.106	.096	.086	.076	.067	.058	.050	.041	.033	.024	.016	.008	...	...	...
50	.947	.375	.257	.226	.203	.185	.169	.155	.143	.132	.121	.111	.102	.093	.085	.076	.068	.061	.053	.046	.039	.031	.024	.017	.010	.004

GENERAL NOTES:

(a) Coefficient values have been rounded to the closest thousandth.

(b) This table has been adapted from Shapiro and Wilk, *Biometrika*, vol. 52, 1965, Tables A-1 and A-2, by permission of Oxford University Press.

NOTE: Although values exist for $n = 2$, they are excessively large (i.e., 8.984, 20.581, and 37.094, respectively), and $n \geq 3$ is required for testing per para. D-7.1.

Step 2: Apply the following additional safety factors:

$$MAWP = \text{lower 95\% CI}/5$$

$$MAWP = \text{lower 95\% CI at } 0.9P/4$$

$$MAWP = \text{lower 95\% CI at } 0.99P/3$$

Step 3: Use the highest of the three values computed.

EXAMPLE: Using the previous set of numbers in the Example of para. D-7.1

$$n = 5$$

$$s = 8.337$$

$$X = 99$$

$$MAWP \text{ 95\% CI} = [99 - (8.337)(1.241)]/5 = 17.73$$

$$MAWP \text{ 95\% CI at } 0.9P = [99 - (8.337)(3.407)]/4 = 17.65$$

$$MAWP \text{ 95\% CI at } 0.99P = [99 - (8.337)(5.741)]/3 = 17.04$$

$$\text{Use } MAWP = 17.73$$

NOTE: The highest of the three values will vary depending on n and the standard deviation of the data.

D-7.3 Method III: Nonparametric Determination of MAWP From Proof Tests

n	6 MAWP	5 MAWP	4 MAWP
≤ 5	No statistical significance	95% CI	95% CI at 0.9P
6–8	...	1	...
9–11	...	2	...
12–14	...	3	...
15–16	...	4	...
17–19	...	5	...
20–22	...	6	...
23–24	...	7	...
25–27	...	8	...
28–29	...	9	1
30–32	...	10	2
33–34	...	11	2
35–36	...	12	2
37–39	...	13	2
40–41	...	14	2
42–43	...	15	2
44–45	...	16	2
46–50	...	17	3

The integers listed are the ranking from the lowest failure pressure value recorded. For example, for

$n = 7$, the MAWP = the lowest recorded failure pressure divided by 5. Similarly, in the case of $n = 10$, the MAWP = the second lowest value divided by 5. If $n > 27$, compute both MAWP values, and use the larger of the two values obtained.

EXAMPLE: If the data in the Examples for Methods I and II had not been normally distributed (and lacking statistical significance with $n = 5$), the MAWP would have been $87/6 = 14.5$. Similarly, if there had been a sixth data point greater than 87 (and the data had not been normally distributed but with a nonparametric CI of 95% based on the lowest value for $n = 6$), the MAWP would have been $87/5 = 17.4$. Alternatively, if the sixth data point had been less than 87, the MAWP would have been the sixth data point divided by 5.

NOTE: For nonparametric analysis, 95% CI at 0.99P requires $n \geq 299$.

D-7.4 Method IV: MAWP Determination Based on Nonfailure Test Pressure

$$MAWP = [(test \text{ pressure})(n^{1/8})]/6$$

which provides the following, where n = number of prototypes tested to a specific pressure:

n	MAWP
1	test pressure/6
2	test pressure/5.5
3	test pressure/5.25
4	test pressure/5
10	test pressure/4.5
25	test pressure/4
75	test pressure/3.5
300	test pressure/3

Similar to the other methods, Safety Factor 6 lacks statistical significance, and Safety Factors 5, 4, and 3 are based on 95% CI at 0.5P, 0.9P, and 0.99P, respectively, where confidence = $1 - p^n$ for a pass/fail basis.

NOTE: Per para. D-5.1.5, prototype testing at pressures less than that incurring failure is limited to special cases requiring advance Committee approval. The "test pressure" is the lowest test pressure used (if different for multiple prototypes of the same design and method of fabrication). None of the prototypes tested are permitted to fail. If any prototype using this method does fail, then Method III shall be used to determine MAWP.

(16)

NONMANDATORY APPENDIX E

GUIDELINES FOR PREPARING A PVHO PERFORMANCE-BASED CASE FOR FLEXIBLE CHAMBERS

E-1 GENERAL REQUIREMENTS

E-1.1 Introduction

This Appendix provides guidance when preparing a PVHO-1 Case to be submitted to the ASME PVHO Standards Committee for nonstandard flexible PVHO chambers. Requirements in the PVHO-1 Standard shall be complied with, including systems, unless otherwise stated in the Case.

The Case shall be all inclusive and address all requirements identified in this Appendix. Acceptable alternatives shall be fully described and technically justified in the proposed Case.

Guidelines for regulating submissions for medical hyperbaric chambers may be found in STP-PT-047.

E-1.2 Scope

E-1.2.1 Application. This Appendix applies to pressure vessels having a pressure boundary that is partially or completely composed of a flexible, nonmetallic material(s) that does not comply with the requirements of PVHO-1. This Appendix applies to pressure vessels that enclose a human within their pressure boundary while under internal pressure exceeding a differential pressure of 2 psi.

PVHOs complying with this Appendix are assumed to have only one pressurized chamber. This Appendix applies to pressure vessels pressurized with air only. Alternate breathing gases including oxygen are limited to individual hoods or breathing masks per occupant. The partial pressure of carbon dioxide shall not exceed 12 mm of mercury.

E-1.2.2 Pressure Boundary. The pressure boundary of the PVHO shall be the PVHO hull and all pressure-retaining components out to the first isolable or blanked/sealed boundary. The pressure boundary shall be defined in the Design Specification.

E-1.3 Exclusions

The following types of vessels are excluded:

- (a) nuclear reactor containments
- (b) pressurized airplane cabins
- (c) aerospace vehicle cabins
- (d) caissons

E-1.4 Design Limitations

The design life of PVHOs complying with this Appendix shall not exceed 10 yr from the date of manufacture.

E-1.5 Design Specification

A Design Specification shall be included in the Case and shall set forth the intended use of the chamber and its operating conditions.

E-1.5.1 Criteria to Be Specified. The Design Specification shall include the following items, at a minimum:

- (a) maximum operating pressure
- (b) maximum design pressure
- (c) minimum and maximum design temperatures
- (d) maximum number of occupants
- (e) maximum occupant weight (for portable or transportable chambers)
- (f) loadings in addition to those induced by pressure and temperature
- (g) external service conditions, as applicable
- (h) corrosion or degradation allowances (to include "none" if applicable)
- (i) assembly and installation requirements
- (j) design life, yr
- (k) design life, pressure cycles
- (l) design life, folding cycles
- (m) pressurization/depressurization rates
- (n) method of atmospheric control
- (o) stored gas requirements
- (p) temperature and humidity parameters, if any
- (q) fire detection and suppression, as applicable
- (r) type(s) of breathing gas delivery, number of outlets and their characteristics, as applicable
- (s) applicable systems section(s) of PVHO-1 to which the PVHO is designed, as follows:
 - (1) medical systems (Section 5)
 - (2) diving (Section 6)
 - (3) submersibles (Section 7)
 - (t) method of monitoring oxygen and carbon dioxide levels

E-1.5.2 Other Codes and Standards. Title(s) and edition(s) of other codes and/or standards used in the

development of the PVHO, and the specific sections used, shall be identified.

E-1.5.3 Certification of Design Specification. A Professional Engineer shall certify that the Design Specification is in compliance with this Appendix and the other standards and codes used. Such certification requires the signature(s) of one or more qualified engineers with the requisite experience and qualifications to address a given portion of the Design Specification. One or more individuals may sign the documentation based on information they reviewed and the knowledge that the objectives of the Appendix have been satisfied.

E-1.6 Manufacturer's Data Report

A Manufacturer's Data Report shall be provided certifying that the manufacturer has built the PVHO in accordance with the PVHO Design and that the design report complies with this Appendix and the Design Specification.

E-1.7 Documentation

E-1.7.1 Documentation Provided to the User. The manufacturer shall provide documentation to the user as required by this Appendix.

A copy of the Manufacturer's Data Report, PVHO-1 Forms GR-1 and GR-1S, and Form U-2 for PVHO parts built to Section VIII of the ASME Boiler and Pressure Vessel Code (the Code), shall be furnished to the user or his designated agent.

Documentation shall include, but is not limited to, the following as applicable:

- (a) PVHO maintenance manual, including any drawings and parts lists necessary to permit the user to properly maintain the PVHO
- (b) PVHO operations manual including any drawings required to properly operate the PVHO
- (c) the vessel coating information
- (d) record of the required markings applied
- (e) list of standards used for design, fabrication, and operation
- (f) seal and gasket sizes and materials
- (g) assembly drawings
- (h) Design Specification
- (i) evidence of successful completion of test(s) required in paras. E-5.2, E-5.3, and E-5.4 of this Appendix

E-1.7.2 Documentation Retained by the Manufacturer for Individual Units. The manufacturer shall retain a copy of the following documentation for at least the life of the delivered PVHO plus 5 yr.

Documentation shall include, but is not limited to, the following as applicable:

- (a) items E-1.7.1(a) through (i)
- (b) the PVHO Design (see para. E-2.2)

(c) Manufacturer's Data Reports and PVHO-1 Forms GR-1 and GR-1S

(d) parts designed to Section VIII of the Code shall meet the documentation requirements of Section VIII of the Code

(e) documentation of any repairs

E-1.7.3 PVHO Design Qualification Documentation.

PVHO Design qualification documentation shall be retained by the manufacturer for at least 5 yr past the design life of the last production unit delivered.

PVHO Design qualification documentation shall include, but is not limited to, the following as applicable:

- (a) all test data recorded per para. E-5.2 of this Appendix
- (b) quality assurance procedures (see para. E-4)
- (c) Process Control Procedure (see para. E-4.6)
- (d) quality assurance records (see para. E-4.11)
- (e) material testing and inspection records
- (f) risk analysis documentation (see para. E-2.8)

E-2 DESIGN

E-2.1 General

This section provides guidance relative to the design and application of PVHOs and their pressure components.

E-2.2 PVHO Design

A PVHO Design shall be prepared in accordance with this Standard prior to the fabrication of prototype or production PVHOs. The PVHO Design shall consist of approved design drawings, manufacturing procedures, and process instructions that unambiguously describe the entire PVHO assembly and its production.

The design drawings shall include top-level assembly drawings, subassembly drawings, and drawings of component parts. Purchased finished parts shall be documented in one or more bills of materials lists.

Manufacturing procedures and process instructions shall suitably document a single acceptable method for each manufacturing operation including, but not limited to, fabrication, joining, lay-up, assembly, inspection, testing, and marking.

The PVHO Design shall consistently produce production PVHOs equal to or better than the prototypes tested to qualify the PVHO Design (see para. E-4.13).

The PVHO Design shall document repairable damage and the applicable repair procedures and process instructions in accordance with para. E-2.10.

E-2.3 Basis of PVHO Design

The PVHO Design shall consider the design loads (see para. E-2.4); applicable environmental considerations, both operational and nonoperational; effects of minimum and maximum temperatures; time under pressure; large displacements associated with deployment (such

as collapsible chambers); long-term storage between usages; and the effects of aging. These and other pertinent effects relevant to the intended construction shall be identified and addressed in the risk analysis in para. E-2.8.

In addition to the design qualification testing required by this Appendix, design analysis shall be performed to the extent necessary to comply with the requirements of this Appendix.

Conformance of the PVHO Design to the requirements of this Standard/Appendix shall be established by a Professional Engineer experienced in relevant pressure vessel design, who shall certify that the PVHO was designed either by him or under his direct supervision, or that he has thoroughly reviewed a design prepared by others, and to the best of his knowledge, the PVHO Design complies with this Appendix.

E-2.4 Design Loads

All loads shall be considered. If a load is not applicable to a particular PVHO, there shall be a statement specifying that the load was considered and is not applicable. The loads to be considered in designing a PVHO shall include, but are not limited to, the following:

- (a) internal or external design pressure
- (b) weight of the PVHO and normal contents under operating and test conditions (this includes additional pressure due to static head of liquids)
- (c) superimposed static reactions from the weight of attached equipment, such as motors, machinery, other pressure vessels, piping, linings, and insulation
- (d) the attachment of internal and external brackets and supports, and supporting equipment, such as umbilicals, piping, locks, and manways
- (e) cyclic and dynamic reactions due to pressure or thermal variations, or from equipment mounted on the PVHO, and mechanical loadings
- (f) wind, snow, and seismic reactions
- (g) impact loadings
- (h) temperature gradients and differential thermal expansion
- (i) loads and loading conditions due to lifting, handling, transportation, and installation
- (j) startup, shutdown, upset, and emergency conditions
- (k) loads for all test configurations
- (l) transmitted loads, such as handling or operating impacts transmitted through guards or cages
- (m) as applicable, loads specified in PVHO-1 Sections 4, 5, 6, and 7 that are not specified above

E-2.5 Access Doors, Hatches, and Service Locks

Access doors, hatches, and service locks shall

- (a) be designed, fabricated, inspected, certified, and tested in conformance with this Standard.

- (b) have a safety interlock system to prevent inadvertent opening and/or unseating of the door, hatch, or service lock when pressure acts to open or unseat the door, hatch, or service lock. The safety interlock system shall not permit pressurization of the door, hatch, or service lock unless the door, hatch, or service lock closure is fully engaged.

- (c) have an external means for monitoring, venting, and equalizing pressure to the compartment being serviced or to atmosphere.

E-2.6 Electrical

Electrical systems within the PVHO shall be intrinsically safe in accordance with NFPA 99 and IEC 60601-1. Electrical components inside the PVHO shall be protected against electrical shock and surge by at least two means of patient protection (MOPP) in accordance with IEC 60601-1 and NFPA 99.

Requirements of NFPA 99 20.2.7.3.13 (low-voltage, low-power equipment) shall apply to electrical equipment installed or used within the PVHO.

Electrical components are not permitted inside the patient's hood or in contact with high levels of oxygen. All electrical controls (primary and secondary) shall be located outside of the PVHO.

Prevention of electrostatic discharges shall comply with IEC 60601-1. Occupants and the PVHO shall be continuously grounded to prevent the possibility of an ignition source.

E-2.7 Unusual Design Features

If the proposed PVHO exhibits unusual characteristics or features not directly addressed in this Appendix, these shall be described, the design criteria used shall be documented and justified, and the adequacy of the testing procedures shall be demonstrated.

E-2.8 Risk Analysis

The PVHO designer shall implement and document an established standard or procedure (such as a failure modes, effects, and criticality analysis or a safety hazards analysis) for identifying, evaluating, and mitigating potential risks associated with the PVHO and its associated systems.

Potential hazards shall include software failure, hardware failure, and operator error. The analysis shall include flammability of materials at elevated pressures as well as unanticipated pressure loss.

The risks identified shall be evaluated and mitigated to a level acceptable to the user or appropriate authority. Mitigation and protective measures may include design features that minimize the probability of occurrence, inspection and tests during and following fabrication, implementation of safety and/or warning devices, protective systems, and caution or warning procedures and labels. The risk analysis results shall be retained by the designer in accordance with para. E-4.11.

Catastrophic failure shall be precluded by appropriate mitigating design features.

E-2.9 Design Report

A Design Report shall be prepared demonstrating that the PVHO Design is supported by design qualification testing and is in compliance with the requirements of this Appendix and the Design Specification. A Registered Professional Engineer, or the equivalent in other countries, shall certify that the Design Report is in compliance with this Standard and the Design Specification.

E-2.10 Repair Specification

A complete list of discrepancies for which repair is permitted, if any, and the situation(s) under which those repairs may be made (e.g., repair is only permitted when manufacturing defects are identified at the time of manufacture) shall be prepared. This list shall document the type and scope of each repairable discrepancy; the location(s) on the PVHO in which repairs may be made; acceptable repair method(s) and procedure(s); materials used; postrepair inspection and testing requirements; and the documentation and record keeping required for the repair, its inspection, and testing.

Each method of repair shall be fully documented and shall meet the requirements of this Appendix. Repair specifications shall be qualified per para. E-5.4 prior to their use.

E-3 MATERIALS

E-3.1 General

All pressure-retaining materials used in the PVHO shall be identified in the Case, complete with their material properties and the standards to which they comply and to which they are tested.

E-3.1.1 Application. This section provides requirements applicable to materials used to fabricate prototype and production PVHOs, including purchased materials, raw materials, materials produced during fabrication, and materials used for repair.

Raw materials used by the PVHO manufacturer to produce pressure-retaining materials (e.g., resin and fibers used to produce a pressure-retaining matrix) shall be treated in the same manner as purchased pressure-retaining materials.

E-3.1.2 Compliance with Standards. All materials shall comply with a national or international standard. Materials not specifically permitted under PVHO-1 may be used provided they conform to a published specification covering chemistry, physical and mechanical properties, methods and process of manufacture, postproduction treatment, and quality control; and they otherwise meet the requirements of this Standard.

Allowable stresses shall be determined in accordance with the applicable allowable stress basis of the Code or a more conservative basis. Materials specifically prohibited by PVHO-1 shall not be used.

E-3.1.3 Alternative Material Specification. Alternatively, the manufacturer shall create and maintain a material specification based on standard test procedures and required test results. The specification shall specify necessary and sufficient parameters to ensure that, as far as the ultimate performance of the PVHO is concerned, all materials used for fabrication are fully equivalent with those used in the prototype testing.

E-3.1.4 Material Traceability. All material used to fabricate prototype or production PVHOs shall be traceable to dated records documenting their production, inspection, processing, and testing.

E-3.1.5 Material Test Samples. A minimum of five samples, taken from each lot of material used in the manufacture of each prototype and production PVHO, shall be tested for key material properties as determined by a Professional Engineer. A lot is defined as that material used in the manufacture of each PVHO plus that required for testing.

Test samples shall be obtained and tested within a suitable time frame such that the properties of the tested samples accurately represent the properties of the materials used in the completed PVHO.

The upper value of the 90% confidence interval of the production material shall be at least as great as the lower value of the 90% confidence interval of the material used in the prototype units that were tested.

E-3.1.6 Supporting Information for Materials. Supporting information for materials and coatings shall include, but is not limited to, the following:

- (a) testing specifications and data to support the specification
- (b) material properties including tear/rip propagation, Shore A hardness, elongation to break, average wall thickness and variance, post-treatment records, and all other physical properties deemed essential to performance
- (c) material test data
- (d) operational limitations
- (e) inspection criteria
- (f) shelf life, corrosion and degradation properties, and any other data that can establish the limitations of the material for the intended use
- (g) cyclic life data at the maximum and minimum design temperatures if material properties are temperature dependent
- (h) strength and elongation data at the maximum and minimum design temperatures if material properties are temperature dependent
- (i) creep and cyclic creep data if material properties are time dependent

(j) flammability tests on all pressure boundary components and components within the PVHO at anticipated oxygen concentrations at design pressure

(k) viscosity

(l) cure or drying time

(m) other relevant properties critical to the performance and safety of all nonstandard materials

(n) a full description of all pressure boundary materials, nonstandard windows, additives, etc.

(o) tear strength/rip propagation of polymers and bond/RF welds, etc., elongation to break, average wall thickness and variance, and all other physical properties deemed essential to performance

(p) folding and abrading tests on the polymeric sheets

(q) rates of degradation (thermal and ultraviolet) of physical/strength properties by actual testing or by accelerating aging, whether the design and prototype testing allow for this ongoing reduction in physical properties or not

(r) a list of chemicals, cleaners, disinfectants, etc., that may be used

(s) documentation of regular visual inspections that will indicate degradation in material properties, e.g., color change, chalkiness on the surface, cracking or creasing along folds, and any other key performance indicators that would necessitate repair or replacement of components and/or red-tagging of the PVHO

Dependence upon published “typical” strength values for materials is not permitted. It shall be ensured that the strength of the materials used in production complies with para. E-3.1.5.

E-3.2 Window Materials

Windows in PVHOs are both desirable and necessary for safety and relief of patient anxiety. PVHO-1 has had a long and successful history of windows in chambers and has no wish to compromise the safety of chambers with substandard windows. Therefore, the following are required for non-PVHO-1 Section 2 windows:

(a) A design certification for each window and matching viewport assembly shall be prepared that includes a summary of engineering calculations and/or a description of the experimental method and data used to verify compliance of the window design with the requirements of this document.

(b) During hydrostatic proof/burst testing ($6\times$ design pressure) and the cyclic pressure testing of the PVHO, no failure shall occur in the window/window seat area.

(c) The exclusions of PVHO-1, para. 2-1.2 shall apply.

(d) A material manufacturer’s certification for each lot of material used for the window shall certify that the material meets or exceeds the minimum values of physical properties specified in the design criteria for the PVHO.

(e) A material certification for each window shall certify that the material meets the minimum values specified in the design criteria for the PVHO and that these properties have been experimentally verified.

(f) The effects of ultraviolet degradation shall be taken into consideration.

E-3.3 Flammability

The materials selected for the construction of the PVHO shall minimize the risk of fire. Consideration shall include flammability, the amount of flame, flame spread, smoke, and toxic gas production.

Materials selected for the PVHO shall take into consideration ASTM G94 and ASTM G63. ASTM G88 shall be used for mitigating risks.

A component-level oxygen hazard analysis shall be completed using the NASA Technical Bulletin 104823, Guide for Oxygen Hazards Analyses on Components and Systems, or equivalent, methodology.

The materials shall be flame resistant and self-extinguishing.

The chamber shall be pressurized with air only (oxygen is limited to the patient’s hood or breathing device only). Oxygen levels within the chamber shall not exceed 25%.

E-3.3.1 Flammability Evaluation. When evaluating and testing for the above-mentioned material characteristics, consideration and testing shall take into account the effects of the PVHO being pressurized to the maximum allowing working pressure (MAWP) while exposed to the maximum anticipated levels of oxygen, both inside and outside of the PVHO.

Experience shows that materials considered flame-proof may burn readily in the presence of extra oxygen and/or compressed air. For example, when applying Cook’s diagram (Fig. A.3.3.14.3 from NFPA 99-2012), the % oxygen index of air at a pressure of 78 psi (equivalent to 165 ft of seawater) is equivalent to 50% oxygen at 1 atm.

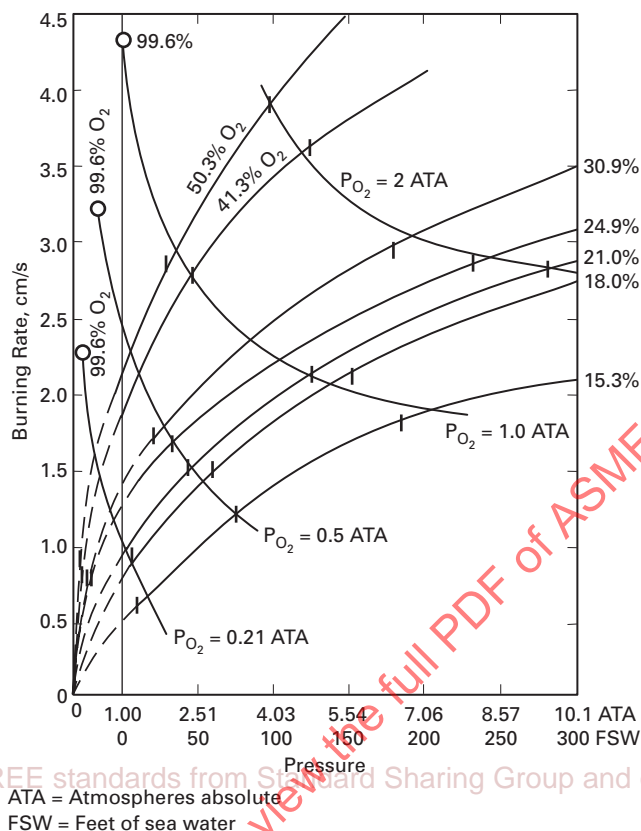
Materials used in, or attached to, pressure-retaining boundaries shall be self-extinguishing when tested in accordance with Test Method 1 of NASA-STD-6001B.

All of the traditional aspects of fire safety shall be addressed including, but not limited to, sources of ignition, fuel (including the material from which the PVHO is fabricated), and oxygen levels.

Adequate means of fire detection and suppression shall be addressed in the design, fabrication, and operation of the PVHO.

E-3.3.2 Materials Qualified to NFPA 701. Materials need not comply with the constraints specified above if they have already been qualified as being nonflammable or self-extinguishing in accordance with Method 2 of NFPA 701 or in accordance with Appendix F of Part 23 (Fire Protection) of the Code of Federal Regulations.

**Fig. A.3.3.14.3 Cook's Diagram:
Atmosphere of Increased Burning Rate**



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GENERAL NOTES:

- The degree of fire hazard of an oxygen-enriched atmosphere varies with the concentration of oxygen and diluent gas and the total pressure. The definition contained in the current edition of NFPA 53, *Recommended Practice on Materials, Equipment, and Systems Used in Oxygen-Enriched Atmospheres*, and in editions prior to 1982 of NFPA 56D, *Standard for Hyperbaric Facilities*, did not necessarily reflect the increased fire hazard of hyperbaric and hypobaric atmospheres.
- In Chapter 14 of NFPA 2012 and in NFPA 99B, *Standard for Hypobaric Facilities*, "atmosphere of increased burning rate" is defined as an oxygen-enriched atmosphere with an increased fire hazard as it relates to the increased burning rate of material in the atmosphere. It is based on a 0.47-in./sec (1.2-cm/s) burning rate (at 23.5% oxygen at 1 atm absolute) as described in this figure.

E-3.4 Material Considerations

Material selection shall consider mutual compatibility. For example, galvanic corrosion shall be addressed.

Materials shall be selected to ensure safety under anticipated normal and abnormal conditions.

E-4 QUALITY ASSURANCE PROGRAM

E-4.1 Certification

All aspects of the Quality Assurance Program shall be outlined in the Case, which shall include, but not be limited to, those outlined in this section. PVHO manufacturers and fabricators shall be certified to ISO 9001, ISO 13485, or equivalent.

E-4.2 General

A qualified third party shall be used to ensure that all PVHOs intended to be marked under this Standard are manufactured and tested to the criteria and requirements set forth herein.

The PVHO manufacturer shall arrange for the inspector to have free access to all areas concerned with the supply or manufacture of materials for the PVHO when so requested. The inspector shall be permitted free access at all times while work on the PVHO is being performed to all parts of the manufacturer's shop that concern the construction of the PVHO and to the site of field-erected PVHOs during the period of assembly and testing of the PVHO. The manufacturer shall keep the inspector

informed of the progress of the work and shall notify him reasonably in advance when PVHOs, or PVHO components, will be ready for any required tests or inspections.

In addition to the requirements of Section 3 of PVHO-1, manufacturers shall include a documented Quality Assurance Plan for the design and manufacture. The Quality Assurance Plan (QAP) shall be reviewed and approved by the purchaser/user and shall include the following elements.

E-4.2.1 Organization. The QAP shall describe the organizational structure, with responsibilities, authorities, and lines of communication clearly delineated. Persons indicated in the QAP to be responsible for verifying the PVHO quality shall have the authority to

- (a) identify problems affecting quality
- (b) initiate, recommend, or provide solutions to quality problems, through designated channels and in accordance with this Appendix
- (c) verify implementation of the solution

E-4.2.2 Design Control. A documented process shall be used to develop and control the PVHO Design, which includes

- (a) a process for design inputs and review
- (b) a requirement for formal design review
- (c) a process for product configuration management and change control

E-4.3 Document Control

The QAP shall describe the manufacturer's measures for ensuring that design documents are correctly translated into manufacturing specifications, drawings, procedures, and shop/lab instructions. Considerations shall be made for reviews and approvals, including those of the purchaser as applicable.

The manufacturer shall include a procedure for ensuring distribution of appropriate documents to the working areas in a timely fashion and a process for ensuring nonuse of obsolete documents.

E-4.4 Procurement Control

The QAP shall describe how the applicable requirements are verified in the procurement documents. The manufacturer shall describe the basis for source evaluation and selection and the method of objective evaluation of the quality of furnished materials, items, and services upon receipt.

E-4.5 Material Control

The QAP shall describe the identification to be applied to material and items upon receipt and that this identification remains until the material or item is incorporated into a PVHO. Identification shall be such that personnel can easily determine quality status, material or item type, specification or part as appropriate, job number,

and any other information necessary to provide full traceability.

E-4.6 Process Control

The QAP shall include a Process Control Procedure that records the identification of materials and items incorporated into the PVHO and each chronological step in its manufacture, including inspection and test steps. The Process Control Procedure shall contain periodic operator and inspector signature points so that product status can be readily determined.

The manufacturer shall identify critical manufacturing activities and ensure that they are accomplished by appropriately trained and qualified personnel. Inspection points shall follow the activities in the process control plan.

E-4.7 Inspection Control

The QAP shall include the measures used by the manufacturer to ensure that inspections are reliable. These measures shall include the following:

- (a) proper qualification of inspection personnel
- (b) calibration of inspection instrumentation
- (c) incorporation of acceptance criteria into inspection points in the Process Control Procedure
- (d) assurance that inspections are performed by persons other than those performing or supervising work
- (e) documentation of all inspections

E-4.8 Test Control

The QAP shall describe the measures used to ensure that tests (including lab tests) are performed consistently and reliably. The following requirements shall be met:

- (a) Tests shall be performed in accordance with written instructions stipulating acceptance criteria.
- (b) Test results shall be documented.
- (c) Examination, measurement, and testing equipment used for activities affecting quality shall be controlled to maintain required accuracy.
- (d) Tests shall be performed by trained and qualified personnel.
- (e) Tests shall be verified by persons other than those performing or supervising the test.

E-4.9 Control of Measuring, Test, and Inspection Equipment

The QAP shall describe the equipment used in inspections and tests and the measures used to ensure appropriate accuracy. Appropriate equipment shall be calibrated and the calibration shall be traceable to standards where they exist. Where such standards do not exist, the equipment manufacturer's recommendations shall be followed.

E-4.10 Control of Nonconforming Items and Materials

The QAP shall describe the measures used by the manufacturer to control materials or items that are found to be discrepant to prevent their inadvertent use. Nonconforming items and materials shall be identified and the discrepant condition(s) shall be documented. The process for determining, documenting, and verifying corrective action shall be described, including the involvement of the purchaser.

E-4.10.1 Repair of Nonconforming PVHOs. Production PVHOs having discrepancies of a type, scope, and location for which repair is permitted per para. E-2.10 may only be repaired using a repair procedure documented per E-2.10 and successfully tested in accordance with para. E-5.4.1. Repairs performed in accordance with para. E-2.10 shall meet the requirements of this section.

E-4.11 Quality Assurance Records

The QAP shall provide for quality assurance records.

(a) Records shall be specified, compiled, and maintained to furnish documentary evidence that services, materials, and completed PVHOs meet this Standard.

(b) Records shall be legible, identifiable, and retrievable.

(c) Records shall be protected against damage, deterioration, or loss.

(d) Requirements and responsibilities for record transmittal, distribution, retention, maintenance, and disposition shall be established and documented.

(e) Records required for traceability shall be retained for a minimum of 12 yr.

E-4.12 Quality Assurance Overview by a Qualified Third Party

A qualified third party shall be employed to ensure that all PVHOs and components produced to this Standard are designed and manufactured to the requirements of this Standard. This includes, but is not restricted to, the following:

(a) The PVHO or component is designed in accordance with this Standard.

(b) The manufacturer is working to the requirements of the quality control system.

(c) The materials used in construction of the PVHO or component comply with this Standard.

(d) All manufacturing operations are conducted in accordance with approved procedures by qualified operators.

(e) All defects are acceptably repaired in accordance with this Standard, including this Appendix.

(f) All prototype and production testing has been performed and witnessed as required by the Manufacturer's Design Report.

(g) The PVHO is marked in accordance with this Standard.

(h) A visual inspection of the PVHO or component is conducted to confirm that there are no material or dimensional defects or discrepancies.

The manufacturer shall arrange and give the third-party inspector free access to all facilities associated with the manufacture of the PVHO or component. The manufacturer shall keep the third-party inspector informed of the progress of the work and shall notify him reasonably in advance when PVHOs or components will be ready for any required tests or inspections.

E-4.13 Modifications to PVHO Design

Any changes to design, dimensions, geometry, fabrication process, specified materials, or material supplier shall require prototype retesting in accordance with the relevant sections of this Standard, including this Appendix. Any changes require a new Case be submitted to the PVHO Standards Committee.

E-5 TESTING

E-5.1 Test Requirements

This section outlines minimum testing requirements. Additional testing may be deemed necessary for each proposed PVHO. All tests shall be detailed in the Case.

The Case shall state the failure criteria for each test performed where not otherwise specified in this section.

All PVHO pressure boundary components shall demonstrate structural integrity through testing in accordance with this section.

All tests shall be documented and shall be witnessed by a qualified third party experienced in pressure vessel design. The inspector shall certify that the test results comply with the testing requirements set forth herein.

Testing shall be conducted at the most critical temperature(s) for which the PVHO is designed.

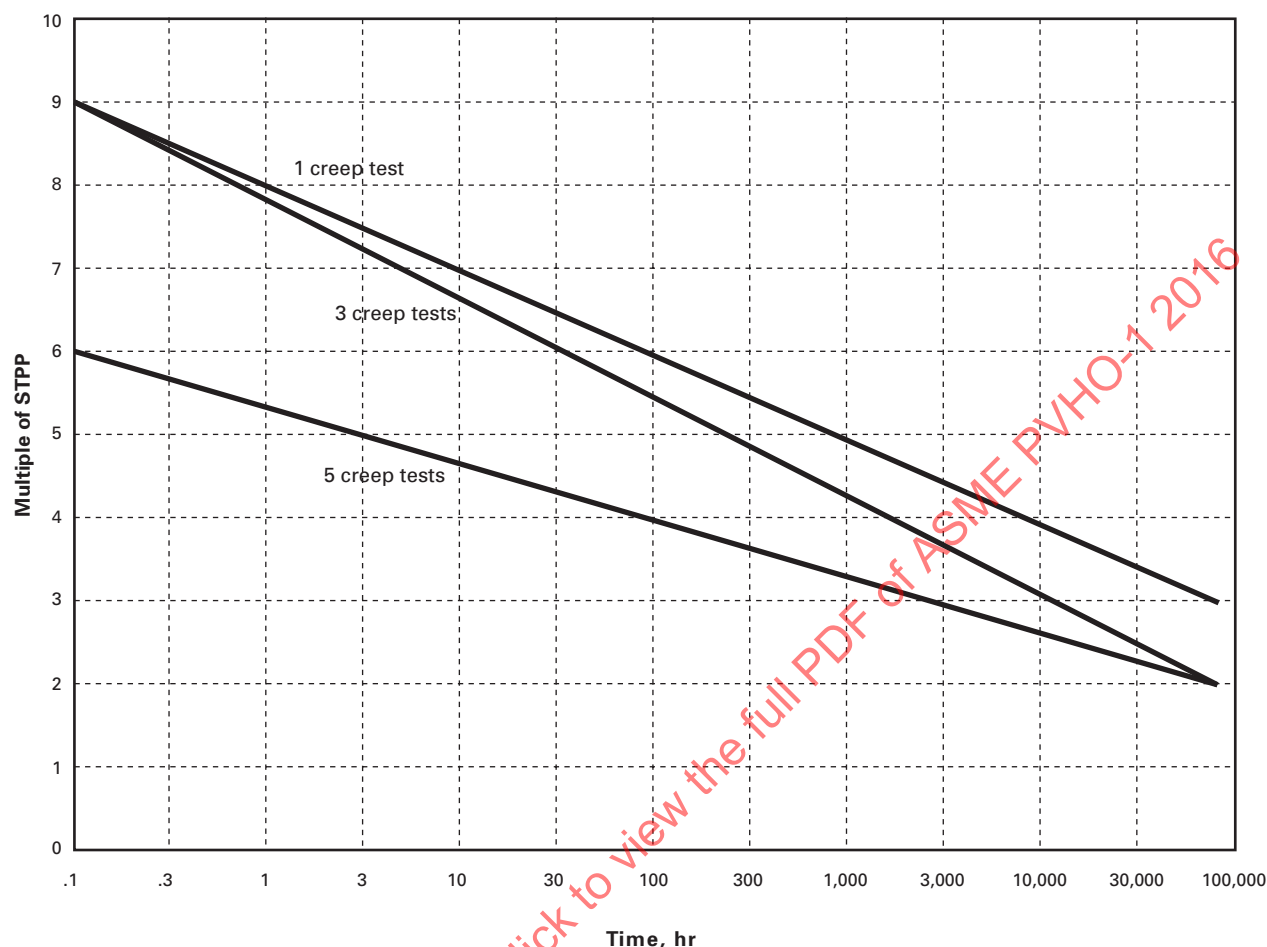
E-5.2 Design Qualification (Prototype) Testing

PVHOs used for design qualification (prototype) testing shall not be used other than for prototype testing. Design qualification testing shall include all pressure boundary components, including windows.

E-5.2.1 Burst or Proof Pressure Tests. Pressure tests shall be conducted on a minimum of three full-scale prototype chambers. These prototype vessels do not have to be completely outfitted. They shall be full size and of identical construction to the end item, with all fabrication completed that in any manner may affect the integrity of the pressure boundary. If desired, prototype chambers that have already been cyclic pressure tested may be used.

The pressurization rate used for proof pressure and cyclic testing shall be in accordance with that stated in

Fig. E-5.2.2.1-1 Number of Test Samples Required for Alternate Creep Test Procedure



GENERAL NOTE: Test duration shall exceed 300 hr.

the Design Specification. The pressurization rate shall not exceed 650 psi/min (4.5 MPa/min).

Failure of a PVHO shall not occur at a pressure of less than 6 times its MAWP.

The test pressure shall be held for a minimum of 30 min.

E-5.2.2 Extended-Duration (Creep-Rupture) Testing.

The long-term strength of the PVHO at maximum design temperature shall be empirically verified using full-scale PVHOs.

E-5.2.2.1 Test Procedure. The PVHOs shall be subjected to sustained pressure at maximum design temperature for at least 300 hr without failure per any one of the following procedures [(a), (b), or (c)] where MAWP is determined in accordance with para. E-5.2.1. See Fig. E-5.2.2.1-1. Three options are available. In all three cases, the test temperature and duration shall be at the most critical design temperature and at least 300 hr.

(a) If only one creep test is to be performed it shall be conducted at a pressure and for a duration longer

than that defined by a straight line on a semi-log plot (rectilinear pressure versus logarithmic time) defined by the point at 9 times the design pressure and at a duration of 0.1 hr at one end and at 3 times the MAWP at 80,000 hr at the other. If the specimen test pressure and duration exceed the pressure and time defined by this line and the test duration is at least 300 hr, then the design meets the creep test requirements.

(b) If three creep tests are to be performed they shall all be conducted at a pressure and for a duration longer than that defined by a straight line on a semi-log plot (rectilinear pressure versus logarithmic time) defined by the point at 9 times the design pressure and at a duration of 0.1 hr at one end and at 2 times the MAWP at 80,000 hr at the other. If all three specimen test pressures and durations exceed the pressure and time defined by this line and the test duration for each specimen is at least 300 hr, the design meets the creep test requirements.

(c) If five creep tests are to be performed they shall all be conducted at a pressure and for a duration longer than that defined by a straight line on a semi-log plot

(rectilinear pressure versus logarithmic time) defined by the point at 6 times the design pressure and at a duration of 0.1 hr at one end and at 2 times the MAWP at 80,000 hr at the other. If all five specimen test pressures and durations exceed the pressure and time defined by this line and the test duration for each specimen is at least 300 hr, the design meets the creep test requirements.

E-5.2.2.2 Alternative Test Procedure. As an alternative to E-5.2.2.1, extended-duration creep-rupture tests shall be performed as follows:

(a) The PVHOs shall be individually subjected to sustained pressure at the maximum design temperature until catastrophic failure occurs.

(b) Each PVHO shall be subjected to a different pressure with sustained temperature, pressure, and duration being recorded.

(c) At least one data point shall be obtained for each of the following log-time cycles: 1 hr to 10 hr, 10 hr to 100 hr, 100 hr to 1,000 hr, and 1,000 hr to 10,000 hr.

(d) The best-fit straight-line log-log plot of pressure versus time shall be constructed based on all extended-duration test data points.

(e) The extrapolated failure at 80,000 hr continuous sustained loading at maximum design temperature shall be greater than 2 times the MAWP as obtained per para. E-5.2.1; otherwise MAWP shall be reduced to a value that is 50% of the extrapolated failure pressure at 80,000 hr duration.

E-5.2.3 Cyclic Design Life. The maximum permissible number of operational pressurizations shall be determined by cyclic testing of a full-scale PVHO. The pressure test cycles shall be from ambient (1 atm) to MAWP and back to ambient. The duration of a cycle shall be determined by adding the times for the two tests described below.

(a) To establish the time for the pressurization cycle, a pneumatic test shall be conducted on the PVHO to determine the time taken for pressurization from ambient pressure to MAWP, plus the time taken for any changes in volume to subside, plus 10 min.

(b) To establish the time for the depressurization cycle, a pneumatic test shall be conducted on the PVHO to determine the time taken for depressurization from MAWP to ambient pressure, plus the time taken for any changes in volume to subside, plus 10 min.

If the material strength is temperature sensitive, cycling shall be performed at the most critical service temperature.

To establish the maximum number of cycles satisfactorily completed on the PVHO under test, the PVHO shall be inspected periodically for leakage or visible damage to any pressure-retaining component. Should leakage occur during cyclic testing, the number of cycles achieved at the previous inspection shall be considered the total number of test cycles performed.

Upon completion of testing, the PVHO shall again be visually inspected for damage. The requirement for acceptance of the cyclic pressure test is that no cracks or other damage shall be visibly detectable, using methods that are normally used for visual inspection of the applicable PVHO material. The number of approved operational cycles, CA , shall be computed as

$$CA = (CT/2) - 1,000$$

where CT is the total number of test cycles performed.

E-5.2.4 Chronological Design Life. In order to establish the design life, the designer shall consider the effects of degradation due to environmental considerations, both operational and nonoperational. The effects of minimum and maximum temperatures, time under pressure, and long-term storage between uses shall be considered.

Regardless of the results of the testing in para. E-5.2.5, the chronological design life shall not exceed 10 yr and shall be measured from the date of original manufacture.

E-5.2.5 Aging. When establishing the chronological, cyclic, folding, or other design life of a PVHO, the cumulative effects of aging on nonmetallic pressure-retaining materials shall be considered. This shall be accomplished by using aged material for the design qualification tests or by appropriately adjusting the test results to account for the properties of the aged material(s).

All types of aging relevant to the pressure-retaining materials incorporated in the completed PVHO shall be considered, including chronological aging, aging due to ultraviolet (UV) or other radiation, exposure to ozone or other compounds, etc.

An aged prototype PVHO shall be obtained for testing by exposing a completed PVHO to the worst-case use or storage conditions permitted for a time period at least equal to the PVHO's chronological design life. During this time period, the PVHO shall be simultaneously exposed to all of the degrading conditions to which exposure during use is permitted.

Alternatively, an aged prototype PVHO may be obtained by artificially aging a new PVHO in accordance with paras. E-5.2.5.1 through E-5.2.5.4.

If use of an aged prototype PVHO is not practical, aged component test samples may be tested and the results used to adjust the design qualification test results obtained from testing a new, unaged PVHO. When using this approach, all pressure-retaining items shall be tested, including joints. Aged test samples shall be obtained as described above or by artificially aging them per the accelerated aging procedures in paras. E-5.2.5.1 through E-5.2.5.4. The maximum allowable operating pressure (MAOP) of the PVHO shall be proportionally adjusted downward based on the test results obtained with the aged test samples versus the test results obtained using unaged material.

E-5.2.5.1 Accelerated Chronological Aging. Prototype PVHOs may be aged in accordance with any of the following (as applicable):

- (a) ISO 2440 for flexible and rigid cellular polymeric materials
- (b) ISO 1419 for coated fabrics
- (c) hydrolysis at standard temperature and pressure (STP) using the Arrhenius reaction rate function, which is illustrated in Fig. E-5.2.5.1-1

E-5.2.5.2 Aging due to UV Exposure. Nonmetallic materials that are subject to natural weathering with exposure to UV radiation (including sunlight) shall be tested using accelerated exposure methods in a manner commensurate with the foregoing. See ASTM D4364-05 or ISO 877-2-1991, Method C.

E-5.2.5.3 Other Aging Mechanisms. Materials that are subject to aging via a mechanism other than chronological or UV aging shall be addressed in a manner no less effective than those described in paras. E-5.2.5.1 and E-5.2.5.2.

E-5.2.5.4 Alternative Approaches. Other equally reliable approaches may be used, including the use of manufacturer's data on material aging.

E-5.2.5.5 Avoiding Aging. The effects of aging, other than chronological aging, may be avoided by prohibiting use of the PVHO under conditions that might degrade the materials used in the PVHO or by using a design that isolates susceptible materials from potentially damaging environmental conditions.

E-5.2.6 Nonmetallic Materials and Toxicity Off-Gas Testing. Off-gas testing shall be performed in accordance with section 1-10 of the PVHO-1 Standard.

E-5.2.7 Leakage and Pressure Drop Tests. All tests shall be performed using the same gas medium with which the PVHO is normally pressurized.

E-5.2.7.1 Maximum Allowable Pressure Drop Rate. In the event of a loss of the pressurization media and/or supply source during operation, the maximum allowable pressure drop rate shall not exceed 1 psi/min or otherwise compromise safety or result in distress of the occupants.

E-5.2.7.2 Pressure Drop Rate Test. The pressure drop rate of three prototype PVHOs shall be measured by pressurizing each PVHO to MAWP at room temperature. The supply of pressurizing media shall then be removed for a period of 15 min during which time the pressure drop rate is measured and recorded. A pressure drop rate exceeding that determined in para. E-5.2.7.1 shall be considered a failure.

E-5.2.8 Additional Prototype Joint Tests. At least two test coupons from each prototype chamber tested and for each type and size of joint, both homogeneous

and heterogeneous joints, shall be tested for peel/tear strength and elongation to break. The test pieces shall be tested in a manner that accurately represents the actual joint conditions experienced during prototype testing and use. The joint test pieces shall exhibit a minimum strength per inch of joint length at least equal to that of the actual joint during prototype testing as per para. E-5.2.1. The strength per inch of joint length of prototype joint test pieces shall be averaged, recorded, and used for comparison to the strength per inch of joint length of production PVHO joint test pieces. Testing shall be conducted at the most critical temperature(s) for which the PVHO is designed.

E-5.2.9 Folding Tests. Collapsible PVHOs shall be subjected to a folding test at room temperature. Folding for storage as well as unfolding and setup shall be performed per the manufacturer's instructions. The PVHO shall be set up as it would be for use, but the PVHO systems need not be attached unless they normally remain attached for storage.

This test begins with the PVHO folded for storage. The PVHO shall be unfolded, assembled, and set up as it would be for use. Parts that are opened or removed to permit ingress and egress of the occupant(s) shall be opened or removed. Once completely set up, the PVHO is then prepared and folded for storage.

The required number of folding test cycles is related to the PVHO's rated number of folding cycles and shall meet the following criteria:

- (a) PVHOs rated for 100 cycles or fewer: 175% of the PVHO's rated number of folding cycles
- (b) PVHOs rated for 101 to 1,000 cycles: 150% of the PVHO's rated number of folding cycles
- (c) PVHOs rated for 1,001 cycles or more: 125% of the PVHO's rated number of folding cycles

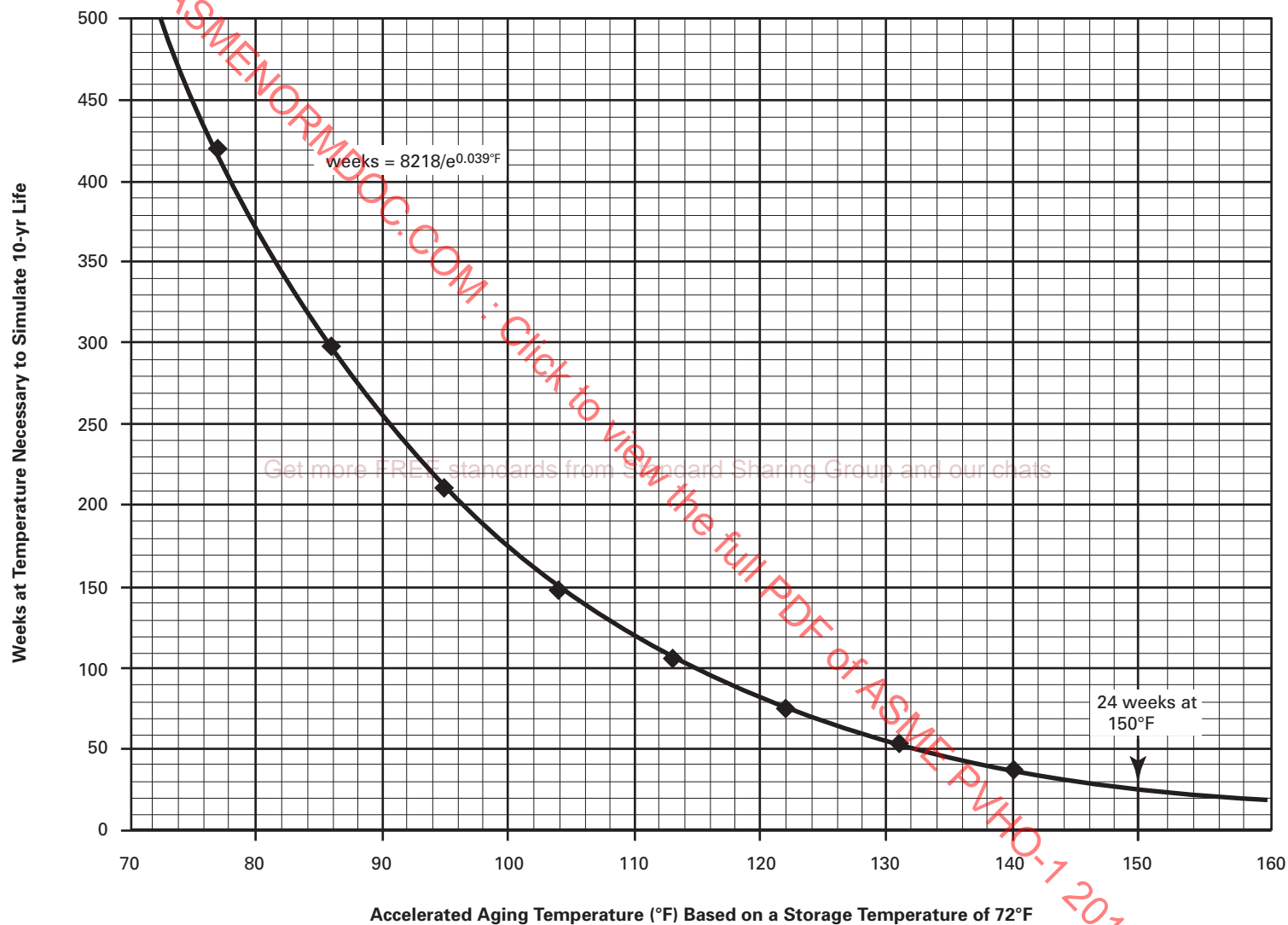
Upon completion of the folding and unfolding test cycles, the PVHO shall be pressurized to 1.5 times the MAWP and held for 15 min at room temperature. The PVHO shall then be pressurized to the MAWP using the same medium with which the PVHO is normally pressurized and held for a period of 15 min while the maximum flow rate of gas required to maintain MAWP is measured. The maximum flow rate measured shall not exceed the leakage rate obtained per para. E-5.2.7.2.

Finally, the chamber shall be inspected for any defects, delamination, wear, or fracture of the pressure boundary, parts that are opened or removed to permit ingress and egress of the occupant(s), or any pressure-resistant or structural component of the PVHO. No damage or permanent distortion of the PVHO is permissible.

E-5.2.10 Pressurized Drop Tests. Portable and transportable PVHOs shall be subjected to a pressurized drop test. The test shall be completed without failure.

Before testing, the PVHO shall be loaded with an evenly distributed load equal to the PVHO's rated occupant weight or 200 lb (90 kg), whichever is greater, using

Fig. E-5.2.5.1-1 Time Versus Test Temperature for Accelerated Aging Test



GENERAL NOTES:

- The accelerated aging temperature should not be greater than 150°F (max) and shall not exceed the material's glass transition temperature, melt temperature, or crystalline forming temperature (−30°F).
- From Karl J. Hemmerich, "General Aging Theory and Simplified Protocol for Accelerated Aging of Medical Devices," *Medical Plastics and Biomaterials Magazine* (originally published July 1998).

bagged sand. The PVHO shall then be pressurized to MAWP, inclined at 45 deg, elevated to a height such that the minimum distance from the lower end to a concrete impact surface is 3 ft (92 cm), and dropped. The pressurized chamber shall then be inclined such that the opposite end will be impacted and the test is repeated. No damage or permanent distortion of the PVHO is permissible.

The PVHO shall then be pressurized to the MAWP using the same medium with which the PVHO is normally pressurized and held for a period of 15 min while the maximum flow rate of gas required to maintain MAWP is measured. The maximum flow rate measured shall not exceed the leakage rate obtained per para. E-5.2.7.2 by more than 20%.

E-5.2.11 Handling Features of Portable and Transportable PVHOs. Portable and transportable PVHOs shall be subjected to a test of features intended for handling the PVHO while it is occupied. This test shall be performed while the PVHO is pressurized and loaded. The test shall be completed without failure.

Before pressurizing, the PVHO shall be loaded with an evenly distributed load equal to twice its rated occupant weight or 400 lb (180 kg), whichever is greater, using bagged sand. Based on the risk analysis required in para. E-2.8, this load shall be increased to account for the worst-case combination of acceleration forces, uneven loading, and other sources of increased load on any handling point(s).

The loaded PVHO shall then be pressurized to MAWP, raised off the floor by using the PVHO's normal handling feature(s), and held for 30 min. No damage or permanent distortion of the PVHO is permissible.

The PVHO shall then be pressurized to the MAWP using the same medium with which it is normally pressurized and held for a period of 15 min while the maximum flow rate of gas required to maintain MAWP is measured. The maximum flow rate measured shall not exceed the leakage rate obtained per E-5.2.7.2.

E-5.2.12 Other Design Qualification Tests. Other testing may be required specific to the intended use of the PVHO. The need for additional testing shall be based on the risk analysis required in section E-2.8.

Test procedures shall be adequate to detect the failures identified by the risk analysis.

E-5.3 Production Testing

E-5.3.1 Proof Pressure Testing. All production units shall be subjected to a hydrostatic or pneumatic test of 1.5 times the MAWP to be held for a minimum of 15 min.

E-5.3.2 Pressure Drop Rate Testing. A pressure drop rate test at MAWP shall be performed using the same medium with which the PVHO is normally pressurized. A pressure drop rate in excess of "normal" (see para. E-5.2.7.1) shall be cause for rejection of the PVHO.

The pressure drop rate for each production PVHO shall be measured by pressurizing each PVHO to MAWP at room temperature for a period of 15 min and measuring the pressure drop rate. A pressure drop rate exceeding that determined in para. E-5.2.7.1 shall be considered a failure.

Every PVHO shall be examined visually and dimensionally for damage following each test. Any signs of cracks, crazing, permanent deformation, or other signs of damage will be cause for rejection of the PVHO.

Tests shall be witnessed and documented by a qualified third party. The third party shall certify the test results and that they comply with the testing requirements of this Standard.

E-5.3.3 Joint Testing. All production PVHOs shall include sufficient joint run-on to provide at least two test coupons for each type of joint, both homogeneous and heterogeneous. If this is not practical, two test coupons shall be produced at the same time and by the same process(es) as the production PVHO and shall be subjected to identical treatment as the PVHO.

The two test coupons for each type of joint shall be tested for peel/tear strength and elongation to break. During testing, the test piece shall be held and loaded in the same manner as was done for the testing required in para. E-5.2.8. No test piece shall fail at a load less than 10% below the average load determined per para. E-5.2.8 for the type of joint tested. Testing shall be conducted at the same temperature(s) used in para. E-5.2.8.

E-5.4 Testing of PVHO Repairs

E-5.4.1 Prototype Repair Testing. Each repair specification documented per para. E-2.10 shall be fully prototype tested in accordance with section E-5 of this Appendix. Each repaired discrepancy tested shall be of the maximum scope permitted and shall be repaired in accordance with the repair procedure developed per para. E-2.10. More than one repaired discrepancy may be tested on a single prototype provided each discrepancy is located such that it does not influence the test results for any other repaired discrepancy. Testing may be performed using a previously tested prototype PVHO or a new PVHO.

The effects of aging shall be addressed as required in para. E-5.2.5. If repair of PVHOs that have aged prior to repair is permitted, the effects of that prior aging on the performance of the repair shall be accounted for.

E-5.4.2 Production Repair Testing. Following completion of all repairs, each repaired production PVHO shall be retested by subjecting it to the complete set of tests required for production PVHOs, including any tests that it might have previously passed.

E-6 DOCUMENTATION

E-6.1 General

As a minimum, documentation shall comply with this section. Documentation requirements shall be detailed in the Case.

All PVHOs shall be provided with documentation in accordance with this section, specific requirements in other sections of this Standard, and the Design Specification.

Where unusual design features are incorporated in a PVHO, comprehensive documentation at least equivalent to that required by the Standard shall be provided for those unusual design features. The documentation shall be prepared, provided to the user, and maintained by the manufacturer in a manner at least equivalent to that required in para. E-1.

E-6.2 Owner's Manual

A current Owner's Manual shall be provided with each PVHO. It shall contain normal and emergency operating procedures as well as adequate information to safely operate and maintain, including in-service inspection criteria for, the PVHO, PVHO systems, and any associated equipment.

The manual should consider the requirements of applicable jurisdictional authorities.

In addition to the items listed in the Design Specification, the manual shall include (as applicable)

- (a) an overview and functional description of the PVHO and its systems
- (b) procedures to operate the PVHO and its systems
- (c) emergency procedures
- (d) drawings and schematics necessary for the operation and maintenance of the PVHO systems
- (e) equipment documentation including maintenance requirements and operating instructions for components and equipment used; this may include a collection of vendor-supplied data, supplier-recommended maintenance procedures, and designer/fabricator/manufacturer-supplied data
- (f) systems description
- (g) cleaning and disinfecting procedures
- (h) suitable cleaning and disinfecting materials
- (i) operational check-off lists (lists shall include equipment requiring operational status verification or inspection prior to each dive/operation)
- (j) special restrictions based on uniqueness of the design and operating conditions
- (k) life-support systems descriptions including capacities
- (l) electrical system description
- (m) ballast system description
- (n) fire-suppression system description
- (o) launch and recovery operation procedures

(p) normal and emergency communications procedures

(q) emergency rescue plan

(r) emergency procedures for situations including, but not limited to, the following:

- (1) power failure
 - (2) break in umbilical cord (if applicable)
 - (3) deballasting/jettisoning
 - (4) loss of communication
 - (5) life-support system malfunction
 - (6) fire
 - (7) entanglement
 - (8) high hydrogen level (if applicable)
 - (9) high oxygen level
 - (10) high carbon dioxide (CO₂) level
 - (11) internal and external oxygen leaks
 - (12) being stranded on the bottom
 - (13) minor flooding
 - (14) specific emergency conditions (characteristic of special types of systems)
 - (15) loss of propulsion
 - (16) deteriorated surface conditions during a dive
- (s) storage requirements for the PVHO and its systems, subsystems, and associated equipment, including, but not limited to, the following:
- (1) maximum and minimum temperature limits
 - (2) maximum storage time limits, if applicable, for equipment including windows, batteries, and nonmetallic materials
 - (3) preservation requirements
 - (4) for gas storage and hydraulic systems, purging requirements and pressure settings
 - (5) special considerations for battery systems
 - (6) maintenance requirements
 - (7) reactivation considerations

E-7 MARKING

Marking requirements shall be included in each Case.

E-7.1 General

Each PVHO produced to this Standard shall have a label permanently attached to the outside of the PVHO, in a conspicuous location. That label shall be of a material suitable for the intended service and shall be marked in a manner that will remain legible and readable for the life of the vessel. The label markings shall be in characters not less than 0.25 in. (6.0 mm) high.

E-7.2 Marking and Attachment of Label

The label may be marked before it is affixed to the PVHO, in which case the manufacturer shall ensure that the label with the correct marking has been applied to the proper vessel.

E-7.3 Label Information

The label shall include the following:

(a) designation of this Standard, PVHO-1, Appendix E

(b) name of the manufacturer of the pressure vessel, preceded by the words "Certified by"

(c) maximum allowable working pressure, psig (MPa) at temperature range, °F (°C)

(d) manufacturer's serial number

(e) year built

(f) design life, yr

(g) design life, pressure cycles

(h) design life, folding cycles (for collapsible chambers)

(i) maximum occupant weight (for portable or transportable chambers, lb (kg))

(j) additional markings shall include the following:

(1) A QUALIFIED OPERATOR IS REQUIRED AT ALL TIMES WHEN THE PVHO IS OCCUPIED.

(2) DO NOT ALLOW OCCUPANTS TO BRING ANY HAZARDOUS ITEMS SUCH AS HAND WARMERS, ELECTRONIC DEVICES, ETC., INTO THE PVHO.

(3) PRESSURIZE WITH AIR ONLY.

(k) additional markings shall be included as required by the Design Specification

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NONMANDATORY APPENDIX F USEFUL REFERENCES

(16)

Codes, standards, specifications, and other references that may be useful to designers and users of PVHOs and PVHO systems, and the names and addresses of sponsoring organizations or publishers, are shown below.

System designers and builders are advised that PVHO systems may also need to comply with one or more of these references in accordance with jurisdictional and/or insurance requirements.

46 CFR 197B, Marine Occupational Safety and Health Standards, Commercial Diving Operations
MIL-H-2815: This document was canceled without replacement in 1997

Publisher: Superintendent of Documents, U.S. Government Publishing Office (GPO), 732 N. Capitol Street, NW, Washington, DC 20401 (www.gpo.gov)

ADC International Consensus Standards for Commercial Diving and Underwater Operations
Publisher: Association of Diving Contractors International (ADC), 5206 FM 1960 West, Suite 202, Houston, TX 77069 (www.adc-int.org)

ANSI NB23, National Board Inspection Code
Publisher: National Board of Boiler and Pressure Vessel Inspectors (NBBI), 1055 Crupper Avenue, Columbus, OH 43229 (www.nationalboard.org)

ASME B31.1, Process Piping
ASME B31.9, Building Services Piping
STP-PT-047, Principles of Safety and Performance for Medical Hyperbaric Chambers: Guidelines for Regulatory Submission
Publisher: The American Society of Mechanical Engineers (ASME), Two Park Avenue, New York, NY 10016-5990 (www.asme.org)

ASTM D621, Test Methods for Deformation of Plastics Under Load

ASTM D4364-05, Standard Practice for Performing Outdoor Accelerated Weathering Tests of Plastics Using Concentrated Sunlight

ASTM G94, Standard Guide for Evaluating Metals for Oxygen Service

Publisher: American Society for Testing and Materials (ASTM International), 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959 (www.astm.org)

DNV OSS 305, Rules for Certification and Verification of Diving Systems

Publisher: Det Norske Veritas (DNV), Veritasveien 1, 1322 Hovic, Norway (www.dnvusa.com)

IEC 60601-1, Medical Electrical Equipment, Part 1: General Requirements for Basic Safety and Essential Performance

Publisher: International Electrotechnical Commission (IEC), 3, rue de Varembe, Case Postale 131, CH-1211, Genève 20, Switzerland/Suisse (www.iec.ch)

IMCA D024, Design for Saturation Diving Systems

Publisher: International Marine Contractors Association (IMCA), 52 Grosvenor Gardens, London SW1W 0AU, United Kingdom (www.imca-int.com)

IMO Code of Safety for Diving Systems, IA808E

IMO MSC/Circ. 981, Guidelines for the Design, Construction, and Operation of Passenger Submersibles Craft
Publisher: International Maritime Organization (IMO), 202 Lambeth Road, London SE1 7JW, United Kingdom (www.imo.org)

ISO 877-2-1991, Method C, Methods of exposure to direct weathering, to weathering using glass-filtered daylight, and to intensified weathering using Fresnel mirrors

ISO 1419, Rubber- or plastics-coated fabrics—Accelerated-ageing tests

ISO 2440, Flexible and rigid cellular polymeric materials—Accelerated ageing tests

Publisher: International Organization for Standardization (ISO), Central Secretariat, Chemin de Blandonnet 8, Case Postale 401, 1214 Vernier, Geneva, Switzerland (www.iso.org)

NASA-STD-6001B, Technical Standard: Flammability, Offgassing, and Compatibility Requirements and Test Procedures

NASA Technical Bulletin 104823, Guide for Oxygen Hazards Analyses on Components and Systems

Publisher: National Aeronautics and Space Administration (NASA), Center for Aerospace Information, 800 Elkridge Landing Road, Linthicum Heights, MD 21090-2934 (www.nasa.gov)

NFPA 53, Recommended Practice on Materials, Equipment, and Systems Used in Oxygen-Enriched Atmospheres

NFPA 99B, Standard for Hypobaric Facilities
NFPA 701, Standard Methods of Fire Tests for Flame
Propagation of Textiles and Films

Publisher: National Fire Protection Association (NFPA),
1 Batterymarch Park, Quincy, MA 02169
(www.nfpa.org)

Rules and Regulations for the Construction and
Classification of Submersibles and Underwater
Systems

Publisher: Lloyd's Register EMEA, 5th Floor, Cunard
Building, Water Street, Liverpool L3 1EG, United
Kingdom (www.lr.org)

Rules for Building and Classing Underwater Vehicles,
Systems and Hyperbaric Facilities

Publisher: American Bureau of Shipping (ABS), 16855
Northchase Drive, Houston, TX 77060
(www.eagle.org)

Rules for Classification and Construction — Part 5:
Underwater Technology

Publisher: Germanischer Lloyd AG, Vorsetzen 35, 20459
Hamburg, Germany (www.gl-group.com/en)

Technical Report R512, "Windows for External or
Internal Hydrostatic Pressure Vessels — Part I," J. D.
Stachiw and K. O. Gray, 1967

Technical Report R527, "Windows for External or
Internal Hydrostatic Pressure Vessels — Part II," J. D.
Stachiw et al., 1967

Technical Report R631, "Windows for External or
Internal Hydrostatic Pressure Vessels — Part III,"
J. D. Stachiw and F. Brier, 1969

Publisher: Naval Civil Engineering Laboratory, Port
Hueneme, California

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PVHO Case 8
Alternative Testing Requirements for Large Subatmospheric Pressure PVHO Chambers

Approval Date: April 30, 2007

This Case has been incorporated into the requirements of the PVHO-1 Standard.

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PVHO Case 10

Use of Clear Plastic Viewport Retaining Covers in Lieu of Metallic Retaining Rings

Approval Date: December 20, 2006

Reaffirmation Date: May 26, 2015

Expiration Date: May 26, 2021

Inquiry: As an alternative to para. 2-2.11.5, is it possible to use clear plastic viewport retaining covers in lieu of metallic retaining rings?

Reply: It is the opinion of the Committee that for O-ring-sealed flat disk and conical frustum standard-geometry PVHO windows in applications where reverse pressure on the viewport window is not possible and the design pressure is less than 135 psig, clear viewport retaining covers may be used provided the following provisions are met:

(a) The thickness of the clear viewport retaining cover shall not be less than 0.25 in. (6 mm) or $0.025D_o$, whichever is greater.

(b) Where retaining screws are used to secure the clear viewport retaining cover, the clearance holes between

the retaining screws and cover shall be large enough to compensate for thermal expansion and contraction of the cover material. Flat washers should be used between the screw head and clear viewport retaining cover.

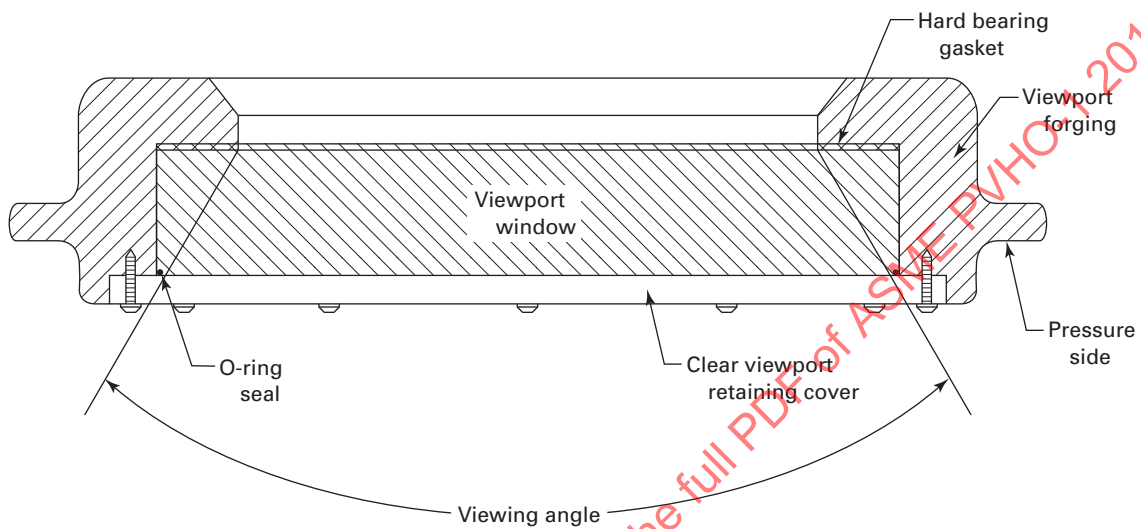
(c) Provision shall be made for equalizing the pressure between the clear viewport retaining cover and viewport window [e.g., a small $\frac{1}{16}$ -in. (1.6-mm) diameter hole located in the cover inside the O-ring seal diameter].

(d) Acrylic plastic (per ASTM D4802-02 or equivalent) and clear polycarbonate plastic (per ASTM C1349-04 or equivalent) are acceptable materials for clear viewport retaining covers.

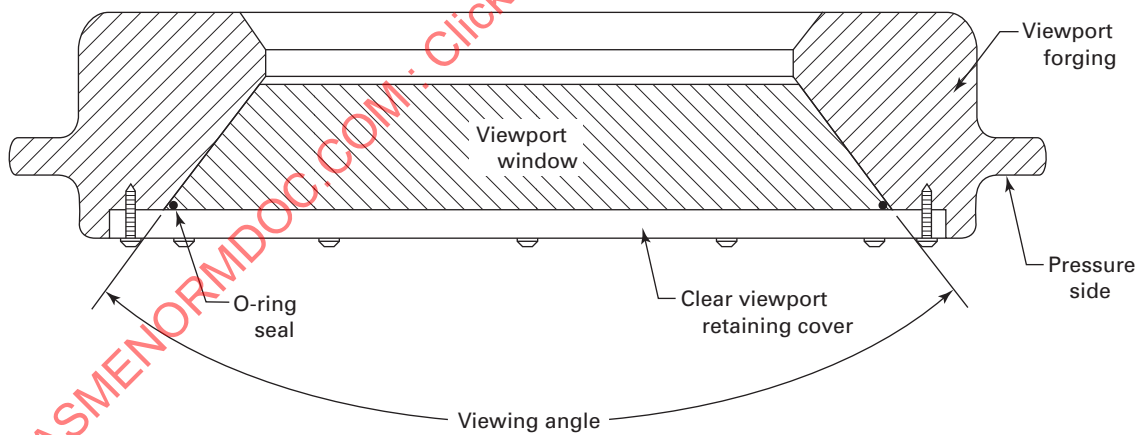
(e) The requirements of paras. 2-2.11.3, 2-2.11.4, 2-2.11.6, and 2-2.11.7 of ASME PVHO-1-2007 apply to clear viewport retaining covers.

(f) Figure 10-1 depicts acceptable configurations for clear viewport retaining covers.

Fig. 10-1 Acceptable Configurations for Clear Viewport Retaining Covers



(a) Flat Disk Viewport Cross Section



(b) Conical Frustum Viewport Cross Section

PVHO Case 11

Use of Nonmetallic Expansion Joint

Approval Date: August 13, 2007

Reaffirmation Date: July 28, 2015

Expiration Date: July 28, 2021

Inquiry: Under what conditions may a ring-reinforced elastomer expansion joint be used as a diving system component in construction under the rules of PVHO-1–2012?

Reply: It is the opinion of the Committee that a ring-reinforced elastomer expansion joint may be constructed under the requirements of PVHO-1–2012 as a diving system component, and be marked as a PVHO-1 pressure vessel part in accordance with PVHO-1–2012, when the requirements of PVHO-1–2012, with the exceptions in the paragraphs below, have been met.

1 GENERAL

1.1 Requirements

(a) The maximum allowable working pressure (MAWP) is 80 psig (0.55 MPa).

(b) The expansion joint will conform to the following configuration, shape, and dimensions: single wide arch unfilled elastomer expansion joint, 30 in. (762 mm) internal diameter, 12 in. (305 mm) overall length, flange-end connections in accordance with ASME B16.1, Class 125, standard expansion joint flanges.

(c) No windows or penetrators are permitted.

(d) The expansion joint serves as a transit (i.e., trunk/tunnel) between other pressure vessels and can permit passage for only one occupant at a time.

(e) The temperature design limits are 0°F to 110°F (–17.8°C to 43.3°C) operational, and 0°F to 150°F (–17.8°C to 65.6°C) nonoperational.

(f) The design and service life is 5 yr from date of manufacture.

(g) The design number of pressure cycles is 1,250.

(h) The design number of displacement fatigue cycles is 50,000.

(i) The minimum ratio of proof pressure to rated pressure (MAWP) is 6:1.

(j) In-service use shall be ventilated with breathing-quality air.

(k) The expansion joint shall only be used in a system that is pressure relieved in accordance with PVHO-1–2012, subsection 1-8.

(l) The maximum flange-to-flange relative displacement is shown in Table 11-1.

Table 11-1 Maximum Flange-to-Flange Relative Displacement

Type	Movement Capability From Neutral Position
Axial compression	0.434 in.
Axial extension	0.936 in.
Lateral deflection	0.452 in.
Angular deflection	1.207 deg
Torsional rotation	0.116 deg

GENERAL NOTE: Movements are defined in the *FSA Technical Handbook*.

1.2 Standards

The expansion joint shall meet all requirements of ASTM F1123-87, Standard Specification for Non-Metallic Expansion Joints; the *Fluid Sealing Association (FSA) Technical Handbook, Non-Metallic Expansion Joints and Flexible Connectors*, sixth edition; and the requirements as specified herein.

2 MATERIALS

All of the materials shall be used in combination to meet the performance requirements of this Code Case. A Process Control Procedure in accordance with para. 5.7 shall identify how the materials are to be used and in what specific quantities.

All materials shall be verified by the purchaser/owner/user and/or by an independent third-party agency designated by them. All materials used in the manufacture of the expansion joint shall be supplied with documentation certifying that each lot used in the manufacture of the expansion joint meets those properties listed. In lieu of the requirements of PVHO-1–2012, subsection 1-6, the requirements in the following paragraphs shall apply. Materials shall conform to the following standards.

2.1 Commercial-Grade Fluoroelastomer

Compound: THD-VT75-10

Material: Fluoroelastomer compound

Temperature Limitations: Typical maximum usable temperature of 392°F (200°C)

Test Requirements:

Physical Properties per ASTM D412

Requirements	Minimum	Maximum
Tensile at break, psi	700	N/A

Physical Properties per ASTM D224

Requirements	Minimum	Maximum
Durometer Shore "A"	65	75

Aged Physical Properties per ASTM D573
Aged 24 hr at 450°F

Requirements	Minimum	Maximum
Tensile at break, psi	1,250	N/A

2.2 Neoprene N4614

Material: Neoprene N4614

Temperature Limitations: Typical maximum usable temperature of 212°F (100°C)

Test Requirements:

Physical Properties per ASTM D412

Requirements	Minimum	Maximum
Ultimate elongation, %	650	N/A

Physical Properties per ASTM D224

Requirements	Minimum	Maximum
Durometer Shore "A"	35	45

Shelf Life: Neoprene N4614 shall be used within 6 weeks after it is calendered

2.3 Neoprene N5157

Material: Neoprene N5157

Temperature Limitations: Typical maximum usable temperature of 212°F (100°C)

Test Requirements:

Physical Properties per ASTM D412

Requirements	Minimum	Maximum
Tensile at break, psi	1,800	N/A
Ultimate elongation, %	475	N/A

Physical Properties per ASTM D573

Requirements	Minimum	Maximum
Durometer Shore "A"	50	60

Shelf Life: Neoprene N5157 shall be used within 6 weeks after it is calendered

2.4 Neoprene N8017

Material: Neoprene N8017

Temperature Limitations: Typical maximum usable temperature of 212°F (100°C)

Test Requirements:

Physical Properties per ASTM D412

Requirements	Minimum	Maximum
Tensile at break, psi	1,450	N/A
Ultimate elongation, %	100	N/A

Physical Properties per ASTM D224

Requirements	Minimum	Maximum
Durometer Shore "A"	80 ± 5	N/A

Shelf Life: Neoprene N8017 shall be used within 6 weeks after it is calendered

2.5 Neoprene N4957

Material: Neoprene N4957

Temperature Limitations: Typical maximum usable temperature of 212°F (100°C)

Test Requirements:

Physical Properties per ASTM D412

Requirements	Minimum	Maximum
Tensile at break, psi	1,200	N/A
Ultimate elongation, %	500	N/A

Physical Properties per ASTM D224

Requirements	Minimum	Maximum
Durometer Shore "A"	45	55

Aged Physical Properties per ASTM D573
Aged 70 hr at 212°F (100°C)

Requirements	Minimum	Maximum
Tensile at break, psi	960	N/A
Ultimate elongation, %	325	N/A

Flame Resistance per MIL-E-15330D (SH)

Requirements	Minimum	Maximum
Afterglow, sec	N/A	4

Shelf Life: Neoprene N4957 shall be used within 6 weeks after it is calendered

2.6 Polyester DD1500

Material: Polyester DD1500

Temperature Limitations: Typical maximum usable temperature of 350°F (176°C)

Test Requirements:

Requirements	Minimum	Maximum
Thread count, epi, warp	26	30
Tensile (denier): warp	44	N/A

2.7 Polyester DD1200

Material: Polyester DD1200

Temperature Limitations: Typical maximum usable temperature of 400°F (204°C)

Test Requirements:

Requirements	Minimum	Maximum
Thread count, epi, warp	17	19
Tensile (denier): warp	500	N/A

2.8 Flange Tie-Down, Steel Cord JZ #5

Material: Steel tire cord

Temperature Limitations: Typical maximum usable temperature of 250°F (121°C)

Test Requirements:

Requirements	Minimum	Maximum
Thread count, epi	16	20
Adhesion, lb	15	N/A

Physical Properties:

Requirements	Minimum	Maximum
Tensile at break, lb per 1-in. strip	71	N/A

2.9 Body Rings

Material Properties: ASME SA-695 Grade 40, minimum yield strength 60,000 psi (413.8 MPa)

Ring Sizes: $\frac{5}{8}$ in. (16 mm) thickness diameter body ring with $31\frac{13}{16}$ in. (808 mm) ring diameter, 2 each per expansion joint; $\frac{3}{4}$ in. (19 mm) thickness diameter body ring with $31\frac{15}{16}$ in. (811 mm) ring diameter, 2 each per expansion joint

3 DESIGN AND MANUFACTURE**3.1 Design**

The expansion joint shall be designed in accordance with the requirements of ASTM F1123-87, Standard Specification for Non-Metallic Expansion Joints, and the *FSA Technical Handbook, Non-Metallic Expansion Joints and Flexible Connectors*, sixth edition. There shall be no window(s), penetrations, or piping associated with this design. The end flanges shall have internal reinforced flanges as an integral part of the shell, and the fluoroelastomer shall be sealed to the internal surface of the expansion joint.

3.2 Requirements

In lieu of the requirements of PVHO-1-2012, subsection 1-7, the following design and fabrication requirements shall apply:

(a) A detailed stress analysis of the metallic portion shall be performed by a Professional Engineer registered in one or more U.S. states or the provinces of Canada, or licensed by any other country that has equivalent licensing procedures, who is experienced in composite pressure vessel design and construction.

(b) A design analysis shall be performed that considers the effects of aging and all applicable environmental considerations (both operational and nonoperational), the effects of minimum and maximum temperatures, time under pressure, cyclic movements, and long-term storage between usages.

3.3 Design Certification

Conformance of the design of the expansion joint to the requirements of PVHO-1-2012 shall be established by one of the two following procedures:

(a) A Professional Engineer registered in one or more U.S. states or the provinces of Canada, or licensed by any other country that has equivalent licensing procedures, who is experienced in composite pressure vessel design, shall certify that the expansion joint was designed either by him or under his direct supervision, or that he has thoroughly reviewed a design prepared by others, and that to the best of his knowledge, the expansion joint complies with PVHO-1-2012 as modified by this Case.

(b) The design of the expansion joint shall be reviewed by an independent third-party agency competent in PVHO systems, and such organization shall provide a certificate verifying that the expansion joint complies with PVHO-1-2012 as modified by this Case.

3.4 Manufacture

The expansion joint shall be manufactured in accordance with a detailed process control plan. The process control plan shall clearly define the details of the manufacturing steps necessary to fabricate the expansion joint and shall document the fabrication process.

The manufacture of the expansion joint shall meet the requirements of ASTM F1123-87, Standard Specification for Non-Metallic Expansion Joints, and the *FSA Technical Handbook, Non-Metallic Expansion Joints and Flexible Connectors*, sixth edition.

The steel ring portion of the expansion joint shall be welded in accordance with the weld procedures, procedure qualifications, and welder qualifications outlined in Section IX of the ASME Boiler and Pressure Vessel Code (the Code).

Nondestructive examination of the ring welds shall be 100% radiograph inspection, in accordance with Section V, Nondestructive Examination, of the ASME Code.

4 TESTING

All tests shall be witnessed by the purchaser/owner/user and/or by an independent third-party agency designated by them. In lieu of the requirements of PVHO-1-2012, paras. 1-7.7 and 1-7.8, the following requirements shall apply.

4.1 Prototype Testing

(a) A proof pressure test shall be performed on at least three completely assembled expansion joints of the same design, shape, and form. If a failure of the vessel occurs under proof pressure testing, the failure shall occur above a pressure equal to or greater than 6 times the rated pressure. Failure shall be defined as a rupture in the body or flange of the expansion joint causing a loss in pressure.

(b) A cyclic pressure/deformation test of at least one completely assembled expansion joint shall be conducted for a minimum of 4,500 cycles. This test shall qualify the expansion joint for 1,250 cycles; 50% of the test cycles shall be performed at the minimum temperature (0°F, -18°C), and 50% of the test cycles shall be performed at the maximum temperature (110°F, 43°C). The test shall include pressurization from zero to the rated pressure and back to zero. The cycle rate time shall be established by conducting cycle testing for 10 cycles at maximum and minimum test temperatures and pressures. The test shall confirm the time required for the expansion joint to stabilize at both the high- and low-pressure values of the cycle test. The pressure hold times shall be either 1.5 times the stabilization time or 1 min, whichever is greater. Failure is defined as a rupture in the body or flange of the expansion joint causing a loss in pressure.

(c) A movement fatigue test of at least one completely assembled expansion joint shall be conducted for a minimum of 50,000 movement cycles. The test shall include a movement fatigue test at the MAWP, and shall include testing at both the maximum and minimum temperatures during the testing; 80% of the movement cycles shall be tested at normal room temperature (65°F to 75°F, 18°C to 23°C), 10% of the movement cycles shall be tested at the minimum temperature (0°F, -18°C), and 10% of the movement cycles shall be tested at the maximum temperature (110°F, 43°C). The fatigue test shall be conducted with the maximum expansion joint movements in a concurrent fashion. Failure is defined as a rupture in the body or flange of the expansion joint, causing a loss in pressure. Movement cycles shall be as defined in the *FSA Technical Handbook of Non-Metallic Expansion Joints*, sixth edition, Chapter III, Section J.

(d) A creep test of one completely assembled expansion joint shall be conducted at maximum temperature for a minimum of 300 hr using the following criteria:

A straight line shall be plotted using semi-log coordinates, with pressure as the y -axis and the log time as the x -axis. One coordinate on the line shall be 720 psi (5 MPa) plotted at 0.1 hr. The other coordinate shall be 240 psig (1.65 MPa) plotted at 40,000 hr. A straight line shall be drawn through these two points. The test pressure and test duration shall exceed the pressure and time defined by that line, with the test duration being at least 300 hr.

(e) An off-gas test of one completely assembled expansion joint shall be conducted at maximum operational temperature in accordance with subsection 1-10 of ASME PVHO-1-2012, with a 12-hr storage period. The dilution effect of the entire PVHO assembly shall be considered. The dilution volume of the PVHO assembly consists of the expansion joint and any additional volumes that cannot be isolated. An independent third-party agency shall be employed to ensure that the test results are less than the established limits.

4.2 Production Testing

(a) Every expansion joint shall be subjected to a hydrostatic test at a pressure of 1.5 times the rated pressure and held for a period of 1 hr without leakage.

(b) Every expansion joint shall be inspected for damage to the sealing areas and shall be subjected to a dimensional check. Any permanent change shall be grounds for rejection.

(c) Every expansion joint shall be subjected to an off-gas test as stated in para. 4.1(e).

5 QUALITY ASSURANCE PROGRAM

5.1 General

A documented Quality Assurance Plan (QAP) shall be developed for the design and manufacture of the expansion joint. The QAP shall be reviewed and approved by the purchaser. This section describes the requirements for the content of the QAP. In addition to the QAP, quality assurance shall meet the requirements of Section 3 of ASME PVHO-1-2012, Quality Assurance for PVHO Manufacturers.

5.2 Organization

The QAP shall describe the organizational structure, with responsibilities, authorities, and lines of communication clearly delineated. Persons shown in the QAP to be responsible for verifying the expansion joint quality shall have the authority and organizational freedom to

- (a) identify problems affecting quality
- (b) initiate, recommend, or provide solutions to quality problems, through designated channels
- (c) verify implementation of solution
- (d) control further processing, delivery, or assembly of a nonconforming item, deficiency, or unsatisfactory condition until proper corrective action has been taken

5.3 Design Control

A methodical process shall be used to develop and control the expansion joint design, which includes

- (a) a process for design inputs and review
- (b) a requirement for formal design review
- (c) a process for product configuration management and change control

5.4 Document Control

The QAP shall describe the manufacturer's measures for ensuring that design output documents are correctly translated into manufacturing specifications, drawings, procedures, and shop/lab instructions. Considerations shall be made for reviews and approvals, including those of the purchaser.

The manufacturer shall include the procedure for ensuring distribution of appropriate documents to the working areas in a timely fashion and the process for ensuring nonuse of obsolete documents.

5.5 Procurement Control

The QAP shall include the controls necessary to ensure that applicable requirements are included in procurement documents. The manufacturer shall describe the basis for source evaluation and selection and the method of objective evaluation of the quality of furnished materials, items, and services upon receipt.

5.6 Material Control

The QAP shall describe the identification applied to material and items upon receipt and shall show that this identification shall remain until the material or item is incorporated into the expansion joint. Identification shall be such that the manufacturer's personnel can easily determine quality status, material or item type, specification, lot or part as appropriate, and job number.

All material properties of production units shall meet or exceed the actual material properties of the prototype test articles.

5.7 Process Control

The QAP shall include a Process Control Procedure that will record the identification of materials and items incorporated into the expansion joint and each chronological step in its manufacture, including inspection and test steps. The Process Control Procedure shall contain periodic operator and inspector signature points so that product status can be readily determined.

The manufacturer shall identify critical manufacturing activities and ensure that they are accomplished by appropriately trained and qualified personnel. Inspection points shall follow the activities in the process control plan.

5.8 Inspection Control

The QAP shall include the measures used by the manufacturer to ensure that inspections are reliable. These measures shall include

- (a) proper qualification of inspection personnel
- (b) calibration of inspection instrumentation
- (c) incorporation of acceptance criteria into inspection points in the Process Control Procedure
- (d) assurance that inspections are performed by persons other than those performing or supervising work
- (e) documentation of all inspections

5.9 Test Control

The QAP shall describe the measures used to ensure that tests (including lab tests) are performed consistently and reliably. The following requirements shall be met:

- (a) Tests shall be performed in accordance with written instructions stipulating acceptance criteria.
- (b) Test results shall be documented.
- (c) Examination, measurement, and testing equipment used for activities affecting quality shall be controlled, calibrated, and adjusted at specified periods to maintain required accuracy.
- (d) Tests shall be performed by trained and qualified personnel.
- (e) Tests shall be verified by persons other than those performing or supervising the test.

5.10 Control of Measuring Test and Inspection Equipment

The QAP shall describe the equipment used in inspections and tests and the measures used to ensure appropriate accuracy. Appropriate equipment shall be calibrated, and the calibration shall be traceable to standards where they exist. Where such standards do not exist, the equipment manufacturer's recommendations shall be followed.

5.11 Control of Nonconforming Items/Materials

The QAP shall describe the measures used by the manufacturer to control materials or items that are found to be discrepant to prevent their inadvertent use. Nonconforming materials/items shall be identified. The discrepant condition(s) shall be documented. The process for determining, documenting, and verifying corrective action shall be described, including the involvement of the purchaser.

5.12 Quality Assurance Records

The QAP shall provide for quality assurance records as follows:

- (a) Records shall be specified, compiled, and maintained to furnish documentary evidence that services, materials, and completed expansion joints meet this and applicable referenced standards.
- (b) Records shall be legible, identifiable, and retrievable.
- (c) Records shall be protected against damage, deterioration, or loss.
- (d) Requirements and responsibilities for record transmittal, distribution, retention, maintenance, and disposition shall be established and documented.
- (e) Records required for traceability shall be retained for a minimum of 12 yr.

5.13 Standard Repair Planning

The QAP shall describe methods for repairing discrepancies that are expected to occur during the expansion joint manufacture.

5.14 Quality Assurance Overview by an Independent Third Party

An independent third-party agency shall be employed to ensure that all expansion joints intended to be classified under this Case are designed and manufactured to the requirements of PVHO-1-2012 and this Case. This includes, but is not restricted to, the following:

(a) The expansion joint is designed in accordance with PVHO-1-2012 and this Case.

(b) The manufacturer is working to the requirements of the quality control system.

(c) The materials used in construction of the expansion joint comply with approved procedures by qualified operators, as required by PVHO-1-2012 and this Case.

(d) All manufacturing operations are conducted in accordance with approved procedures by qualified operators, as required in PVHO-1-2012 and this Case.

(e) All defects are acceptably repaired.

(f) All prototype and production testing has been performed and witnessed as required by PVHO-1-2012 and this Case.

(g) The expansion joint is marked in accordance with PVHO-1-2012 and this Case.

(h) A visual inspection of the expansion joint is conducted to confirm that there are no material or dimensional defects.

The manufacturer shall arrange and give the third-party inspection agency free access to all facilities associated with the manufacture of the expansion joint. The manufacturer shall keep the third-party inspection agency informed of the progress of the work and shall notify them reasonably in advance when expansion joints will be ready for any required tests or inspections.

6 MARKING

(a) The PVHO shall be marked with a neoprene nameplate containing the data stated in subsection 1-9 of PVHO-1-2012. The nameplate shall be permanently vulcanized into the expansion joint at the completion of the manufacturing process.

(b) PVHO-1 Case 11 Form, Manufacturer's Data Report for Pressure Vessels for Human Occupancy, shall be completed to certify that each expansion joint meets the requirements of PVHO-1-2012 and this Case.

PVHO-1 Case 11 Form Manufacturer's Data Report for Pressure Vessels for Human Occupancy

<i>(Completed by Manufacturer)</i>		
1. Manufactured and certified by	_____	
2. Manufactured for	_____	
3. Vessel identification	_____	_____
	(manufacturer's serial no.)	(year built)
4. The design, construction, workmanship, and chemical and physical properties of all parts meet the applicable material specifications of PVHO-1- _____ (year) and Addenda _____ (date) and Case Nos. _____.		
5. Manufactured for a maximum allowable working pressure of 80 psi, a maximum working temperature of _____ °F, and a hydrostatic test pressure of _____ psi (internal).		
6. Design analysis conducted by	_____	
7. Manufacturing Process Control Plan	_____	_____
	(manufacturing no.)	(date)
		(completed by)

THIRD-PARTY CERTIFICATION	
<i>(Completed by Third-Party Representative)</i>	
User's Design Specification on file at	_____
Manufacturer's Design Report on file at	_____
Prototype test program attested by	_____
Quality Assurance Plan reviewed by	_____
	(name and date)
Fabrication documentation reviewed by	_____
	(name and date)
Production testing witnessed by	_____
	(name and date)

CERTIFICATION OF COMPLIANCE	
We certify that the statements made in this report are correct and that all details of the design, material, construction, and workmanship and marking of this vessel conform to the ASME Safety Standard for Pressure Vessels for Human Occupancy (PVHO-1) and PVHO Case 11.	
Date _____	Signed _____

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PVHO Case 12

Use of Nonmetallic Braid-Reinforced Flexible Membrane Vessels Under PVHO-1–2012

Approval Date: March 1, 2009
Reaffirmation Date: September 21, 2015
Expiration Date: September 21, 2021

Inquiry: Under what conditions may portable nonmetallic braid-reinforced flexible membrane hyperbaric stretchers and/or treatment systems be used in construction under the rules of PVHO-1–2012?

Reply: It is the opinion of the Committee that portable nonmetallic braid-reinforced flexible hyperbaric stretchers and/or treatment systems may be constructed under the requirements of PVHO-1–2012 and be marked as a PVHO when the requirements of PVHO-1–2012 with the following exceptions and additions have been met.

NOTE: Case 12 was originally approved in 2009 under the rules of PVHO-1–2007. Revisions made to section 6 of this Case have allowed compliance with PVHO-1–2012.

1 GENERAL

This Case covers a range of similarly designed and constructed PVHOs. The PVHOs may be of different shapes and sizes and have different pressure ratings depending on their application. The parameters are limited to those listed below.

The flexible PVHOs shall each comprise a braided liquid crystal polymer (LCP) fiber tube [Fig. 12-1(b)] enclosing a pressure-retaining membrane of impermeable polyurethane-coated nylon [Fig. 12-1(c)]. The membrane is rigidly attached to a number of segmented aluminum clamp plates [Fig. 12-1(d)] at each end of the tube. The LCP fiber tube and coated nylon membrane are totally enclosed in a reinforced fire-retardant, polyurethane-coated nylon outer cover [Fig. 12-1(a)] to protect the tubes from normal wear and tear and ultraviolet exposure (sunlight), as well as for retaining the lifting straps in position.

The braided LCP tube also encloses two flexible LCP fiber rings [Fig. 12-1(f)], one at each end of the tube, outboard of the clamp plates. The flexible LCP fiber rings and clamped membrane are sufficiently flexible to allow for the patient to enter and exit the PVHO, as well as for insertion and removal of the end closures. The end closures comprise acrylic spherical sector windows [Fig. 12-1(g)] set in nylon protection rings [Fig. 12-1(e)] that are suitably shaped to engage with the pressure-retaining membrane. Services to the PVHO are provided through an aluminum penetrator plate, centrally positioned in one end closure. The other end may be fitted with a medical lock or an additional penetrator plate.

The PVHOs and associated systems shall be designed, constructed, inspected, tested, marked, and installed (if applicable) to PVHO-1–2012, Sections 1, 2, 3, 4, 5, and 6 (as applicable), with exceptions and additions detailed in this Case.

All PVHOs shall fall within one of the categories in Table 12-1 depending on their size, number of occupants, maximum allowable working pressure (MAWP), service, and gas outlets/built-in breathing system (BIBS).

The following design and performance criteria shall also apply:

- (a) The MAWP shall not exceed 75 psig (0.52 MPa).
- (b) The outside diameters of the PVHOs shall be between 23 in. and 48 in. (58.5 cm and 122 cm).
- (c) The maximum length shall not exceed 120 in. (305 cm).
- (d) The vessel shall have removable end closures, incorporating windows.
- (e) The design number of pressure cycles shall not exceed 4,000 cycles.
- (f) The life of the flexible tube and end closure assemblies shall be 10 yr from the date of manufacture or on completion of the allowable number of pressure cycles stated in section 6 of this Case, whichever is achieved first.
- (g) The design operating temperature range shall be from 0°F to 100°F (–18°C to 38°C).
- (h) The design storage temperature shall range from –10°F to +150°F (–23°C to +66°C) using the storage cases supplied with the PVHO.
- (i) The pressurizing gas shall only be air, and a label to this effect shall be suitably displayed.
- (j) The breathing gases, oxygen or air, shall be supplied to the occupant(s) of the PVHOs through BIBS masks or hoods. The operator shall select the breathing gas supply from the external control box. The operator shall also ensure that sufficient gases are available for flushing the PVHO if necessary and there shall be sufficient emergency gas supplies to complete the proposed treatment safely. All exhaled gases shall leave the PVHO via an overboard dump.
- (k) All PVHOs shall have fire protection as specified in the relevant section of PVHO-1–2012 (Sections 5 and 6).

Fig. 12-1 Typical Configuration

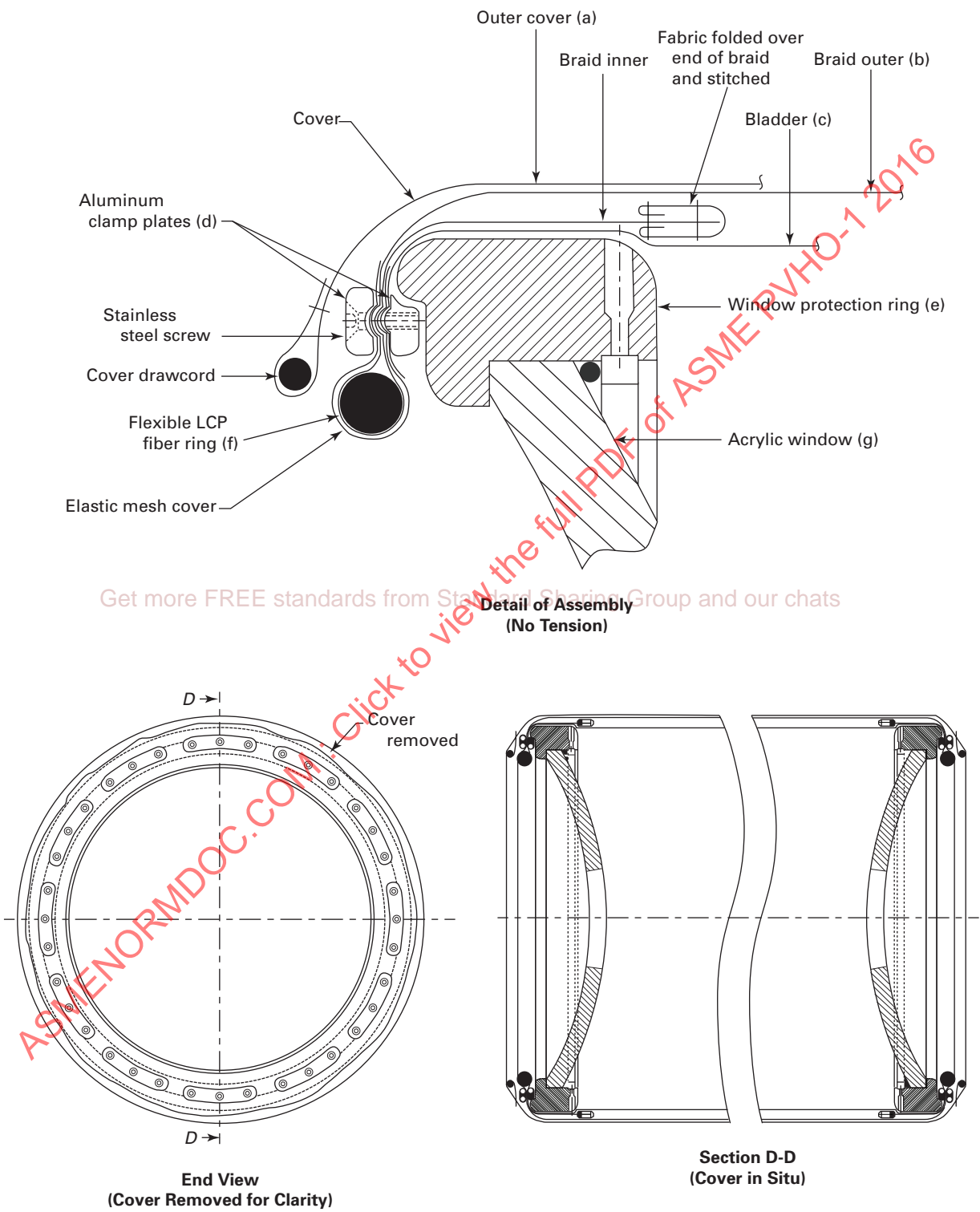


Table 12-1

Diameter Range, in.	Maximum Number of Occupants	MAWP Range, psig	PVHO Service	Breathing Gas Outlets
23–30	One	33.5–75	Diving (Section 6) and Medical (Section 5)	1
30–48	One	33.5	Diving (Section 6) and Medical (Section 5)	1
36–48	Two	33.5	Diving (Section 6) only	2

(l) All two-occupant PVHOs shall carry a hyperbaric fire extinguisher.

A User's Design Specification shall be developed or provided for each model.

2 MATERIALS

Materials shall meet PVHO-1–2012, subsection 1-6 with the exception of the flexible tube that shall conform to Table 12-2 (see also Table 12-3). All of the materials of the flexible tube shall be used in combination to meet the performance requirements of this Case. A Process Control Procedure in accordance with para. 5.7 shall identify how the materials are to be used and in what specific quantities.

All materials used in the manufacture of the flexible tube shall be supplied with supporting documentation consistent with the requirements of the Quality Management System detailed in section 5 of this Case. Each lot used in the manufacture of the flexible tube shall meet those properties listed.

Material shelf life shall be identified as being suitable for long-term storage between uses and shall not exhibit visual or performance deterioration through aging for the entire life of the PVHO. The PVHO shall be stored in cases that meet the sealing requirements of IP67 and DEF STAN 81-41.

3 DESIGN AND MANUFACTURE

3.1 Design

The PVHO and associated systems shall be designed in accordance with PVHO-1–2012 and this Case.

3.2 Requirements

In subsection 1-7 of PVHO-1–2012, the design and manufacture of the PVHO and associated systems shall only be in accordance with paras. 1-7.4 to 1-7.11 and the following requirements:

(a) A detailed stress analysis shall be performed by a Professional Engineer registered in one or more U.S. states or the provinces of Canada, or licensed by any other country that has equivalent licensing procedures, who is experienced in composite pressure vessel design and construction.

(b) The stress analysis shall include full geometric modeling and a detailed finite element analysis of the PVHO and the flexible tube-to-window interface during assembly and disassembly, and under varying pressures up to a minimum of 6 times the MAWP. The loads applied by lifting handles, straps, and slings, as well as the position and weight of the occupants, shall be considered.

(c) The design analysis shall consider the effects of aging of the tube materials plus the effects of folding, unfolding, and long-term storage of the components. The design shall ensure that no damage will occur to any of the tube components by acute bending or by bending at less than the minimum bend radius for each component. Acute bending is defined as a bend in the LCP braid or the flexible membrane at an inside angle of less than 5 deg. The minimum bend radius for the fiber or flexible membrane shall be no less than 0.05 in. (1.25 mm).

(d) There shall be no penetrations in the pressure-retaining section of the flexible tube of the PVHO.

(e) The design and manufacturing process shall produce a flexible tube such that the assembly will not be damaged by the assembly process, pressurization, disassembly, or storage of the PVHO.

(f) The MAWP shall be the lesser of 75 psig or one-sixth of the proof pressure test results.

(g) The windows shall meet the requirements of PVHO-1–2012, Section 2, with the exception of para. 2-2.9. The design of the viewport flange shall be conducted as a part of the stress analysis requirement of para. 3.2(b) of this Case. The windows shall have standard window geometry (spherical sector with square edge) and qualify to meet the in-service guidelines of PVHO-2–2012.

(h) The windows shall be fitted with a nylon protection ring secured to the windows with a retainer rigidly attached to the protection ring and sealed with an O-ring. The protection ring shall seal against the flexible membrane of the tube.

(i) In lieu of the requirements of para. 4-9.6.1 of PVHO-1–2012, the number of occupants shall be defined by the number of breathing gas outlets supplied and as defined in the manufacturer's specification.

(j) In lieu of the requirement of para. 6-3.1(b) in PVHO-1–2012, the minimum internal circumference of

Table 12-2 Structural Nonmetallic Materials of Construction — Pressure Tube

Component	Material/Material Properties	Typical Values	Test Procedure or Specification
Membrane	Double-sided aromatic polyether polyurethane-coated nylon fabric	Fabric: high tenacity 940 dtex polyamide Threads: 11/cm warp, 10/cm weft Wt. $205 \pm 10 \text{ g/m}^2$ Base nylon fabric to be scoured and heat set Coating/side: 0.2 mm Total thickness: 0.70 mm (nominal) Total weight: 0.73 kg/m^2 Tensile strength: Warp min. 2 850 N/5 cm Weft min. 2 400 N/5 cm Tear strength: Warp min. 1 600 N/5 cm (chisel cut) Weft min. 1 400 N/5 cm Adhesion (min.): 250 N/5 cm Cold resistance: $-30^\circ\text{C} \pm 5$	ISO 13934-1:1999 ISO 4674-1:2003
Braided main tube and end ring	Liquid crystal polymer (LCP) fiber filament yarn	1500 denier 300 filaments/yarn Density: 1.4 g/cm^3 Tensile strength ($\pm 10\%$): 3.2 GPa, 25.9 g/denier, 465 ksi Tensile modulus: 75 GPa, 600 g/denier, 10,760 ksi Equilibrium moisture regain < 0.1%	ASTM D885-07
Outer cover and braid end fabric	PU-coated woven polyester fabric cover and braid end fabric	Base fabric: mass 180 g/m^2 Threads: 17/cm warp, 13/cm weft Coated fabric: total mass 240 $\pm 10 \text{ g/m}^2$ Tearing strength: $\geq 75 \text{ N}$ across warp, $\geq 85 \text{ N}$ across weft Tensile strength: $\geq 1 800 \text{ N/50 mm}$ warp, $\geq 1 200 \text{ N/50 mm}$ weft	ISO 4674-1:2003 Method A2 ISO 13934-1
Handle straps and lifting slings	Nylon webbing with stainless steel fittings	Structural items — not pressure boundary items	ISO 1492-1:2000+A1

GENERAL NOTE: For brief description of test procedures and specifications listed in this table, see Table 12-3.

Table 12-3 Test Procedures and/or Specifications Listed in Table 12-2 or Referred to in Case 12

Specifications	Details
ASTM D885-07	Standard test methods for tire cords, tire cord fabrics, and industrial filament yarns made from man-made organic-based fibers
ISO 1421:1998	Rubber- or plastic-coated fabrics for determination of tensile strength and elongation at break
ISO 1492-1:2000+A1	Textile slings Safety Flat woven webbing slings, made of man-made fibers for general-purpose use
ISO 4674-1:2003	Rubber- or plastic-coated fabrics Determination of tear resistance — Part 1: Constant rate of tear methods
ISO 13934-1:1999	Textiles Tensile properties of fabrics Determination of maximum force and elongation at maximum force using the strip method
DEF STAN 81-41 Pt. 1 Issue 6, including STANAG 4280	Ministry of Defense — Packaging of Defense Material
93/42/EEC	European Council directive concerning medical devices

the flexible entry to the PVHO shall be 56 in. (142 cm), when the maximum overall diameter of the PVHO is less than 23.5 in. (600 mm).

(k) All load-bearing lifting handles, straps, and slings shall be designed to meet the requirements of EN1492-1:2000 and be labeled. The number of occupants shall be taken into account.

(l) Any changes to the design, materials, or manufacturing procedures of the nonmetallic components of the flexible tube shall be cause for prototype retesting.

3.3 Design Certification

Conformance of the design of the PVHO to the requirements of PVHO-1-2012 shall be established by one of the two following procedures:

(a) A Professional Engineer registered in one or more U.S. states or the provinces of Canada, or licensed by any other country that has equivalent licensing procedures, who is experienced in composite pressure vessel design, shall certify that the PVHO was designed either by him or under his direct supervision, or that he has thoroughly reviewed a design prepared by others, and that to the best of his knowledge, the PVHO complies with PVHO-1-2012 and this Case.

(b) The design of the PVHO shall be reviewed by an independent third-party agency experienced in both nonmetallic pressure vessel design and PVHO systems, and as such, the organization shall provide a certificate that the PVHO complies with PVHO-1-2012 and this Case.

3.4 Manufacture

The tube shall be manufactured in accordance with a detailed process control plan.

The process control plan shall clearly define the details of the manufacturing steps necessary to fabricate the flexible tube and shall document the fabrication process. Any anomalies found during the manufacturing process shall be fully documented and may be corrected according to the process control repair plan. Any production testing already completed shall need to be repeated.

The materials and manufacturing processes used for production units shall be identical to those used for the tested prototypes.

4 TESTING

All prototype testing shall be witnessed by an independent third-party certifying agency experienced in composite pressure vessel technology. In lieu of the testing requirements of PVHO-1-2012, the requirements in paras. 4.1 and 4.2 of this Case shall apply.

4.1 Prototype Testing

(a) *Pressure Proof Test.* Hydrostatic proof tests shall be performed on at least three completely assembled

PVHOs of the same design, shape, and format at maximum operating temperature. Each PVHO shall be pressurized to 6 times the design pressure and held without failure for a period of 30 min. Failure of the acrylic window assembly or the release of a window through the ends of the flexible tube shall be cause for failure of the prototype design. Should higher pressures be achieved, then the MAWP of the PVHO may be calculated using the applicable statistical analysis method defined in para. D-7 of Nonmandatory Appendix D.

Regardless of test results, the MAWP defined in para. (a) above shall not be exceeded. The outer protective cover may be removed from the assembled PVHO for the pressure proof tests in order to visually record and identify the mode of failure.

(b) *Drop Test.* A drop test of at least one complete PVHO of each size on concrete shall be conducted without failure. The PVHO shall be fitted with end closures and loaded with 200 lb (90 kg) of bagged sand per occupant and then pressurized to the MAWP. The PVHO shall be inclined at 45 deg and elevated to a height such that the minimum distance to the concrete impact surface is 3 ft (92 cm) and then dropped. No leakage, damage, or permanent distortion of the PVHO is permissible.

(c) *Cyclic Hydrostatic Test.* A cyclic hydrostatic pressure test of each size of completely assembled PVHO shall be conducted for between 4,000 and 10,000 cycles. The test shall comprise pressurization from 2 psig (or less but sufficient to ensure that the end closures remain sealed) to the MAWP and back to 2 psig at maximum operating temperature.

The duration of a cycle shall be determined by adding the times for the two tests described in (1) and (2) below.

(1) To establish the time for the pressure cycle, a hydrostatic test shall be conducted on the PVHO to determine the time taken for pressurization from ambient pressure to MAWP, plus the time taken for any changes in volume, caused by stress settlement, to subside.

(2) To establish the time for the depressurization cycle, a hydrostatic test shall be conducted on the PVHO to determine the time taken for depressurization from MAWP to ambient pressure, plus the time taken for any changes in volume, caused by stress relaxation, to subside.

To establish the maximum number of cycles satisfactorily completed on the unit under test, the pressure-retention properties of the vessel shall be checked every 2,000 cycles for leakage or any damage to any component of the pressure-retaining parts of the PVHO. Should leakage occur during cyclic testing, or at a cyclic level, then the maximum number of cycles achieved at the previous cyclic level shall be defined as CT and be used to determine the number of approved operational cycles (CA) for the PVHO using the following calculation:

$$CA = (CT/2) - 1,000$$

(d) *Extended-Duration (Creep-Rupture) Test.* A fully assembled pressure-retaining part of the PVHO shall be subjected to proof pressure testing at a pressure of 5 times the MAWP of the PVHO at maximum operating temperature for a period of at least 300 hr.

If at the completion of testing the following criteria are met, the PVHO shall be considered to have acceptable creep behavior:

A straight line shall be plotted using semi-log coordinates with pressure on the linear scale (y) and time on the logarithmic scale (x). The beginning coordinate of the line shall be the pressure at 0.1 hr and the MAWP multiplied by 9. The end coordinate on the line shall be twice the MAWP at 80,000 hr. A straight line shall be drawn through these two coordinates. This line represents the minimum pressure-time acceptance line. Failure to the left and below the pressure-time acceptance line is disallowed.

(e) *Cold Storage Test.* A test shall be conducted at least twice, demonstrating that the pressure-retaining part of the PVHO can be assembled and inflated at minimum operating temperature. The PVHO shall be folded and stored for a minimum of 8 hr at minimum operating temperature immediately prior to the commencement of the tests.

(f) *Off-Gassing Toxicity Test.* An off-gassing toxicity test shall be carried out that meets the requirements of subsection 1-10 of PVHO-1-2012.

(g) *Cyclic Folding Test.* A folding and unfolding test shall be carried out on the flexible tube of the PVHO for a minimum of 4,000 cycles. At the end of the test, the tube shall be inspected to ensure that there is no damage, delaminations, or other defects to any of the components of the flexible tube or cover.

(h) *Puncture Test.* A puncture test using a $\frac{3}{8}$ -in. (10-mm) wide flat screwdriver shall be performed on one PVHO at MAWP. The force to puncture the bladder shall be at least 225 lb (102 kg). After the screwdriver punctures the PVHO body, there shall be no tearing or rapid decompression.

Flexible tube and viewport components used in prototype testing above shall not be used in production PVHOs.

4.2 Production Testing

Every completely assembled PVHO shall be subjected to a pneumatic test at a pressure of 1.5 times the MAWP and held for a period of 1 hr with a permissible leakage rate of 2% per hour. Internal and external air temperatures shall be measured and recorded at the beginning and end of each test so that compensation may be made for any temperature differences.

Every PVHO shall be examined visually and dimensionally for damage following each test. Cracks, permanent deformations, or other signs of damage shall be grounds for rejection of the PVHO.

5 QUALITY ASSURANCE

5.1 General

PVHOs built to this Case shall be built by manufacturers whose Quality Management System is approved and certified by a certified body as meeting the requirements of ISO 13485:2003 and European Directive 93/42/EEC Annex II (excluding Section 4) for Medical Devices. In addition, the requirements of Section 3 of PVHO-1-2012 shall be met in full.

A documented Quality Assurance Plan (QAP) shall be developed for the design and manufacture of the PVHO. This section describes the requirements of the content of the QAP.

5.2 Organization

The QAP shall describe the organizational structure, with responsibilities, authorities, and lines of communication clearly delineated. Persons shown in the QAP to be responsible for verifying the PVHO quality shall have the authority and organizational freedom to

- (a) identify problems affecting quality
- (b) initiate, recommend, or provide solutions to quality problems through designated channels
- (c) verify implementation of solution
- (d) control further processing, delivery, or assembly of a nonconforming item, deficiency, or unsatisfactory condition until proper corrective action has been taken

5.3 Design Control

A methodical process shall be used to develop and control the PVHO design, which includes

- (a) a process for design inputs and review
- (b) a requirement for formal design review
- (c) a process for product configuration management and change control

5.4 Document Control

The QAP shall describe the manufacturer's measures for ensuring that design output documents are correctly translated into manufacturing specifications, drawings, procedures, and shop/lab instructions. Considerations shall be made for reviews and approvals, including those of the purchaser.

The manufacturer shall include the procedure for ensuring distribution of appropriate documents to the working areas in a timely fashion and the process for ensuring nonuse of obsolete documents.

5.5 Procurement Control

The QAP shall include the controls necessary to ensure that applicable requirements are included in procurement documents. The manufacturer shall describe the basis for source evaluation and selection and the method of objective evaluation of the quality of furnished materials, items, and services upon receipt.

5.6 Material Control

The QAP shall describe the identification applied to material and items upon receipt and shall show that this identification shall remain until the material or item is incorporated into the PVHO. Identification shall be such that the manufacturer's personnel can easily determine quality status, material or item type, specification, lot or part as appropriate, and job number.

All material properties of production units shall meet or exceed the actual material properties of the prototype test articles.

5.7 Process Control

The QAP shall include a Process Control Procedure that shall record the identification of materials and items incorporated into the PVHO and each chronological step in their manufacture, including inspection and test steps. The Process Control Procedure shall contain periodic operator and inspector signature points so that product status can be readily determined.

The manufacturer shall identify critical manufacturing activities and ensure that they are accomplished by appropriately trained and qualified personnel. Inspection points shall follow the activities in the process control plan.

5.8 Inspection Control

The QAP shall include the measures used by the manufacturer to ensure that inspections are reliable. These measures shall include

- (a) proper qualification of inspection personnel
- (b) calibration of inspection instrumentation
- (c) incorporation of acceptance criteria into inspection points in the process control plan
- (d) assurance that inspections are performed by persons other than those performing or supervising work
- (e) documentation of all inspections

5.9 Test Control

The QAP shall describe the measures used to ensure that tests (including lab tests) are performed consistently and reliably. The following requirements shall be met:

- (a) Tests shall be performed in accordance with written instructions stipulating acceptance criteria.
- (b) Test results shall be documented.
- (c) Examination, measurement, and testing equipment used for activities affecting quality shall be controlled, calibrated, and adjusted at specified periods to maintain required accuracy.
- (d) Tests shall be performed by trained and qualified personnel.
- (e) Tests shall be verified by persons other than those performing or supervising the test.

5.10 Control of Measuring Test and Inspection Equipment

The QAP shall describe the equipment used in inspections and tests and the measures used to ensure appropriate accuracy. Appropriate equipment shall be calibrated, and the calibration shall be traceable to standards where they exist. Where such standards do not exist, the equipment manufacturer's recommendations shall be followed.

5.11 Control of Nonconforming Items/Materials

The QAP shall describe the measures used by the manufacturer to control materials or items that are found to be discrepant to prevent their inadvertent use. Nonconforming materials/items shall be identified. The discrepant condition(s) shall be documented. The process for determining, documenting, and verifying corrective action shall be described, including the involvement of the purchaser.

5.12 Quality Assurance Records

The QAP shall provide for quality assurance records.

- (a) Records shall be specified, compiled, and maintained to furnish documentary evidence that services, materials, and completed PVHOs meet this and applicable referenced standards.
- (b) Records shall be legible, identifiable, and retrievable.
- (c) Records shall be protected against damage, deterioration, or loss.
- (d) Requirements and responsibilities for record transmittal, distribution, retention, maintenance, and disposition shall be established and documented.
- (e) Records required for traceability shall be retained for a minimum of 12 yr.

5.13 Standard Repair Planning

The QAP shall describe methods for repairing discrepancies that are expected to occur during the PVHO manufacture.

5.14 Quality Assurance Overview by an Independent Third Party

An independent third-party agency shall be employed to ensure that all PVHOs under this Case are designed and manufactured to the requirements of PVHO-1-2012 and this Case. This includes, but is not restricted to, the following:

- (a) The PVHO is designed in accordance with PVHO-1-2012 and this Case.
- (b) The manufacturer is working to the requirements of the quality control system.
- (c) The materials used in construction of the PVHO comply with approved procedures by qualified operators, as required by PVHO-1-2012 and this Case.

Fig. 12-2 Example Marking of Case 12 PVHO

PVHO-1-2012 (Case 12)	
Certified by	

(name of manufacturer)	
_____ psi/MPa/msw/fsw internal	
(maximum allowable working pressure)	
_____ °F	_____ °C
(operating temperature range)	
_____	_____
(manufacturer's serial no.)	(year built)
Section (5 or 6 or 5 and 6) _____	
(Single-occupancy, Section 5 (Medical) and/or Section 6 (Diving); Dual-occupancy, Section 6 (Diving) only)	
Number of Occupants	_____
	(1 or 2 occupants)

Fig. 12-3 Additional Markings for Case 12 PVHOs

Overall chamber length	_____ in.	_____ cm
Allowable number of pressure cycles:	(as defined following prototype testing)	
Allowable number of folding for storage cycles	(as defined following prototype testing)	
Flexible tube expiration date:	(DD/MM/YYYY)	
Storage temperature (min./max.):	+10°F/+150°F — 23°C/+66°C	
PRESSURIZE WITH AIR ONLY		
CONSTANT SUPERVISION REQUIRED DURING TREATMENT		
THIS EQUIPMENT IS ONLY TO BE OPERATED BY QUALIFIED PERSONNEL, FULLY AWARE OF THE PROCEDURES DETAILED IN THE MANUAL AND AS DIRECTED AND SUPERVISED. USE BY NONQUALIFIED PERSONNEL IS EXPRESSLY PROHIBITED		
DO NOT EXPOSE PVHO TO DIRECT SUNLIGHT OR UV LIGHT SOURCES FOR EXTENDED PERIODS		

(d) All manufacturing operations are conducted in accordance with approved procedures by qualified operators, as required by PVHO-1-2012 and this Case.

(e) All defects are acceptably repaired.

(f) All prototype and production testing has been performed and witnessed as required by PVHO-1-2012 and this Case.

(g) The PVHO is marked in accordance with PVHO-1-2012 and this Case.

(h) A visual inspection of the PVHO is conducted to confirm that there are no material or dimensional defects.

The manufacturer shall arrange and give the third-party inspection agency free access to all facilities associated with the manufacture of the PVHO. The manufacturer shall keep the third-party inspection agency informed of the progress of the work and shall notify them reasonably in advance when PVHOs will be ready for any required tests or inspections.

6 MARKING

(a) In lieu of PVHO-1-2012, subsection 1-9, a label shall be permanently and rigidly attached to the outside surface of the flexible tube and shall be permanently marked, close to one end, with the data required in PVHO-1, para.1-9(a) and the information shown in Fig. 12-2.

(b) In addition to the above, the PVHO and/or its control box shall be prominently marked as shown in Fig. 12-3.

(c) The PVHO shall also indicate, by description or geographically, items that shall not be permitted in the chamber. These should include cell phones; electronic devices (especially those using lithium batteries); flammable items such as matches, lighters, and hand warmers; and sharp objects such as needles and knives.

(d) PVHO-1 Case 12 Form, Manufacturer's Data Report for Pressure Vessels for Human Occupancy, shall be completed to certify that each PVHO meets the requirements of PVHO-1-2012 and this Case.

PVHO-1 Case 12 Form Manufacturer's Data Report for Pressure Vessels for Human Occupancy

1. Design criteria _____
2. Manufactured and certified by _____
3. Manufactured for _____
4. Vessel identification _____
(manufacturer's serial no.) (year built)
5. The design, construction, workmanship, and chemical and physical properties of all parts meet the applicable material specifications of PVHO-1— (year) and Case Nos. _____.
6. Manufactured for a maximum allowable working pressure of _____ psig _____ barg
_____ msw _____ fsw, a maximum working temperature of _____ °F _____ °C
and a pneumatic internal test pressure of _____ psig _____ barg _____ msw _____ fsw.
7. Design analysis conducted by _____
8. Designed for one occupant/one or two occupants (delete as applicable)
9. Windows: Certification Reports, properly identified and signed by the window fabricator, are attached for the following items:

Nos.	Location	Type	Diameter	Nominal Thickness	How Attached

10. Penetrator Plate No. _____ Penetrator Blank No. _____ Medlock No. _____

CERTIFICATION OF DESIGN

User's Design Specification on file at _____

Manufacturer's Design Report on file at _____

User's Design Specification certified by _____ State _____ Reg. no. _____

Manufacturer's Design Specification certified by _____ State _____ Reg. no. _____

Prototype test program attested by _____

Quality Assurance Program reviewed by _____

Manufacturer's documentation reviewed by _____
(name and date)

Production testing witnessed by _____
(name and date)

CERTIFICATION OF COMPLIANCE

We certify that the statements made in this report are correct and that all details of the design, material, construction, and workmanship conform to the ASME Safety Standard for Pressure Vessels for Human Occupancy (PVHO-1) and PVHO Case 12.

Date _____ Company name _____ Signed _____

PHVO Case 13
Use of Finished Flat Disk Acrylic Window With Thickness Less Than $\frac{1}{2}$ in. Under PVHO-1-2012

Approval Date: February 4, 2009
Reaffirmation Date: May 26, 2015
Expiration Date: May 26, 2021

Inquiry: Under what conditions is it permissible for a finished flat disk acrylic window to have a thickness less than $\frac{1}{2}$ in. (13 mm)?

Reply: It is the opinion of the Committee that finished flat disk acrylic windows may have a thickness less than $\frac{1}{2}$ in. (13 mm) provided that the windows

(a) will not be exposed to environmental conditions that might result in degradation of the acrylic properties (e.g., seawater, direct outdoor sunlight, solvent vapors, nuclear radiation)

(b) comply with all of the requirements of Section 2 of PVHO-1-2012 and the following additional conditions and limitations:

(1) The maximum design pressure (MAWP) does not exceed 75 psig (0.52 MPa).

(2) The finished window thickness is not less than $\frac{1}{4}$ in. (6.35 mm).

(3) The critical dimension for scratches is 0.005 in. (0.13 mm).

(4) Visible inclusions are not permitted (regardless of size).

(5) The window shall be annealed in accordance with the annealing schedule for 0.50-in. (13-mm) thick acrylic windows.

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PHVO Case 14
Use of Pressure Vessels Incorporating Cast Acrylic Cylinders Without the UV Stabilizer
Under PVHO-1–2012

Approval Date: April 15, 2009
Reaffirmation Date: May 26, 2015
Expiration Date: May 26, 2021

Inquiry: Under what conditions is it permissible for cast acrylic cylinders to be used without a UV inhibitor being added?

Reply: It is the opinion of the Committee that it is permissible for cast acrylic cylinders to be used without the addition of a UV stabilization agent provided the following conditions are met:

(a) Storage and use are limited to a protected indoor environment where there is low exposure to UV radiation.

(b) The window markings shall include “PVHO-1 Case 14 Low UV,” as shall the associated PVHO-1 Forms.

(c) The window is not subject to life extension beyond design life.

(d) The window shall comply with all other relevant requirements of PVHO-1–2012.

PHVO-1 Case 15

Use of Polyester-Jacketed, Aliphatic-Coated Bladder, Zippered Closure Cylindrical Vessels in the Construction of PVHOs Under PVHO-1–2012

Approval Date: April 6, 2010
Reaffirmation Date: March 9, 2016
Expiration Date: March 9, 2021

Inquiry: Under what conditions may a portable flexible polyester-jacketed, aliphatic-coated bladder with redundant zipper closures be used in construction under the rules of PVHO-1–2012?

Reply: It is the opinion of the Committee that a portable flexible polyester-jacketed, aliphatic-coated bladder with redundant zipper closures may be constructed under the requirements of PVHO-1–2012 and be marked as a PVHO when the requirements of PVHO-1–2012, with the following exceptions and additions, have been met.

1 GENERAL

The PVHO chamber is a flexible composite cylinder consisting of an inner bladder [Fig. 15-1(c)], an outer jacket [Fig. 15-1(g)], and webbing secured with mechanical safety buckles [Fig. 15-1(d)]. The bladder and jacket are closed with four overlapping zippers [Fig. 15-1(e)] that provide an initial pressure seal. Two opposing transparent windows permit viewing of the occupant [Fig. 15-1(b)]. Connections for pressurization and breathing gas are located at the ends [Fig. 15-1(a)]. The window shield (Fig. 15-2) is supported by the jacket and webbing [Fig. 15-1(f)].

The chamber is pressurized with a continuous flow of air that is expelled through a ventilation valve.

The PVHOs shall be designed, constructed, inspected, tested, marked, and installed (if applicable) to PVHO-1–2012, Sections 1 through 6, with exceptions and additions detailed in this Case.

1.1 Exclusions

The following sections/paragraphs of PVHO-1–2012 are not applicable to vessels built under this Case:

- (a) subsection 1-6 and paras. 1-7.1 through 1-7.3, 1-7.5, 1-7.8, and 1-7.11 through 1-7.16
- (b) subsections 2-2, 2-7, 2-8, and 2-10
- (c) paras. 5-1.5 and 5-5.7
- (d) paras. 6-2.8.1(a) and (b), 6-2.8.2(d), and subsection 6-3, except for para. 6-3.6.1
- (e) Section 7

1.2 User's Design Specification

A User's Design Specification shall be provided. The User's Design Specification shall include the following data:

- (a) The maximum number of occupants is one.
- (b) The maximum allowable internal working pressure (MAWP) is 15 psig (103.4 kPa).
- (c) Pressurization gas is air, with an exhaust valve and overpressure relief valve.
- (d) The breathing gas supplied to the occupant of the PVHO shall be through a built-in breathing system (BIBS) mask. The operator of the PVHO shall have external control of the supply of breathing gas. The operator shall ensure that sufficient gas is available for flushing the PVHO, if necessary, and there shall be sufficient emergency gas available to complete the proposed treatment safely. All exhaled gas shall leave the PVHO via an overboard dump system.
- (e) The pressurization/depressurization rates shall be no greater than 1 psi/min (6.89 kPa/min).
- (f) Airflow rate to maintain MAWP shall not exceed 15 standard ft³/hr (SCFH).
- (g) The PVHO shall have two windows in the body of the chamber. The windows shall permit external viewing of the occupant's head, face, chest, and arms.
- (h) Maximum internal length is 91.75 in. (2.33 m).
- (i) Internal diameter shall be 23 in. (0.584 m) nominal.
- (j) Four overlapping zippers shall be used. Each zipper shall be able to effect a pressure seal.
- (k) The design temperature limits are 0°F to 100°F (–18°C to 38°C). The design storage temperature range is –10°F to 150°F (–23°C to 66°C).
- (l) The design number of pressure cycles shall not exceed 4,000 cycles.
- (m) The rated life is 10 yr from the date of manufacture or on completion of 4,000 pressure cycles, whichever occurs first.
- (n) Penetrators shall be located in the ends. Two breathing gas penetrators shall be compatible with the BIBS. One sensor penetrator shall be provided.
- (o) Lifting handles shall be provided to allow occupant transport while under pressure.

Fig. 15-1 Typical PVHO Configuration

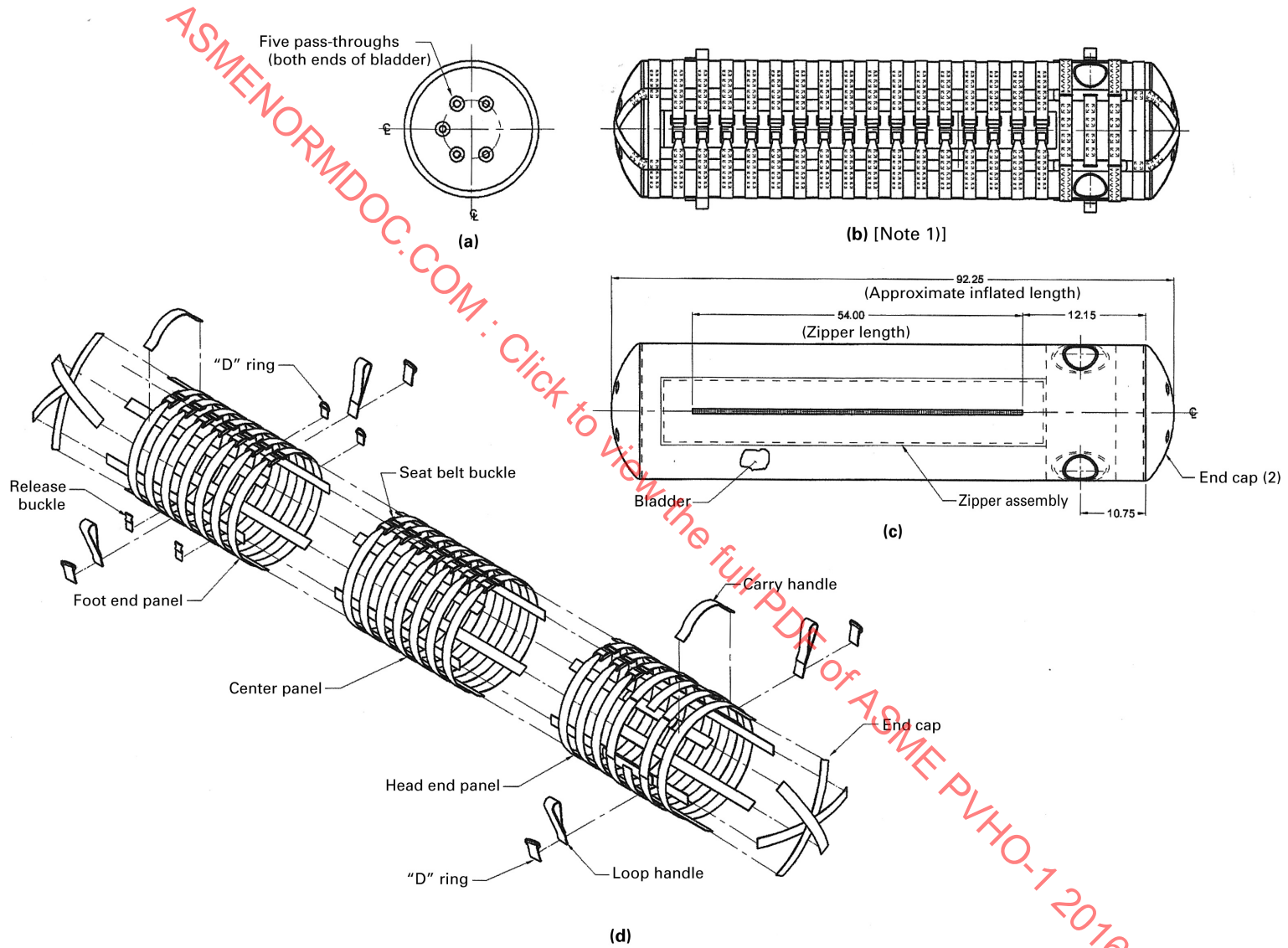
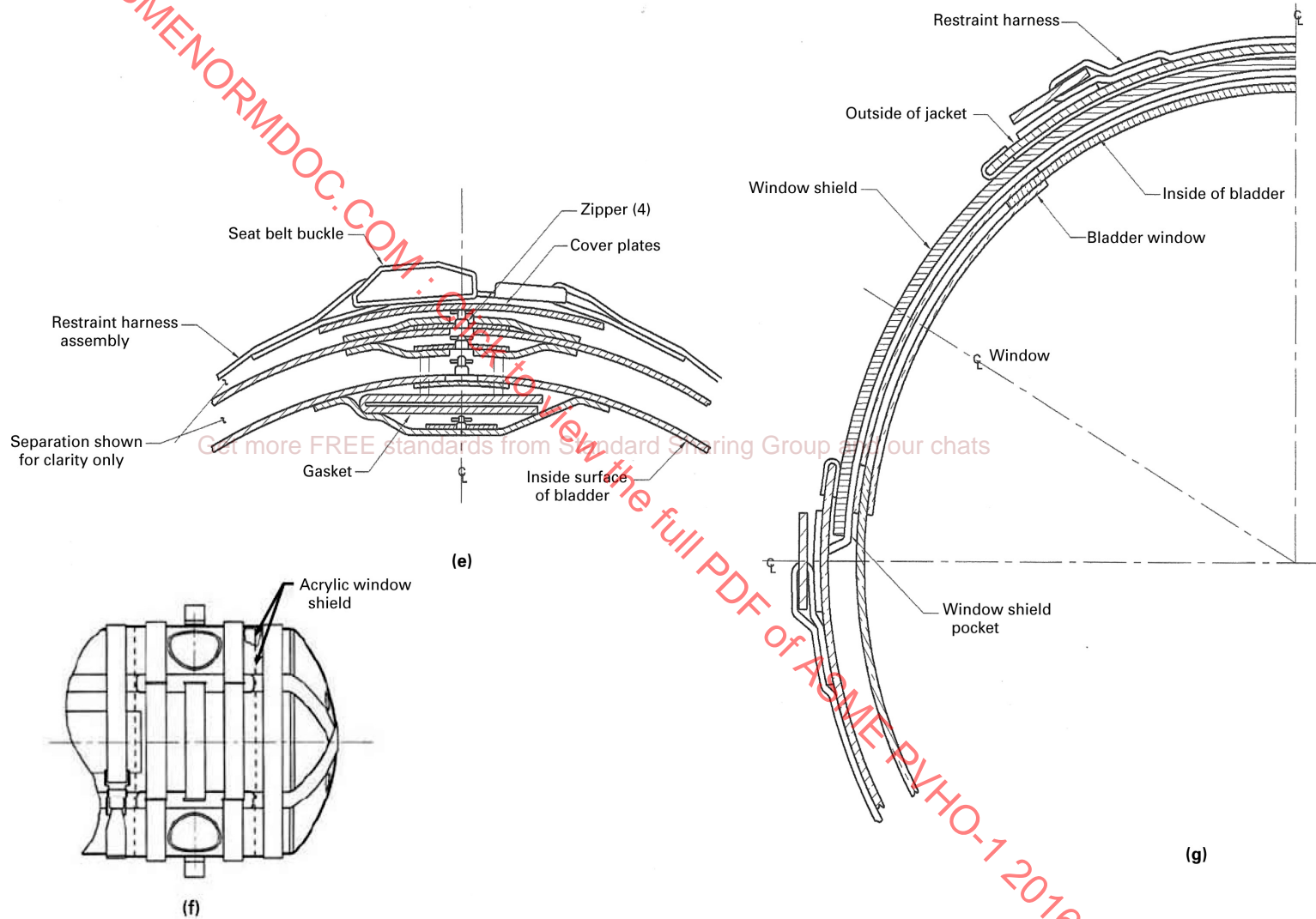


Fig. 15-1 Typical PVHO Configuration (Cont'd)

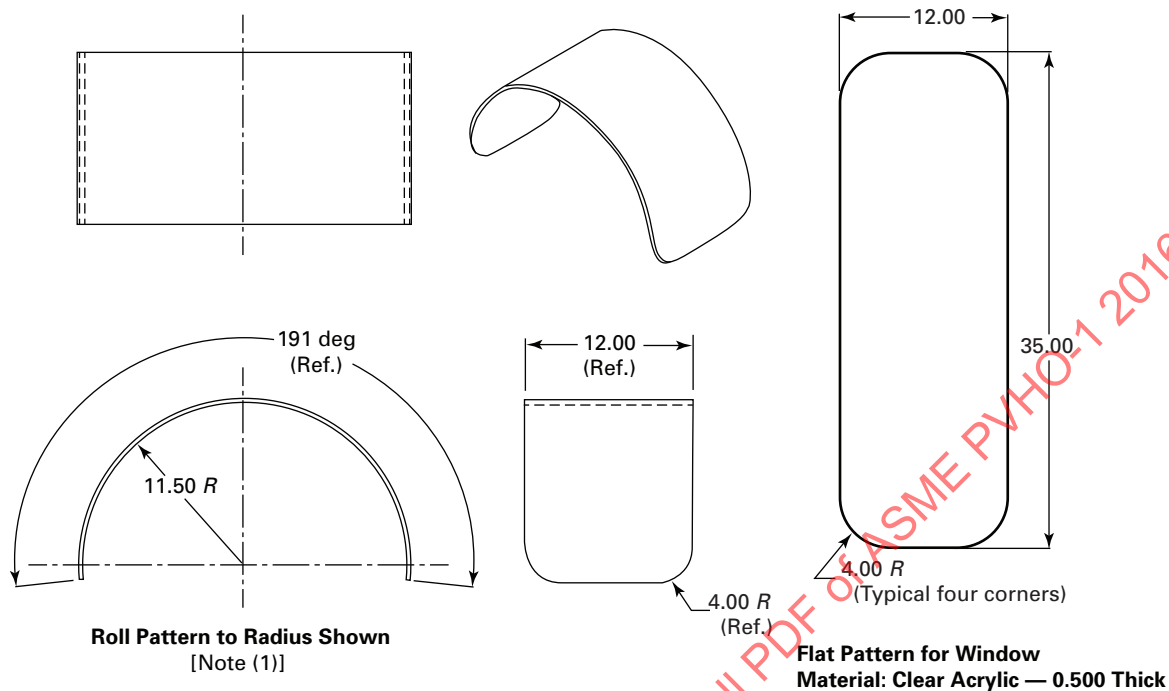


PATENT PENDING

NOTE:

(1) Chamberlite shown enlarged for clarity.

Fig. 15-2 Window Shield



NOTE:

(1) Anneal after forming to relieve stress.

(p) Temperature control of the environment is ambient.

(q) Fire suppression is provided by a portable fire extinguisher.

(r) No corrosion allowance is required.

(s) Bladder joining will be RF welding only. No adhesives are allowed except for sealing of exterior seams.

window shield, film, and penetrator flange, shall include batch and lot information. Test conditions are $70^{\circ}\text{F} \pm 5^{\circ}\text{F}$ and $65\% \text{ RH} \pm 5\% \text{ RH}$. The relevant strength data shall be recorded on the Manufacturer's Data Report. Any changes of primary strength material shall be cause for full prototype retesting and shall be submitted as a new Case.

2 MATERIALS

In lieu of the requirements of PVHO-1-2012, subsection 1-6 and Section 2, the materials in Table 15-1 shall be used. All of the materials shall be used in combination to meet the performance requirements of this Case. A Process Control Procedure in accordance with para. 5.7 of this Case shall identify how the materials are to be used and in what specific quantities. All materials used shall be supplied with supporting documentation consistent with the requirements of the Quality Management System detailed in section 5 of this Case. Each lot shall meet the ASTM or federal standards material specifications as indicated. Material shelf life shall be identified as being suitable for long-term storage between uses and shall not exhibit visual or performance deterioration through aging for the entire life of the PVHO.

Material test reports for the primary strength members, which are the webbing, jacket, buckles, bladder,

3 DESIGN AND FABRICATION

In lieu of PVHO-1-2012, subsection 1-7, the design and fabrication shall be in accordance with this Case and the following requirements. Any changes to the design or manufacturing procedures of the PVHO shall be cause for full prototype retesting and shall be submitted as a new Case.

3.1 Design Analysis

A stress analysis shall be performed by a Professional Engineer (PE) registered in one or more of the U.S. states or the provinces of Canada, or licensed by any other country that has equivalent licensing procedures, who is experienced in fabric composite pressure vessel design and construction.

3.2 Requirements

(a) The MAWP shall be 15 psig (100 kPa) at 100°F (38°C).

Table 15-1 PVHO Materials of Construction

Component	Material Properties	Test Procedure or Specification
Base fabric	Polyethylene terephthalate (PET) 1,500 denier 13 oz–15 oz, thread count 35/35 threads/in.	...
Coated bladder fabric	39 oz/yd ² –45 oz/yd ² Aliphatic PU/PVC alloy Tensile strength: Warp: 823-lb minimum Fill: 712-lb minimum Adhesion RF: 24-lb/in. minimum Low-temperature flexibility: –20°F 12 hr Flammability: oxygen index > 25%	... ASTM D751, Procedure B ASTM D751, Procedure B ASTM D751 DIN 53546 ASTM D2863
Polyester jacket	The outer cover shall be woven polyester 36 oz/yd ² . The fabric shall be prestretched, have multifilament warp, spun filling double twill weave, 84 × 51 count. Breaking strength: Warp: 1,300-lb minimum Fill: 550-lb minimum	... ASTM D5034 ASTM D5034
Clear polyester polyurethane film window	Hardness: 90–95 Shore A Ultimate tensile strength: 1 in. × 1 in. 5,000 lb Ultimate elongation: 400% Minimum tensile modulus at 100% elongation: 1,400 psi Minimum tear resistance: 650 lb/in. Low-temperature bending: –20°F 12 hr Film thickness: 0.052 in. — 5%	ASTM D2240 ASTM D412, Method A ASTM D412 ASTM D412 ASTM D624, Die C DIN 53546 ...
Acrylic window shield	The window shield material shall be in accordance with PVHO-1–2012 requirements. However, the window, which is a sector of a cylinder and supported by fabric and webbing, is a nonstandard window. The test program in section 4 of this Case exceeds the requirements for STPP in para. 2-2.6 of PVHO-1–2012 and is an alternative to the requirements for determination of LTPP and CPP. Thickness: 1/2 in.	...
Zipper closures	To meet federal spec CID A-A-55634A	OII-03 CEF P09P 54 and OII-03 CEF P10P 54
Webbing	Polyester, 2.42 oz/yd, 0.07 in. thick, 2 in. wide Minimum breaking strength: 6,000 lb Breaking strength tested to Web Sling and Tie Down Association T-4 or Fed Std 191A Method 4108	FMVSS 571.209
Safety buckle	Minimum breaking strength: 3,360 lb	FMVSS 571.209
Silicone rubber	Durometer 30 Shore A	ASTM D2240
Polyester thread	4 Cord (Tex 270) Type 2 Class 1; FF (Tex 90) Type 1, Class 3	MIL-DTL-32072
Neoprene-coated nylon	13 oz fabric 1/16 in. thick, 65–75 durometer, cured both sides with rubber meeting tensile strength at 300% elongation: 1,400-psi minimum	ASTM D2000-BC-714
Penetrator flange	Texin 950 aromatic polyether-based thermoplastic polyurethane with Shore D hardness of 50 Minimum tensile strength: 6,000 psi Minimum tensile strength at 100% elongation: 2,000 psi Threads of flange: aluminum 6061-T6511 Anodized to	... ASTM D412 ASTM D412 ASTM B221-02 QQ-A-200/8 MIL-A 8625 F Ty2, Class 2
Lifting bridle	If chamber is to be used as a hyperbaric stretcher, then straps and bridles shall be provided that meet ASME B30.9.	...
Aluminum load diffuser plate	...	SB209 6061-T6

(b) Temperature range shall be between 0°F and 100°F (−18°C and 38°C).

(c) The MAWP shall be based on testing three prototypes to at least 6 times the MAWP.

(d) The design analysis shall consider the effects of aging of the polyester jacket and longitudinal and hoop webbing, plus the effects of folding, unfolding, and long-term storage of the collapsed chamber. The design shall ensure that no damage will occur to the cloth within the composite shell by acute bending or by bending at less than the minimum bend radius of the material. Acute bending is defined as a bend in the cloth shell at an inside angle of less than 5 deg. The minimum bend radius for the cloth shall be no less than 0.05 in. (1.25 mm). Strength reduction due to sewn connections shall be based on test data and included in the analysis. Procedures shall be written as to the type of stitch, length of stitch, stitch pattern size, type and size of thread, and results from the break test.

(e) All penetrators shall be located in the ends.

(f) The two windows shall be located in the body.

3.3 Design Certification

Conformance of the design of the PVHO to the requirements of PVHO-1-2012 shall be established by one of the two following procedures:

(a) A PE registered in one or more of the U.S. states or the provinces of Canada, or licensed by any other country that has equivalent licensing procedures, who is experienced in fabric composite pressure vessel design, shall certify that the PVHO was designed either by the PE or under the PE's direct supervision, or that the PE has thoroughly reviewed a design prepared by others, and that the PVHO complies with PVHO-1-2012 and this Case.

(b) The design of the PVHO shall be reviewed by an independent third-party agency competent in PVHO systems and experienced in fabric composite design, and such an organization shall provide a certificate that the PVHO complies with PVHO-1-2012 and this Case.

3.4 Fabrication

The PVHO shall be manufactured in accordance with a detailed process control plan. The process control plan shall clearly define the details of the manufacturing steps necessary to fabricate the PVHO and shall document the fabrication process. Any anomalies found during the manufacturing process shall be fully documented and may be corrected according to the process control repair plan.

Any production testing already completed shall need to be repeated. The materials and manufacturing processes used for production units shall be identical to those used for the tested prototypes.

4 TESTING

All prototype testing shall be witnessed by an independent third-party certifying agency experienced in fabric design. In lieu of the testing requirements of PVHO-1-2012, the requirements in paras. 4.1 and 4.2 shall apply.

4.1 Prototype Testing

Deviation from established design parameters, materials of construction, or fabrication process control that affect performance of the structure shall require that a new prototype qualification test be conducted. PVHOs used for prototype testing shall not be used other than for testing.

(a) Proof Pressure Test

(1) Proof pressure tests shall be conducted on a minimum of three full-scale prototype chambers. These prototypes shall be full size and of identical construction to the end item, with all fabrication completed that in any manner may affect the integrity of the pressure boundary.

(2) The rated pressure shall be based on a minimum 6:1 ratio of proof pressure determined by testing three prototype chambers to at least 90 psig for 30 min. Rated pressure testing shall be performed at the most critical service temperature of 100°F (38°C).

(3) The material in the primary strength members shall be tested to determine actual breaking strength. The test data shall be recorded and retained.

(b) *Drop Test.* A drop test of at least one PVHO on concrete shall be conducted without failure. The PVHO shall be loaded with an evenly distributed load of 200 lb (90 kg) of bagged sand and then pressurized to the rated pressure. The PVHO shall be inclined at 45 deg, elevated to a height such that the minimum distance to the concrete impact surface is 3 ft (92 cm), and then dropped. The chamber shall then be inverted (opposite end impacted) and dropped again. No damage, permanent distortion, or increased ventilation rate of the PVHO is permissible.

(c) *Cyclic Pressure Test.* The maximum permissible number of design cycles shall be determined by cyclic testing of a full-scale PVHO.

(1) The cyclic pressure test shall be from 0 ambient to MAWP and back to 0 ambient. The PVHO shall be pressurized to MAWP, and the time when expansion ceases shall be measured. This time shall be doubled, and the greater of the doubled time or 1 min shall be used as the minimum hold time at pressure. Cyclic testing shall be performed at the most critical service temperature of 100°F (38°C).

(2) The number of approved operational cycles, CA, shall be computed as

$$CA = (CT/2) - 1,000$$

where CT = total number of test cycles performed. The chamber shall be cycled for a minimum of 10,000 cycles.

(3) Every 2,000 cycles, the PVHO shall be visually inspected for damage and excessive airflow rate. The requirement for acceptance of the cyclic pressure test is that no crack (or other damage) shall be visibly detectable, using methods that are normally used for visual inspection of the applicable material. In addition, airflow rate shall not exceed 110% of normal.

(d) *Creep Test.* Extended-time tests of three completely assembled PVHOs that have either undergone proof pressure testing without failure or alternatively have not been previously tested shall be conducted at the most critical service temperature using the following criteria:

(1) A straight line shall be plotted using semi-log coordinates with pressure on the linear scale (y) and time on the logarithmic (x). The beginning coordinate of the line shall be the pressure at 0.1 hr and the MAWP multiplied by 9. The end coordinate on the line shall be twice the MAWP at 80,000 hr. A straight line shall be drawn through these two coordinates. This line represents the minimum pressure-time acceptance line. Failure to the left and below the pressure-time acceptance line is disallowed.

(2) A test pressure shall be applied such that the time without failure shall exceed the pressure-time acceptance line; however, the minimum time shall be at least 300 hr.

(3) If all three chambers exceed the 300 hr and minimum pressure-time acceptance line, the PVHO has acceptable creep behavior.

(e) *Cold Storage Test.* A cold storage test demonstrating that the chamber can be assembled and inflated at minimum operating temperature shall be conducted. The chamber shall be folded and stored for a minimum of 8 hr at -10°F (-23°C) and then inflated to operating pressure in a period not exceeding 15 min. Repeat the cold storage test a minimum of two times. No increase in airflow rate, damage, or permanent distortion is permissible.

(f) *Cycle Folding Test.* A chamber shall be subjected to 4,000 cycle folding exercises. The chamber shall be unzipped and laid flat on a table at room temperature. The chamber shall have each end cap folded down flat against the opening. One end shall be folded onto itself three times. The final fold shall be lifting the folded chamber onto the end cap. This will create a size suitable for storage in the carrying case. After this is completed, it shall be unfolded to the flat position and zippers closed. Upon completion of the 4,000 cycles, the chamber shall be inspected for any defects, delamination, wear, or fracture of the zipper or body.

(g) *Off-Gas Test.* The off-gas requirements of subsection 1-10 of PVHO-1-2012 shall be satisfied.

(h) *Puncture Test.* A puncture test using a $\frac{3}{8}$ -in. (10-mm) wide flat screwdriver shall be performed on one PVHO at MAWP. The force to puncture the bladder shall be at least 225 lb (102 kg). After the screwdriver punctures the PVHO body, there shall be no tearing or rapid decompression.

(i) *Airflow Rate Test.* The airflow rate to maintain MAWP shall be determined by pressurizing three PVHO prototypes to MAWP at room temperature for a period of 60 min and measuring the volume of air expelled. The average of the three volumes shall be the "normal" airflow rate used for comparison with production units.

(j) *Zipper Seal Test.* The chamber shall have redundant zippers that provide an initial pressure seal of the bladder. To assess adequacy of the zipper in setting the seal, one of the redundant zippers shall be engaged about one-quarter of its length. Other zippers shall be open. The chamber shall be pressurized to MAWP. Repeat for other zippers. All zippers shall generate a pressure seal to pass the zipper seal test.

4.2 Production Testing

(a) All production units shall be subjected to a pneumatic test of 1.5 times the MAWP to be held for 60 min. In addition, airflow rate shall be measured at MAWP over a 60-min period.

(b) Following testing, the PVHO shall be inspected for damage to the sealing areas. Every PVHO shall be examined visually and dimensionally. Any sign of cracks, permanent deformation, or other damage or airflow rate in excess of "normal" [see para. 4.1(i)] by more than 10% or exceeding 15 SCFH shall be cause for rejection of the PVHO.

5 QUALITY ASSURANCE PROGRAM

5.1 General

The requirements of PVHO-1-2012, Section 3 require a Quality Assurance Program (QAP) compliant to ISO 13485 be developed for the design and manufacture of the PVHO. The QAP shall comply with the requirements in paras. 5.2 through 5.14 of this Case and shall be reviewed and accepted by an independent third-party inspection agency experienced in fabric composite design.

5.2 Organization

The QAP shall describe the organizational structure, with responsibilities, authorities, and lines of communication clearly delineated. Persons shown in the QAP to be responsible for verifying the PVHO quality shall have the authority and organizational freedom to

- (a) identify problems affecting quality
- (b) initiate, recommend, or provide solutions to quality problems through designated channels
- (c) verify implementation of solution

(d) control further processing, delivery, or assembly of a nonconforming item, deficiency, or unsatisfactory condition until proper corrective action has been taken

5.3 Design Control

A methodical process shall be used to develop and control the PVHO design, which includes

- (a) a process for design inputs and review
- (b) a requirement for formal design review
- (c) a process for product configuration management and change control

5.4 Document Control

The QAP shall describe the manufacturer's measures for ensuring that design output documents are correctly translated into manufacturing specifications, drawings, procedures, and shop/lab instructions. Considerations shall be made for reviews and approvals, including those of the purchaser. The manufacturer shall include the procedure for ensuring distribution of appropriate documents to the working areas in a timely fashion and the process for ensuring nonuse of obsolete documents.

5.5 Procurement Control

The QAP shall include the controls necessary to ensure that applicable requirements are included in procurement documents. The manufacturer shall describe the basis for source evaluation and selection and the method of objective evaluation of the quality of furnished materials, items, and services upon receipt.

5.6 Material Control

The QAP shall describe the identification applied to material and items upon receipt and shall show that this identification shall remain until the material or item is incorporated into the PVHO.

Identification shall be such that the manufacturer's personnel can easily determine quality status, material or item type, specification, lot or part as appropriate, and job number. All material properties of production units shall meet or exceed the actual material properties of the prototype test articles.

5.7 Process Control

The QAP shall include a Process Control Procedure that will record the identification of materials and items incorporated into the PVHO and each chronological step in its manufacture, including inspection and test steps. The Process Control Procedure shall contain periodic operator and inspector signature points so that product status can be readily determined. The manufacturer shall identify critical manufacturing activities and ensure that they are accomplished by appropriately trained and qualified personnel. Inspection points shall follow the activities in the process control plan.

5.8 Inspection Control

The QAP shall include the measures used by the manufacturer to ensure that inspections are reliable. These measures shall include

- (a) proper qualification of inspection personnel
- (b) assurance that inspections are performed by persons other than those performing or supervising work
- (c) documentation of all inspections

5.9 Test Control

The QAP shall describe the measures used to ensure that tests (including lab tests) are performed consistently and reliably. The following requirements shall be met:

- (a) Tests shall be performed in accordance with written instructions stipulating acceptance criteria.
- (b) Test results shall be documented.
- (c) Examination, measurement, and testing equipment used for activities affecting quality shall be controlled, calibrated, and adjusted at specified periods to maintain required accuracy.
- (d) Tests shall be performed by trained and qualified personnel.
- (e) Tests shall be verified by persons other than those performing or supervising the test.

5.10 Control of Measuring Test and Inspection Equipment

The QAP shall describe the equipment used in inspections and tests and the measures used to ensure appropriate accuracy. Appropriate equipment shall be calibrated, and the calibration shall be traceable to standards where they exist. Where such standards do not exist, the equipment manufacturer's recommendations shall be followed.

5.11 Control of Nonconforming Items/Materials

The QAP shall describe the measures used by the manufacturer to control materials or items that are found to be discrepant to prevent their inadvertent use. Nonconforming materials/items shall be identified. The discrepant condition(s) shall be documented. The process for determining, documenting, and verifying corrective action shall be described, including the involvement of the purchaser.

5.12 Quality Assurance Records

The QAP shall provide for quality assurance records.

- (a) Records shall be specified, compiled, and maintained to furnish documentary evidence that services, materials, and completed PVHOs meet this and applicable referenced standards.
- (b) Records shall be legible, identifiable, and retrievable.
- (c) Records shall be protected against damage, deterioration, or loss.

(d) Requirements and responsibilities for record transmittal, distribution, retention, maintenance, and disposition shall be established and documented.

(e) Records required for traceability shall be retained for a minimum of 12 yr.

5.13 Standard Repair Planning

The QAP shall describe methods for repairing discrepancies that are expected to occur during the PVHO manufacture.

5.14 Quality Assurance Overview by an Independent Third Party

An independent third-party agency shall be employed to ensure that all PVHOs produced under this Case are designed and manufactured to the requirements of PVHO-1-2012 and this Case. This includes, but is not restricted to, the following:

(a) The PVHO is designed in accordance with PVHO-1-2012 and this Case.

(b) The manufacturer is working to the requirements of the quality control system.

(c) The materials used in construction of the PVHO comply with Table 15-1 as required by PVHO-1-2012 and this Case.

(d) The manufacturing operations are conducted in accordance with approved procedures by qualified operators as required by PVHO-1-2012 and this Case.

(e) All defects are acceptably repaired.

(f) All prototype and production testing has been performed and witnessed as required by PVHO-1-2012 and this Case.

(g) The PVHO is marked in accordance with PVHO-1-2012 and this Case.

(h) A visual inspection of the PVHO is conducted to confirm that there are no material or dimensional defects.

The manufacturer shall arrange and give the third-party inspection agency free access to all facilities associated with the manufacture of the PVHO. The manufacturer shall keep the third-party inspection agency informed of the progress of the work and shall notify them reasonably in advance when PVHOs will be ready for any required tests or inspections.

6 MARKING

(a) In lieu of PVHO-1-2012, subsection 1-9, the external surface of the jacket shall be permanently marked with stencil, close to one end, with the data required in PVHO-1-2012, para. 1-9.1, and the following (sample) designation:

15-PVHO (C15)-HTI-0001-2009

where

15 = rated pressure, psig

PVHO (C15) = PVHO designator and Case number

HTI = manufacturer's initials

0001 = manufacturer's unique identification for the PVHO

2009 = year of manufacture

(b) The jacket of the PVHO shall be labeled to indicate

(1) maximum operating pressure is 15 psig (100 kPa)

(2) operating temperature range [min./max.: 0°F (−18°C)/100°F (38°C)]

(3) storage temperature range [min./max.: −10°F (−23°C)/150°F (66°C)]

(4) allowable life is 4,000 cycles

(5) airflow rate to maintain operating pressure is 15 SCFH

(6) expiration date 10 yr from date of manufacture

(c) The marking shall state, CHAMBER CANNOT BE USED AFTER EXPIRATION DATE, and there shall be cautionary notes that the chamber should not be exposed to direct sunlight or UV light sources for an extended period and diver treatment is not recommended; the chamber is for emergency use only. The following notice shall also be marked on the PVHO: NOT FOR HOSPITAL USE, HEALTH CARE FACILITIES, INCLUDING NURSING HOMES, LIMITED-CARE FACILITIES, OR CLINICS.

(d) The following restriction shall be conspicuously marked at the inlet port: PRESSURIZE WITH AIR ONLY (23.5% O₂ max.).

(e) The vessel shall also display the following notices:

(1) ATTENDANT REQUIRED AT ALL TIMES.

(2) ITEMS THAT CAN BE DANGEROUS INSIDE A CHAMBER (SUCH AS FLAMMABLE ITEMS, OPEN FLAMES, HAND WARMERS, AND ELECTRONIC DEVICES) ARE PROHIBITED.

(3) CHAMBER SHALL BE OPERATED BY QUALIFIED PERSONNEL.

7 DOCUMENTATION

Form GR-1 in PVHO-1-2012 shall be replaced with PVHO-1 Case 15 Form, Manufacturer's Data Report for Pressure Vessels for Human Occupancy. All other documentation requirements of paras. 1-7.9, 5-1.3, 6-1.4, and 6-2.11 shall be complied with.

The definition of "lot" for fabricator's testing requirements and traceability is the amount of homogeneous run of material made at the same time in a predetermined quantity (i.e., yards or pounds) and the specific quantity received from such lot. Each lot shall, as far as practical, consist of units of product of a single type, grade, class, size, and composition; manufactured under essentially the same conditions and at essentially the same time.

PVHO-1 Case 15 Form Manufacturer's Data Report for Pressure Vessels for Human Occupancy

1. Manufactured and certified by _____
2. Manufactured for _____
3. Vessel identification _____
(manufacturer's serial no.) (year built)
4. The design, construction, workmanship, and chemical and physical properties of all parts meet the applicable material specifications of PVHO-1-2012 and Case No. 15.
The ultimate strength of the webbing at 100°F is _____, the jacket is _____, the buckle is _____, the bladder is _____, the penetrator flange is _____, and the film is _____.
5. Window shield: Certification Reports, properly identified and signed by the window fabricator, are attached for the acrylic material.
6. Manufactured for a maximum allowable working pressure of 15 psig (103.4 kPa), a maximum working temperature of 100°F (38°C), and a pneumatic internal test pressure of 22.5 psig (155 kPa) and maximum of 4,000 cycles.
Ten-year life ending _____.
7. Design analysis conducted by _____

CERTIFICATION OF DESIGN, FABRICATION, AND QUALITY ASSURANCE

User's Design Specification on file at _____

Manufacturer's Design Report on file at _____

Prototype test program attested by _____

Quality Assurance Program reviewed by _____

Fabrication documentation reviewed by _____

CERTIFICATION OF COMPLIANCE

We certify that the statements made in this report are correct and that all details of the design, material, construction, and workmanship of this vessel conform to the ASME Safety Standard for Pressure Vessels for Human Occupancy (PVHO-1) and PVHO Case 15.

Date _____ Company name _____ Signed _____

PHVO-1 Case 16

Use of Nylon-Jacketed, Aliphatic-Coated Bladder, Zippered Closure Cylindrical Vessels in the Construction of PVHOs Under PVHO-1–2012

Approval Date: November 20, 2012
 Reaffirmation Date: December 3, 2015
 Expiration Date: December 3, 2021

Inquiry: Under what conditions may a portable flexible nylon-jacketed, aliphatic-coated bladder with redundant zipper closures be used in construction under the rules of PVHO-1–2012?

Reply: It is the opinion of the Committee that portable flexible nylon-jacketed, aliphatic-coated bladder-type cylindrical vessels with redundant zipper closures may be constructed under the requirements of PVHO-1–2012 and be marked as a PVHO when the requirements of PVHO-1–2012, with the following exceptions and additions, have been met.

1 GENERAL

The PVHO chamber shall be a flexible composite cylinder consisting of an inner bladder (see Fig. 15T38145), an outer jacket, and webbing secured with mechanical safety buckles. The bladder and jacket are closed with three overlapping zippers that provide an initial pressure seal. Two opposing transparent windows permit viewing of the occupant. Connections for pressurization and breathing gas are located at the ends. The window shield (clear viewport retaining cover, see Section A-A in Fig. 15T38145) is supported by the jacket and webbing.

The chamber shall be pressurized with a continuous flow of air that shall be expelled through a ventilation valve. The PVHO and associated systems shall be designed, constructed, inspected, tested, and marked (and installed if applicable) to ASME PVHO-1–2012, Sections 1, 2, 3, 4, and 5 with exceptions and additions detailed in this Case.

1.1 Exclusions

The following sections/paragraphs of PVHO-1–2012 are not applicable to vessels built under this Case:

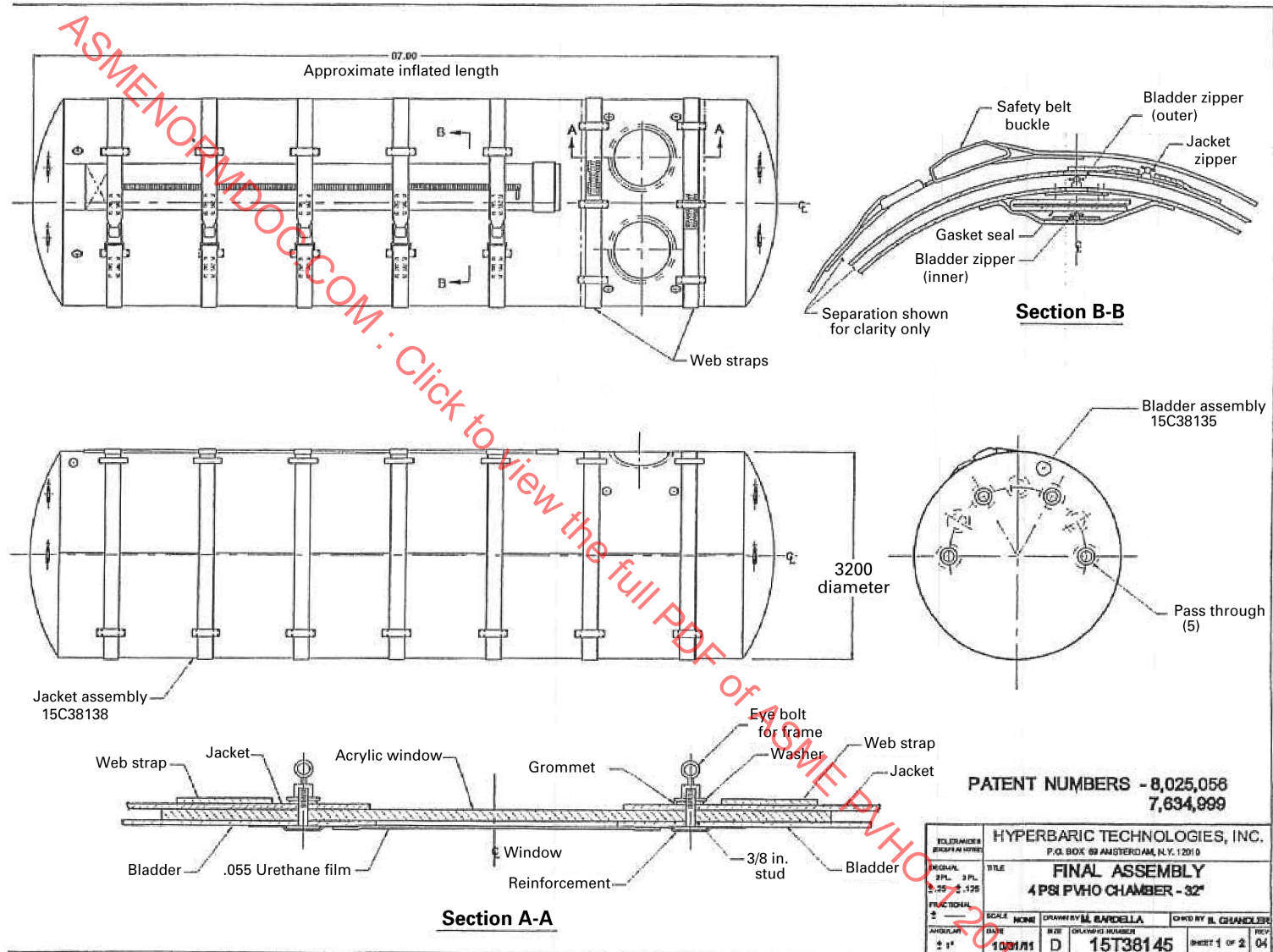
- (a) sections 1-6, 1-7.1 through 1-7.3, 1-7.5, 1-7.8, and 1-7.11 through 1-7.16
- (b) sections 2-2, 2-7, 2-8, and 2-10
- (c) section 5-5.7
- (d) Section 6
- (e) Section 7

1.2 User's Design Specification

A User's Design Specification shall be provided. The User's Design Specification shall include the following data:

- (a) The maximum number of occupants is one.
- (b) The maximum allowable internal working pressure (MAWP) shall be 4 psig (0.275 bar).
- (c) Pressurization gas shall only be air, and a label to this effect shall be suitably displayed, and an exhaust valve and an ASME overpressure relief valve shall be fitted with a "gag" device operable from outside the chamber.
- (d) The breathing gas supplied to the occupant of the PVHO shall be 100% oxygen through a built-in breathing system (BIBS) mask or hood. The operator of the PVHO shall have external control of the supply of breathing gas. The operator shall ensure that sufficient gas is available for flushing the PVHO if necessary, and there shall be sufficient emergency gas available to complete the proposed treatment safely. All exhaled gas shall leave the PVHO via an overboard dump system.
- (e) The pressurization/depressurization rates shall be no greater than 1 psi/min.
- (f) Chamber managed airflow rate to maintain MAWP shall not exceed 15 standard ft³/hr (SCFH).
- (g) The PVHO shall have two windows in the body of the chamber. The windows shall permit external viewing of the occupant's head, face, chest, and arms.
- (h) Maximum internal length shall be 97 in. (2.46 m).
- (i) Internal diameter shall be 32 in. (0.8128 m) nominal.
- (j) Three overlapping zippers shall be used. The outer zipper is necessary for ease in preparing the sealing gasket for inflation and would also prevent rapid air loss in the unlikely event of premature opening of the inner zippers.
- (k) The design temperature limits shall be 32°F to 100°F (0°C to 37°C). The design storage temperature range shall be –30°F to 150°F (–34.5°C to 65.5°C).
- (l) The design number of pressure cycles shall not exceed 4,000 cycles.
- (m) The rated life is 10 yr from the date of manufacture, or on completion of the 4,000 pressure cycles, or

Fig. 15T38145 PVHO Chamber



GENERAL NOTES: Chamber is shown inflated.