ASME PVHO-1–2007

(Revision of ASME PVHO-1–2002)

Safety Standard for Pressure Vessels for Human Occupancy

AN AMERICAN NATIONAL STANDARD

The American Society of Mechanical Engineers

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Three Park Avenue • New York, NY 10016

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The next edition of this Standard is scheduled for publication in 2010. There will be no addenda issued to this edition.

ASME issues written replies to inquiries concerning interpretations of technical aspects of this Standard. Once approved, interpretations are published on the ASME Web site under the Committee Pages at http://cstools.asme.org and are subsequently published in the next edition of this Standard.

Users of this Standard are advised to check the ASME PVHO Committee Web page periodically for interpretations, errata, and cases.

The American Society of Mechanical Engineers
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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 has 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 (−18°C) to 150°F (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 has been 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 have been expanded to include unstiffened and ring stiffened cylinders, in addition to spheres. New additions are the sections pertaining to application specific PVHOs. Sections are included for medical hyperbaric systems, diving systems, submersibles, and quality assurance. The piping section has been expanded. Where possible, Mandatory Appendices have been incorporated into the body of the document. All forms have been 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.

There is still important work being accomplished by the Subcommittee in the areas of PVHOs utilizing nonstandard materials including nonmetallic PVHOs and expanding post construction considerations. A companion document (PVHO-2) that covers in-service guidelines for PVHO acrylic windows has been published.

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

ASME PRESSURE VESSELS FOR HUMAN OCCUPANCY COMMITTEE

(The following is the roster of the Committee as of December 28, 2006.)

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CORRESPONDENCE WITH THE PVHO COMMITTEE

General. ASME Standards are developed and maintained with the intent to represent the consensus of concerned interests. As such, users of this Standard may interact with the Committee by requesting interpretations, proposing revisions, proposing PVHO cases and attending Committee meetings. Correspondence should be addressed to:

Secretary, PVHO Standards Committee
The American Society of Mechanical Engineers
Three Park Avenue
New York, NY 10016-5990

Proposing Revisions. Revisions are made periodically to the Standard to incorporate changes that appear necessary or desirable, as demonstrated by the experience gained from the application of the Standard. Approved revisions will be published periodically.

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.

Interpretations. Upon request, the PVHO Standards Committee will render an interpretation of any requirement of the Standard. Interpretations can only be rendered in response to a written request sent to the Secretary of the PVHO Standards Committee.

The request for 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, which are necessary to explain the question; however, they should not contain proprietary names or information.

Requests that are not in this format will be rewritten in this format by the Committee prior to being answered, which may inadvertently change the intent of the original request. ASME procedures provide for reconsideration of any interpretation when or if additional information that might affect an interpretation is available. Further, persons aggrieved by an interpretation may appeal to the cognizant ASME Committee or Subcommittee. ASME does not "approve," "certify," "rate," or "endorse" any item, construction, proprietary device, or activity.

PVHO Cases. The ASME PVHO Committee issues Cases. Although PVHO Cases do not constitute formal revisions of the Standard, they may be used as representing considered opinions of the PVHO Committee. Once approved, Cases are posted on the ASME PVHO Committee Web page at http://cstools.asme.org and are subsequently published with the next edition of this Standard. PVHO Cases are not part of the Standard and are included for information only following the nonomandatory appendices.

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.

Errata. ASME issues errata (corrections to errors introduced in the Standard during the publishing process; e.g., typographical errors, misspellings, grammatical errors, incorrect publication of revisions). Once approved, errata are posted on the ASME PVHO Committee Web page at http://cstools.asme.org and are subsequently published with the next edition of the Standard.

Attending Committee Meetings. The PVHO Standards Committee regularly holds meetings, which are open to the public. Persons wishing to attend any meeting should contact the Secretary of the PVHO Standards Committee.

IN MEMORIAM

The PVHO Committee wishes to acknowledge three of our Charter members who died unexpectedly during the production of this edition; they were major contributors to PVHO for more than 20 years. Audley L. (Len) Aaron died in October 2004, Edward M. Briggs died in December 2005, and Jerry D. Stachiw died in April 2007.

Aaron was a major contributor to the development of this document. In addition, he supported PVHO as a tireless contributor, Subcommittee Chair, Standards Committee Vice Chair, and Charter member. His presence, as well as his continual guidance to the committee that "less is more" when it comes to the wordiness of our documents, will be truly missed.

Briggs was an active member from 1975 until his death in 2005. He served as Standards Committee Chair from 1980 until 1991 and as a member of the Board of Pressure Technology from 1982 to 2001. He will be kindly remembered as the "resident friendly curmudgeon" of the group and the person who kept PVHO pointed in the right direction.

Stachiw had been a driving force behind PVHO since its inception. PVHO established its uniqueness by providing reliable and certifiable acrylic window configurations. Most of the information used for PVHO windows was generated by Stachiw from work he accomplished while with the Navy and as a world-recognized consultant in PVHO window technology. He served for 35 years on the committee and was an Honorary Member since 1987. He continued to attend meetings and contributed to the technical advancement of the current edition of PVHO-1. Stachiw also provided valuable input to the development of PVHO-2.

ASME PVHO-1–2007
SUMMARY OF CHANGES

Following approval by the ASME PVHO Committee and ASME, and after public review, ASME PVHO-1–2007 was approved by the American National Standards Institute on June 20, 2007.

ASME PVHO-1–2007 has been revised in its entirety.

SPECIAL NOTE:

The cases to PVHO-1 follow the last page of this edition. The cases, however, are not part of the Standard itself.

SAFETY STANDARD FOR PRESSURE VESSELS FOR HUMAN OCCUPANCY

Section 1
General Requirements

1-1 INTRODUCTION

This Standard defines the requirements that are applicable to all Pressure Vessels for Human Occupancy (PVHOs) fabricated to this Standard and shall be used in conjunction with specific requirements in other Sections and mandatory appendices of this Standard.

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 (Code), Section VIII 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 its pressure boundary while under internal or external pressure exceeding a differential pressure of 2 psi. PVHOs include, but are not limited to, submersibles, diving bells, personnel transfer capsules; and 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 closure
(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 Specifications.

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.

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 E 208 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 Table UG-84.3 or Table AM-204.3, 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 form of material shall comply with the requirements of the specifications listed in either Table UG-84.3 or Table AM-203.3, as applicable, in all respects, except 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), (b), and (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), (b), and (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 design minimum 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, B, and C shall be Type No. 1 of Table UW-12 for Section VIII, Division 1 vessels or shall comply with AF-221 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. Backing strips shall be removed.

(c) Intermediate heads may be designed in accordance with Fig. UW-13.1(f) 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 shell mean radius times the shell thickness from the centerline of the butt weld to either side [reference Fig. UW-13.1(f) 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 para. 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 Category A, B, and D butt welds shall be 100% radiographed. All Category C and D corner welds shall be 100% ultrasonically examined. Both the above radiographic and ultrasonic inspection shall be performed in accordance with 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 Division 1.

(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 must be sound. This must be shown by MT or PT examination. If necessary, chipping, grinding, or melting-out may be required to assure 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 magnetic particle examination (Section V, Article 7, of the Code) or liquid penetrant testing (Section V, Article 6, of the Code). The acceptance criteria shall be those of the applicable requirements 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 it 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 of either 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) Where applicable, 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.

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 according to the applicable section of this Standard and/or the specified Division of Section VIII of the Code.

1-7.9 Documentation

A copy of the Manufacturer's Data Report, PVHO Form GR-1, and Forms U-1 and U-2 for PVHOs built to Section VIII of the Code, shall be furnished to the user or his designated agent. The Manufacturer shall retain a copy of the Manufacturer's Data Reports and PVHO Form GR-1 and all viewport supporting documents per Section 2 on file for at least 5 years from date of manufacture. Nondestructive testing documentation shall meet the requirements of Section V of the ASME Code. Documentation shall also include

(a) instructions critical to the maintenance of the PVHO

(b) instructions critical to the operation of the PVHO
(c) the vessel coating information
(d) stamping
(e) standards used
(f) seal and gasket sizes and materials
(g) assembly drawings
(h) user design specification
(i) evidence of successful completion of test(s) required in para. 1-7.8

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 Design

1-7.13.1 General. All external pressure hulls, regardless of the design rules used, will be subjected to an external pressure test in accordance with para. 1-7.13.6(a).

This paragraph provides alternative rules to those given in Section VIII, Division 1, UG-28, UG-29, and UG-33, or Section VIII, Division 2, Article D-3, 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 chamber design that is lighter weight than that using the rules of Section VIII, Divisions 1 and 2. When used, this paragraph shall be made applicable to the entire vessel.

The hull design must consider all load conditions in addition to external pressure loadings. These loading conditions shall include, but are not limited to, those specified in Division 1, UG-22 and Division 2, AD-110.

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 AD-520(b), as applicable. The required thickness shall be determined in accordance with para. 1-7.13.4. The factor, F, used in UG-37(c) and AD-520(a) shall be 1.0. Openings in shells that exceed these limitations require a special design based upon 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 midbay in stiffened cylinders. If 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.

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 areas of load application where stress distribution may be nonlinear 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_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}

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}

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

e_x = local deviation from a straight line measured along a meridian over a gauge length, L_x

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).

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 outstanding 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, $I = \pi R^3 t$, in.^{4}

I_F = the value of I_s', which makes a large stiffener act as a bulkhead. The effective length of shell is

= $L_e = 1.1\sqrt{(D_o t)}\ (A_1/A_2)$

I_s' = moment of inertia of ring stiffener plus effective length of shell about centroidal axis of combined section, in.^{4}

= $I_{s+} A_s Z_s^2\ [L_e t\ /\ (A_s + L_e t)] + L_e t^3/12$

I_s = moment of inertia of ring stiffener about its centroidal axis, in.^{4}

$L, L_1, L_2, L_3, L...$ = design length of unstiffened vessel section between lines of support. 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)

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 = gage length measured along meridian of cylinder, in.

M_s = $L_s/\sqrt{R_o t}$

M_x = $L/\sqrt{R_o t}$

P = applied external pressure, psi

PT = external test pressure, equal to 1.25P, psi

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 ACS-1, AHA-1, and AQT-1 of Section VIII, Division 2 of the Code. Materials not acceptable for use for pressure parts are identified in para. 1-6. General requirements for materials are listed in para. 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 Articles F-4 and F-6 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.

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 ⅜ 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 ⅝ 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:

FS = 2.0 if $F_{ic} \le 0.55\ F_y$
= $2.407 - 0.741\ F_{ic}/F_y$ if $0.55\ F_y < F_{ic} < F_y$
= 1.667 if $F_{ic} \ge F_y$

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 for stiffened and unstiffened cylindrical shells is given by the following equations:

P = minimum of P_1 and P_2
$P_1 = 2F_{ha}(t/D_o)$
$P_2 = 1.067F_y(t/D_o)$

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
F_{ha} = F_y/FS if $F_{he}/F_y \ge 2.439$
= $(0.7\ F_y/FS)\ (F_{he}/F_y)^{0.4}$ if $0.552 < F_{he}/F_y < 2.439$
= F_{he}/FS if $F_{he}/F_y \le 0.552$

and where
C_h = $0.55(t/D_o)$ if $M_x \ge 2(D_o/t)^{0.94}$
= $1.12\ M_x^{-1.058}$ if $13 < M_x < 2(D_o/t)^{0.94}$
= $0.92\ /\ (M_x - 0.579)$ if $1.5 < M_x \le 13$
= 1.0 if $M_x \le 1.5$
F_{he} = $1.6C_hE(t/D_o)$

(d) Sizing of Stiffener Rings

(1) Small Rings

$$I_s' \ge 1.5F_{he}\ L_sR_c^2\ t/E(n^2 - 1)$$

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

$$n^2 = 2D_o^{3/2}/3L_Bt^{1/2}$$

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

(2) Large Ring Acting as a Bulkhead

$$I_s' \ge F_{hef}L_FR_c^2t/2E$$

(3) Stiffener Geometry Requirements. Stiffener geometry requirements are as follows. See Fig. 1-17.13.1-2 for stiffener geometry and definition of terms.

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

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

(b) Web of tee stiffener or leg of angle stiffener attached to shell

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

(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 AF-130.2. In place of the maximum deviation requirements specified in UG-80(b)(2) or AF-130.2(a), 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

$n = c\left[\sqrt{(R/t)}/(L/R)\right]^d$

$c = 2.28(R/t)^{0.54} \le 2.80$

$d = 0.38(R/t)^{0.044} \le 0.485$

and

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

(3) All requirements of UG-80(a) or AF-130.1 are applicable. The requirements of UG-80(b)(3), (6), (7), (8), and UG-80(b)(10) or AF-130.2(b) and AF-130.4 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.

$e_x = 0.002R$

$L_x = 4\sqrt{(Rt)}$ but not greater than L for cylinders

$= 25t$ across circumferential welds

$L_x < 95\%$ 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 iterative procedure following. 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 ⅜ 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 = the larger of C_1 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 with the value of C calculated in step 1. Move horizontally to an intersection with the solid curve. Extrapolation beyond the upper or lower limits of the curve is prohibited. When values of C fall outside the limits of Fig. 1-7.13.5, design shall follow rules of Section VIII, UG-28(d) for Division 1 or AD-320 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 neither be less than ⅜ in. (10 mm) 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 Article D-3 (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 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 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.

1-7.13.6 External Pressure Test

(a) Test Pressure. All vessels designed in accordance with section 1-7.13 shall be subjected to an external hydrostatic pressure test that subjects every part of the vessel to an external pressure, *PT*, not less than 1.25*P* 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 Gaging. As part of the hydrostatic test, strain gages are to be applied to the pressure hull. Gages are to be applied at hard spots, discontinuities, high-stress regions, and other locations deemed appropriate. Appropriate strain gage types (single gage, or biaxial/triaxial strain gage rosettes) are to be used at each location. A drawing(s) shall be created indicating the locations of the gages on the pressure hull. At the conclusion of the test, a hydrostatic test report shall be created. This report shall include strain gage locations, strain gage type at each location, the criteria used to select the strain gage 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 gage 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, 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, Appendix 1-6(g) and that calculated from section 1-7.13.

1-7.15 Rectangular Door Design

If rectangular openings are employed in either Division 1 or 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 Appendix 4. For Division 1 vessels, Appendix 4 of Division 2 may be used as a guide using the allowable stress of Division 1.

1-7.16 Supports and Attachments

Consideration shall be given to the following:

(a) The design must 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 is to 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 AR (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 frangible seal as permitted in Section VIII, UG-135(e) and Appendix M of Division 1 and Appendix 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 _____psi (_____MPa) (internal) and/or _____psi (_____MPa) (external) at _____°F (_____°C) maximum and _____°F (_____°C) minimum

(4) manufacturer's serial number

(5) year built

(6) design criteria: PVHO-1–2007; 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(b)-1 or Fig. 1-9(b)-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.

(c) Nameplates shall have markings produced by casting, etching, embossing, de-bossing, 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 and readable.

(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 OFFGAS TESTING

(a) All nonmetallic materials offgas volatile substances that may be toxic. The rate of offgassing 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, offgassed 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 (CO_2), offgassed volatiles will accumulate. Thus, after fabrication and completion of all outfitting, the toxicity offgas 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 Offgas Testing Procedures

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

(2) Where the normal duration of PVHO occupation is less than 8 hr, the PVHO is to be sealed and maintained at maximum operating temperature for at least 8 hr, after which time atmospheric gas samples are to be obtained from inside the PVHO and analyzed. The offgassing test is to be performed with all openings sealed and with the PVHO at one atmosphere (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 GC/MS methods. The concentration level of volatile compounds shall not exceed the TLV values set forth in the current edition of the *ACGIH Threshold Limit Values for Chemical Substances*, or the OSHA PELs set forth in 29 CFR 1910.1000, as stipulated by the user. If any of those limits are exceeded, the PVHO must be well ventilated with clean air, and the procedure must 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 must 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 exception that the PVHO is to be sealed and maintained at maximum operating temperature for at least the maximum duration of exposure anticipated. The ACGIH TLV (or OSHA PEL) values used for evaluation shall be modified by multiplying them by a value of *Fp* as shown in Table 1-10 (linear interpolation is permitted):

(6) Where normal durations of PVHO occupation exceed 24 hr, the duration of offgas 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 offgas duration may be limited to 24 hr, with the results multiplied by five, provided that the quantification and reporting limits were less than 5 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 five) 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 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 must not exceed 0.1 ppm, regardless of their ACGIH TLV (or OSHA PEL), or duration of occupation. That is, Table 1-10 does NOT apply for 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 are to be in accordance with paras. (3), (5), or (6) above, as applicable.

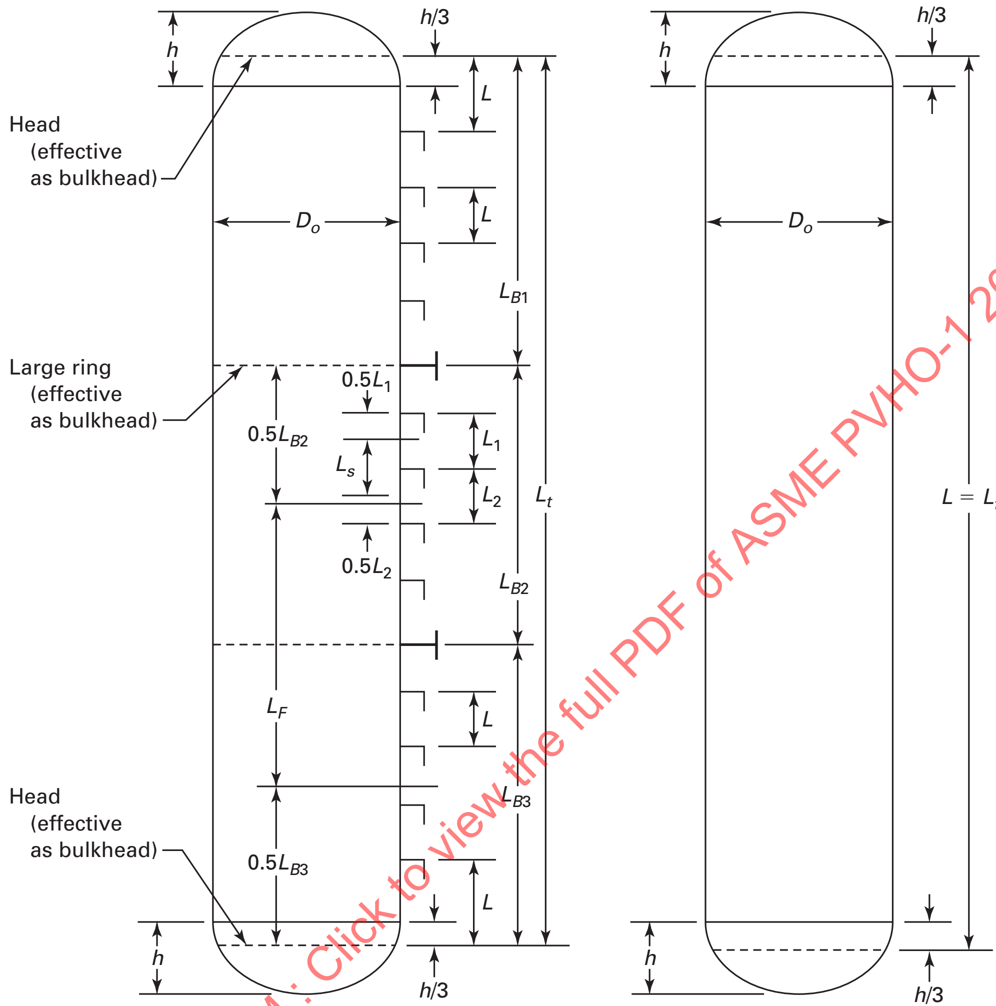
(9) Where potential sources of mercury vapor are anticipated, on-site testing for its presence should be done using either color-change indicator tubes with a sufficiently low detection limit or a gold-film type analyzer. Evaluation of test results are to be in accordance with paras. (3), (5), or (6),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

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

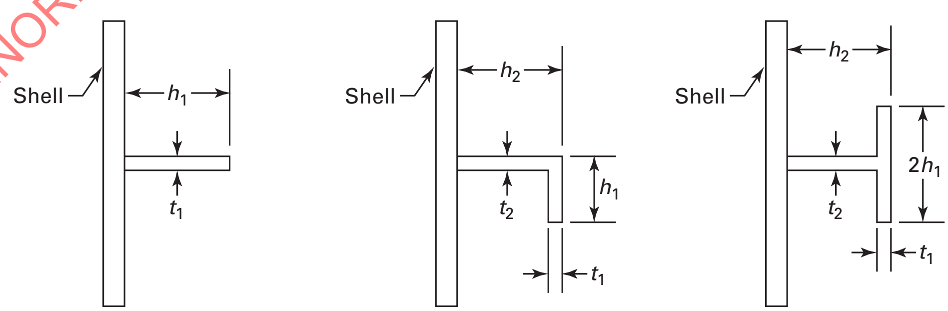
Fig. 1-7.13.1-1 Geometry of Cylinders



(a) Ring Stiffened

(b) Unstiffened

Fig. 1-7.13.1-2 Stiffener Geometry

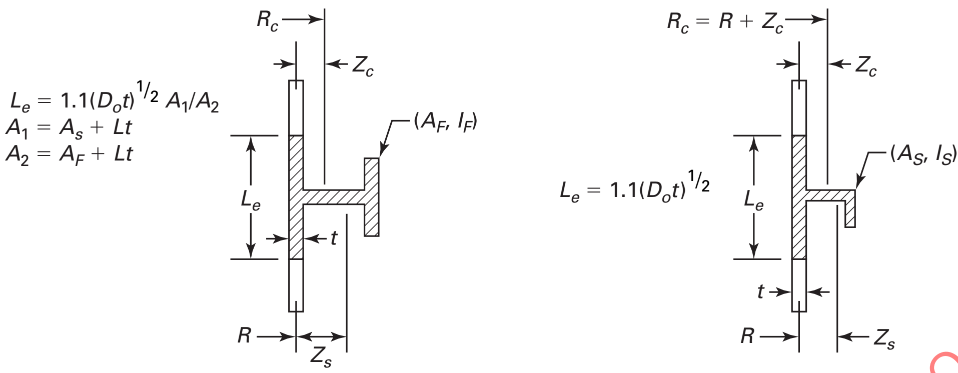


(a) Bar

(b) Angle

(c) Tee

Fig. 1-7.13.1-3 Sections Through Rings



(a) Large Ring That Acts as a Bulkhead

(b) Small Ring

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

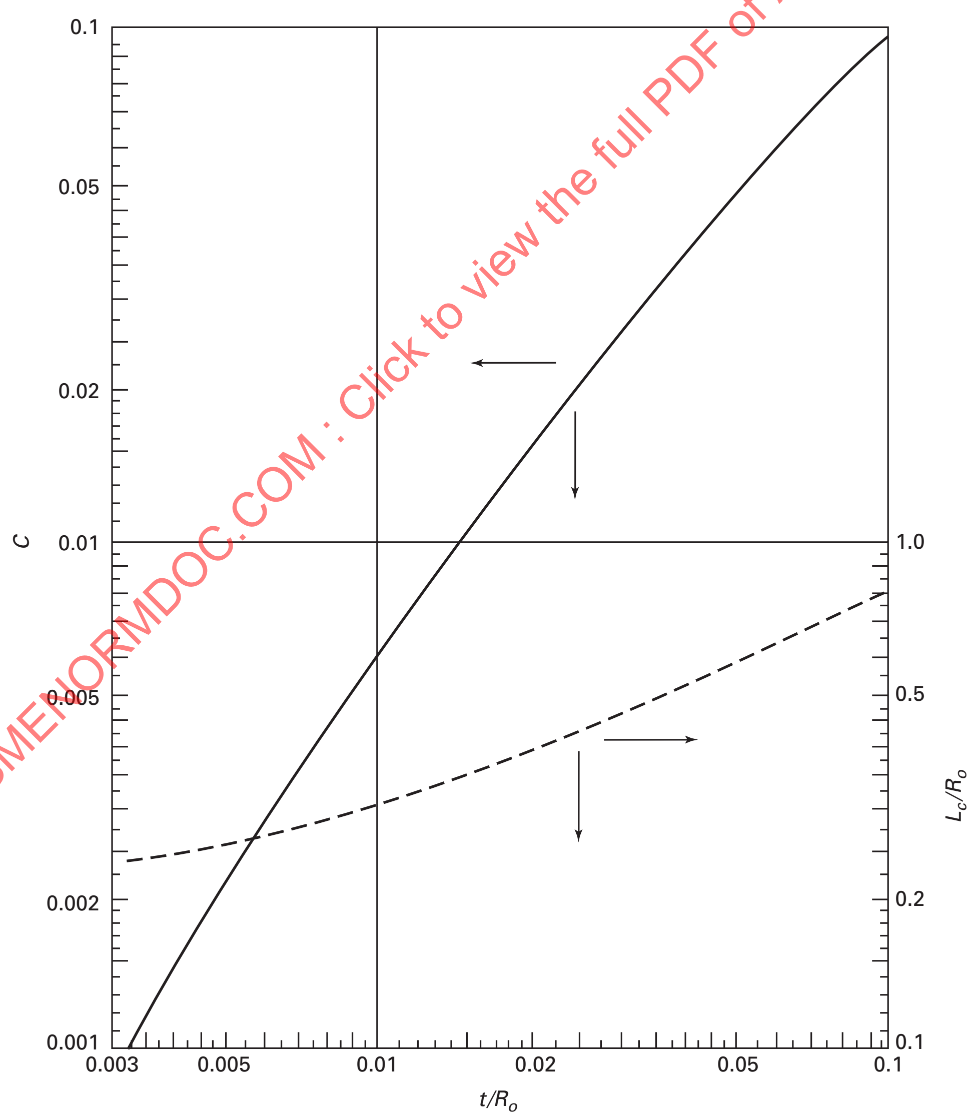


Fig. 1-9(b)-1 Form of Nameplate, U.S. Customary

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 number) (Year built)

____
(Design criteria)

Fig. 1-9(b)-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 number) (Year built)

____
(Design criteria)

Table 1-10 Conversion Factor, *Fp* (For PVHO Occupation Exceeding 8 hr)

Duration of Exposure	*Fp*
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

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 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 Form PVHO-1 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)

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

PVHO-1 Form GR-1S Manufacturer's Data Report Supplementary Sheet
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 serial no.) (year built)

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

Date ____________. 20______ Company name ______________________________ Signed ______________________________
(PVHO manufacturer) (representative)

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

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) temperature 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, or the total duration of pressure cycles during 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 para. 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 section 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 section 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 section 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 section 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.)

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

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 must 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 incandescent 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 must 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 on Figs. 2-2.10.1-1 and 2-2.10.1-2 and Table 2-2.3.2-1, and t/D_i on 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 (STCP)

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, 2-2.5.1-5, 2-2.5.1-6, and 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 included an 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, 2-2.5.1-2, and 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 conversion factors 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 conversion factors 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 conversion factors 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.

(e) For *spherical sector acrylic windows with square edge*, shown in Fig. 2-2.2.1-2, use conversion factors 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 conversion factors 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 he 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 conversion factors 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 conversion factors 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 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 ambient temperature range of 70°F to 77°F (21°C to 25°C) in a flange that satisfies the requirements of para. 2-2.9.

The evaluation of a window design is to 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 will 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 is to 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 is to 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 will 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 (CF)

2-2.6.1 Case Submittal Procedure. Acrylic windows of nonstandard geometry, or of standard geometry but with nonstandard lower conversion factors (CF) 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 conversion factor for windows meeting the design parameters of section 2-2.

(a) Prior to submission for review, the window design must 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, must 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 duration in design temperature environment without cracking

2-2.6.4 STPP Test Procedure. The STPP of the 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) rate 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 the 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 must exceed the LTPP. The extrapolated failure at 80,000 hr must be at least two times the design pressure.

(f) An alternative to the LTPP tests defined in paras. (b), (c), (d), and (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 sustained pressure equal to 0.9 STPP.

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

(3) Three windows shall be tested at 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 cyclic proof pressure (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 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 must 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°F (5.5°C)

(b) for the long-term pressurization of para. 2-2.6.5, +10°F (5.5°C)

(c) for the cyclic pressurization of para. 2-2.6.6, +25°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 years, while for the windows in the latter category it shall be 10 years. 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 Disc 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 years 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 years from the date of fabrication for $t/D_i < 0.5$ and 20 years 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 years from the date of fabrication for $t/D_i < 0.5$ and 20 years 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 years 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 years 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 years 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 years 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 are not to 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°F (+0/−2.6°C). Brief deviations from the above temperature tolerances are allowed, provided that the deviations do not exceed +10°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 assure 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 exceed $0.001D_o$ 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 must 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 must 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 must be less than $0.002D_i$.

(b) Angular deformation of the window seat at maximum internal or external design pressure must 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 must be 64 μin. RMS or finer, except surfaces in contact with a bearing gasket shall not exceed 125 μin. 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 will 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 must be of sufficient thickness to permit adequate compression without permanent set. Double beveled disk and cylindrical windows shall utilize, 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 utilize, 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 may utilize 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 must be compatible with the window material, and the potting compound must 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 must precompress the gasket to ensure a minimum of 0.01 in. 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, utilizing 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_f of the window.

For flat discs, 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 measured 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 specifications of seal ring manufacturers 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 must not exceed ⅛ 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 neither permitted in the surface of any window shape, nor 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 on 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, $0.125t$ for spherical sectors with square edges, $0.125t$ for cylinders, and $0.25t$ for flat disks under one-way pressurization. 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 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.

2-2.11.12 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 must 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 gage 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 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 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 gage inserted between the mating plane surfaces of the flat disk window or a circular plug gage and the bare seat cavity. The axial force used to seat the window or the plug gage 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 gage 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 μin. RMS.

2-2.12.8 Viewing Surface. Viewing surfaces shall be polished to satisfy ASTM D 702 optical clarity requirements.

2-2.12.9 Other Surfaces. All other surfaces shall be machined or sanded to attain at least a 63 μin. 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 capable of being 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 with addenda.

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 will be shown, and any additional information utilized in the design will 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 paragraph. 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 (see Fig. 2-2.2.1-4), 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 upon the convex surface of the window.

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 that 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 utilized for the fabrication of inserts, provided that the selected alloy is corrosion resistant to stagnant seawater and its tensile and compressive yield strength 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 utilized 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 must 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 μin. 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 μin. 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.

(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 μin. 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 or 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 ≥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 section 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 Groves. 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 para. 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 section 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, 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 must 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 must 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 ½ 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 must 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 must 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 utilized 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 castings 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 para. 2-3.4(a) and (b) on specimens cut from each casting.

(e) Type 2 custom castings shall have tests performed according to para. 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.

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 are to 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 D 638, using a testing speed of 0.20 in. (5.0 mm) per min ±25%.

(b) Tests for compressive deformation shall be per ASTM D 695.

(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 120°F (50°C). The sample size is a ½ in. (12.5 mm) cube. To test nominal ½ 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 ½ in. (12.5 mm) height; instead test a sample, ½ in. × ½ in. (12.5 mm × 12.5 mm) nominal thickness. For materials that are cast with irregular surfaces or thicker than ½ 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)

(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 are to 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, a minimum sensitivity of 0.02%, a photometer having reproducibility of +1% of full scale, and the practices of ASTM E 308 to measure the spectral transmittance in the 290 nm to 330 nm wavelength band. Report the value of one specimen of ½ in. ±0.01 in. (12.7 ± 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 casting 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 casting with the opposite faces polished.

(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 are to 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 ¼ 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 μL aliquot of the plastic-solvent solution into the gas chromatograhic 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 20–30 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. 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 ASTM D 638 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) assuring 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 section 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 assure the finished window meets the dimensional tolerances, material quality, and surface finish requirements specified in sections 2-2, 2-3, and 2-4. Windows that meet the requirements of sections 2-2, 2-3, and 2-4, plus 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 will be considered during a visual inspection; all others will be disregarded.

(a) For spherical sectors with conical edge, hyperhemispheres, NEMO windows, conical frustums with $t/D_i \geq 0.5$, 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 cm^3) of contiguous volume

(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 with $t/D_i < 0.5$, 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 cm^3) 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. 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, double-beveled disks with $t/D_i < 0.5$, 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 inches.

(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 must 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 must be ≥11,000 psi, and the short-term design critical pressure of the window must meet the requirement of this Standard.

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

(c) The minimum tensile strength must be ≥9,000 psi, and the window's STCP must 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 will be considered during a visual inspection; all others will be disregarded.

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

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

(2) critical dimension: 0.06 in. (1.5 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 with $t/D_i < 0.5$, 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: 0.06 in. (1.5 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 allowed on the bearing and sealing surfaces, on any faces of double beveled disks and cylinders, and 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 low pressure face of spherical sector with square edge, and 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 section 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:

50–100–PVHO–RT–21–XX

Year of window fabrication
Fabricator's serial number of window
Window fabricator's name or identification symbol
Initials for Pressure Vessel Human Occupancy
Maximum temperature, °F (°C)
Design pressure, psi (MPa)

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 are to be marked by the window fabricator with PVHO identification per para. 2-6.1 only if the design, material manufacturer, material testing, and fabrications 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 must 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, VP-2, VP-3, VP-4, and VP-5) shall be retained for each window as follows:

(a) One copy of PVHO-1 Forms VP-1, VP-2, VP-3, VP-4, and 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, VP-2, VP-3, and 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 lab, or pressure test the windows according to section 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, VP-2, VP-3, VP-4, and VP-5 for a period not less than the design life of the window plus 2 years.

(e) It shall be the responsibility of the window fabricator to possess and retain PVHO-1 Forms VP-1, VP-2, VP-3, and 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 years.

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.

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 pressuring medium during the test shall be the design temperature for which the window is rated with a tolerance of +0/−5°F (+0/−2.5°C). Brief deviations from the above temperature tolerances are allowed, providing 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 years.

2-8 INSTALLATION OF WINDOWS IN CHAMBERS

2-8.1 Cleaning

The window cavity seat in the flange must 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 must be checked for chemical compatibility with acrylic.

2-8.3 Assembly

After placement of the window inside the window cavity, the primary elastomeric seal will 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 acceptance criteria of section 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 section 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 section 2-5. The assessment of damage shall be performed by an authorized representative of the chamber manufacturer or user, or 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 the severely damaged windows must 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 utilized, 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 must be repaired by a window fabricator.

(b) Repair of severely damaged windows is to 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 must be accompanied by the original Design (PVHO-1 Form VP-2) and the Fabrication Certification (PVHO-1 Form VP-1).

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

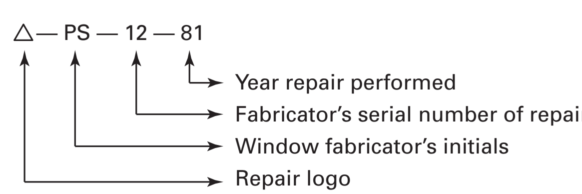
(e) Upon completion of repair, the window is to be annealed according to the schedule of Table 2-4.5-1.

(f) After annealing, the repaired window shall be inspected to assure 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 has been 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 is to be annealed per para. 2-4.5.

(f) Location and extent of spot casting repairs are to be noted on a sketch attached to the Window Certification.

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 must 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 section 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 section 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), (b), and (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). Utilize 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 drawing 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 0–2,500, 2,500–5,000, 5,000–7,500, and 7,500–10,000 psi. For operational pressures above 10,000 psi (69 MPa), utilize Table 2-2.3.2-1.

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 must 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 on 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 bevels on the edges of windows cannot exceed the limits shown on Figs. 2-2.11.10-1 and 2-2.11.10-2.

Step 2: Seal designs that deviate from the requirements of this Standard must 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, must be fabricated by an accredited window fabricator utilizing materials and a production process that meet the requirements of sections 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 Acrylic Window Design Certification, PVHO-1 Form VP-2, filled out by the window designer. PVHO-1 Form VP-2, together with the window drawing, will 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 section 2-4). Review all of the paperwork, which must accompany the window (PVHO-1 Forms VP-1, VP-2, VP-3, and VP-4). Check for completeness and signatures. Compare the marking on the window bearing surface with

(a) the identification number on the Fabrication Data Report, PVHO-1 Form VP-1.

(b) the design temperature and pressure on the Acrylic Window Design Certification, 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, VP-2, VP-3, and VP-4, are 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 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 section 2-7 for details of pressure testing), the test must 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 the Pressure Testing Certification, PVHO-1 Form VP-5.

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

2-10.5 Sample Calculations

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 × P = 10 × 1,000
= 10,000 psi
STCP = 10,000 psi/(145 psi/MPa)
= 68.96 MPa

Step 1.5: Calculate the dimensionless ratio for windows:

t/D_i = 0.41 for STCP = 68.96 MPa
α = 90 deg (Fig. 2-2.5.1-4)

Step 1.6: Calculate nominal window dimensions:

T/D_i = 0.41 D_i = 10 in.
α = 90 deg
t = 0.41 × 10 in. = 4.1 in.

Add 0.1 in. to thickness for future operational contingencies:

Nominal angle = 90 deg
Nominal D_i = 10 in.
Nominal t = 4.2 in.
Nominal D_o = 18.4 in.

Step 1.7: Apply dimensional tolerances to windows:

D_o = 18.400 +0.000/−0.020 in. (to sharp edge)
t = 4.200 +0.020/−0.000 in.
α = 90 +0.25/−0.00 deg
Bearing surface finish = 32 μin. RMS

Step 2.1: Calculate nominal dimensions for seat cavity:

D_o = 18.400 in. α = 90 deg
D_i/D_f = 1.03 for pressure range N = 1 and included angle 90 deg
D_f = 10.000/1.03 = 9.709 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:

D_f = 9.704 +0.010/−0.000 in.
α = 90 +0.00/−0.25 deg
= 18.400 +0.20/−0.000 in.

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.

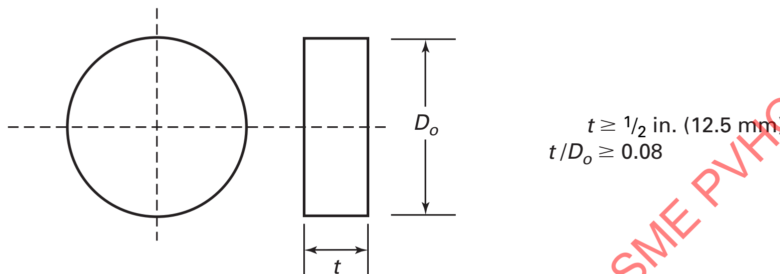
Step 3.2 Enter the following final viewport dimensions on drawing:

Window:
D_o = 18.400 +0.00/−0.020 in. (to sharp edge)
= 17.800 +0.00/−0.020 in. (to beveled edge)
T = 4.200 +0.020/−0.00 in.
α = 90 +0.25/−0.000 deg

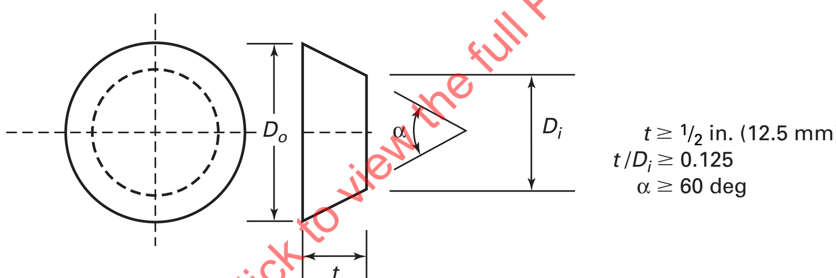
Seal:
O-ring thickness = ¼ in. (nominal)
O-ring inside diameter = 17.75 in. (nominal)

Seat:
D_o = 18.400 +0.020/−0.000 in.
D_f = 9.709 +0.010/−0.000 in.
α = 90 +0.000/−0.25 deg

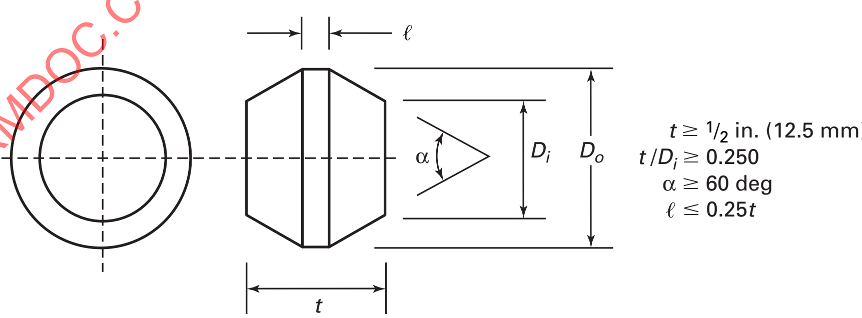
Fig. 2-2.2.1-1 Standard Window Geometries



(a) Flat Disk Window

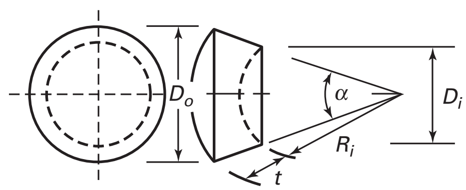


(b) Conical Frustum Window



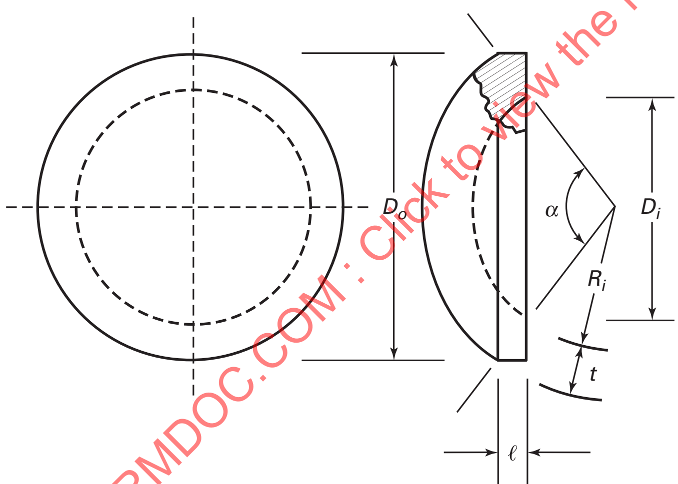
(c) Double Beveled Disk Window

Fig. 2-2.2.1-2 Standard Window Geometries



$t \geq 1/2$ in. (12.5 mm)
$\alpha \geq 30$ deg
$t/R_i \geq 0.09$ for $\alpha \geq 60$ deg
$t/R_i \geq 0.06$ for $\alpha \geq 90$ deg
$t/R_i \geq 0.03$ for $\alpha = 180$ deg

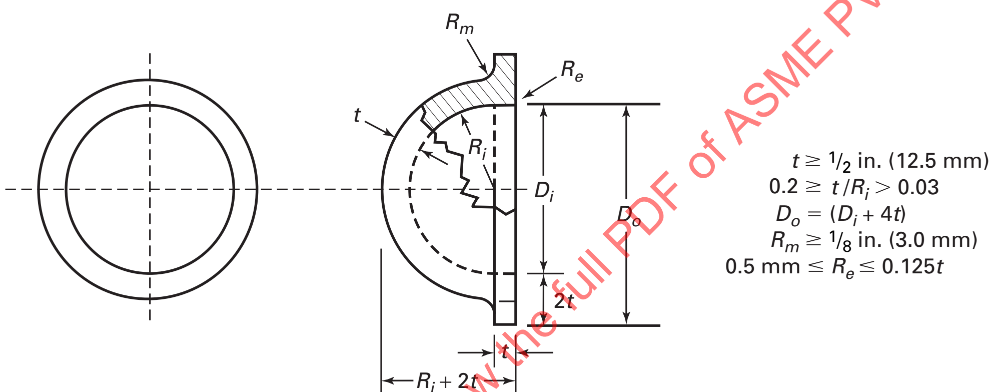
(a) Spherical Sector Window With Conical Edge



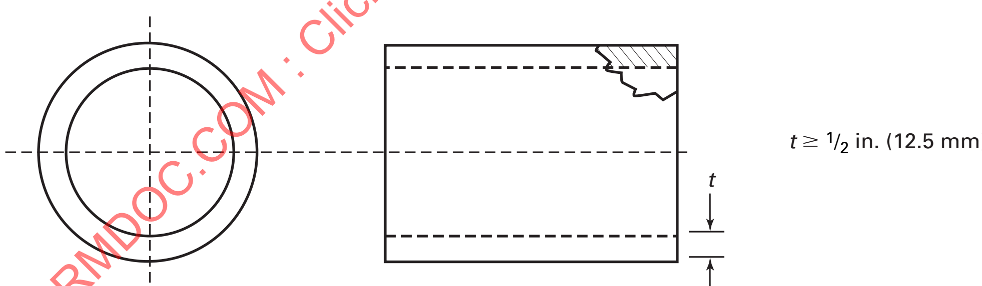
$t \geq 1/2$ in. (12.5 mm)
30 deg $\leq \alpha \leq$ 150 deg
$t/R_i \geq 0.03$
$D_i = 2R_i \sin \alpha/2$
$D_o = 2R_o \sin \alpha/2$
$R_o = R_i + t$
$\ell = t \sin (90 \text{ deg} - \alpha/2)$

(b) Spherical Sector Window With Square Edge

Fig. 2-2.2.1-3 Standard Window Geometries

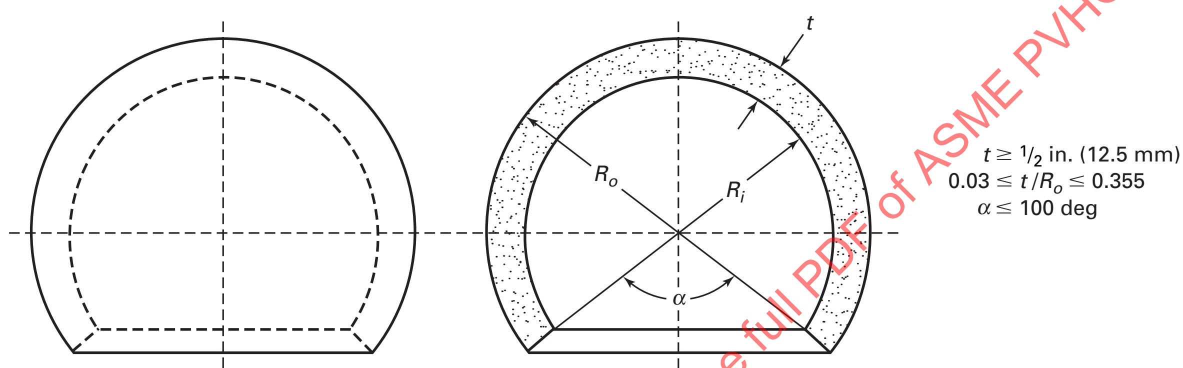


(a) Hemispherical Window With Equatorial Flange

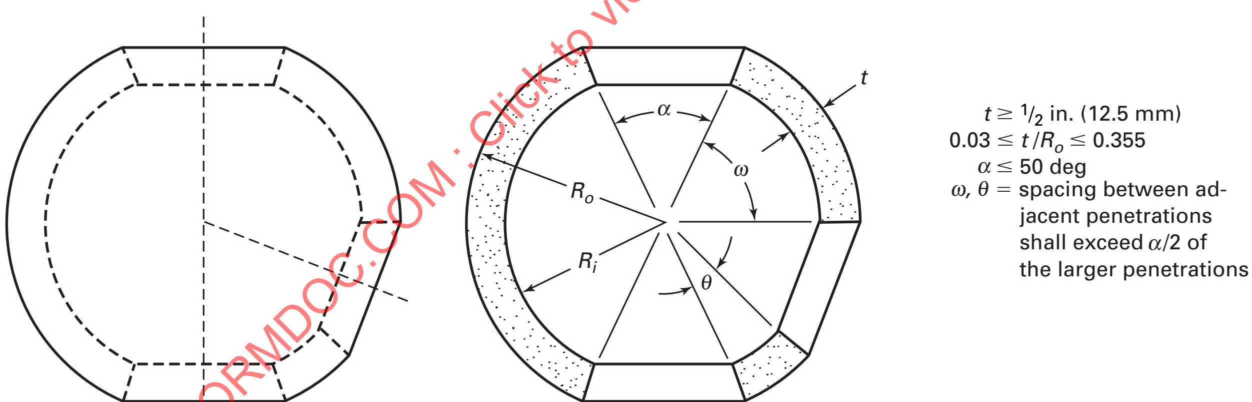


(b) Cylindrical Window

Fig. 2-2.2.1-4 Standard Window Geometries



(a) Hyperhemispherical Window



(b) NEMO Window

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

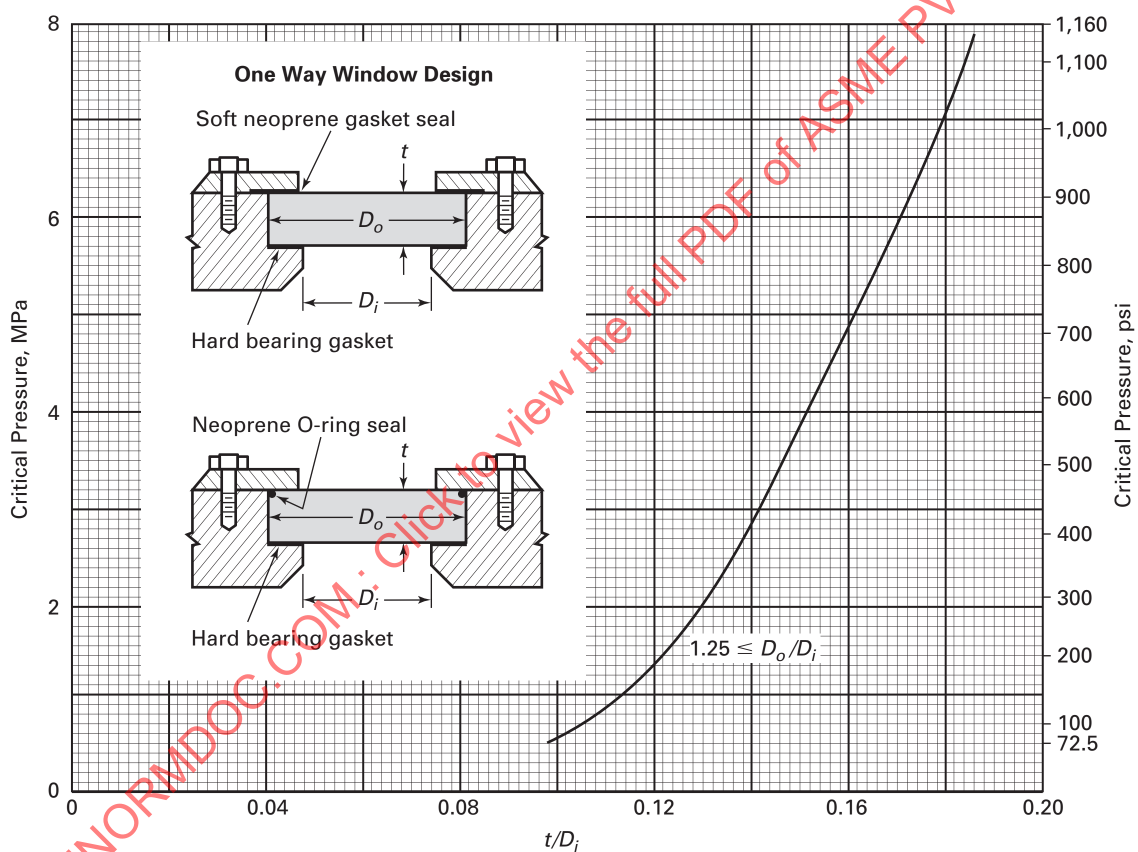


Fig. 2-2.5.1-2 Short-Term Critical Pressure of Flat Disk Acrylic Windows

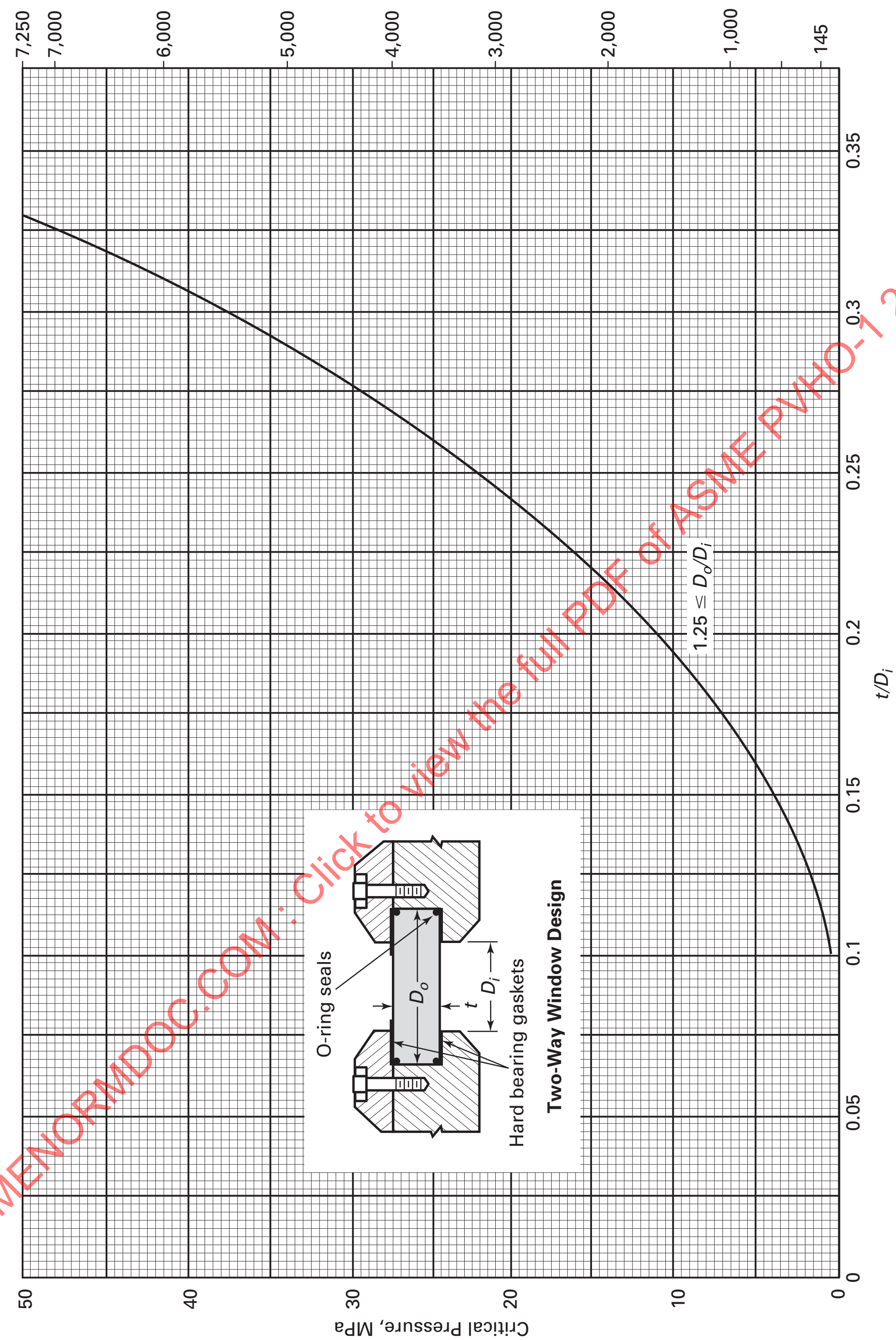


Fig. 2-2.5.1-3 Short-Term Critical Pressure of Flat Disk Acrylic Windows

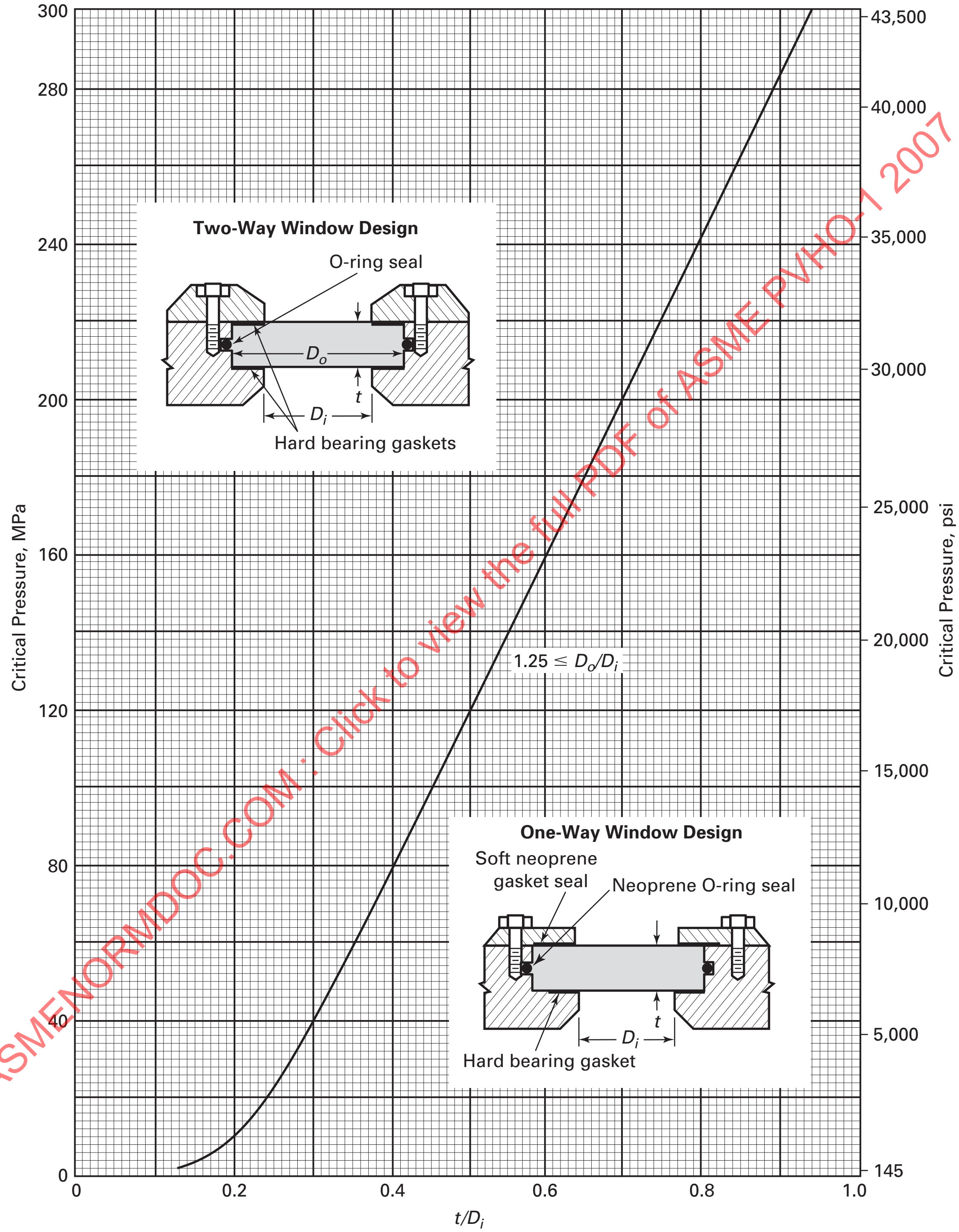


Fig. 2-2.5.1-4 Short-Term Critical Pressure of Conical Frustum Acrylic Windows

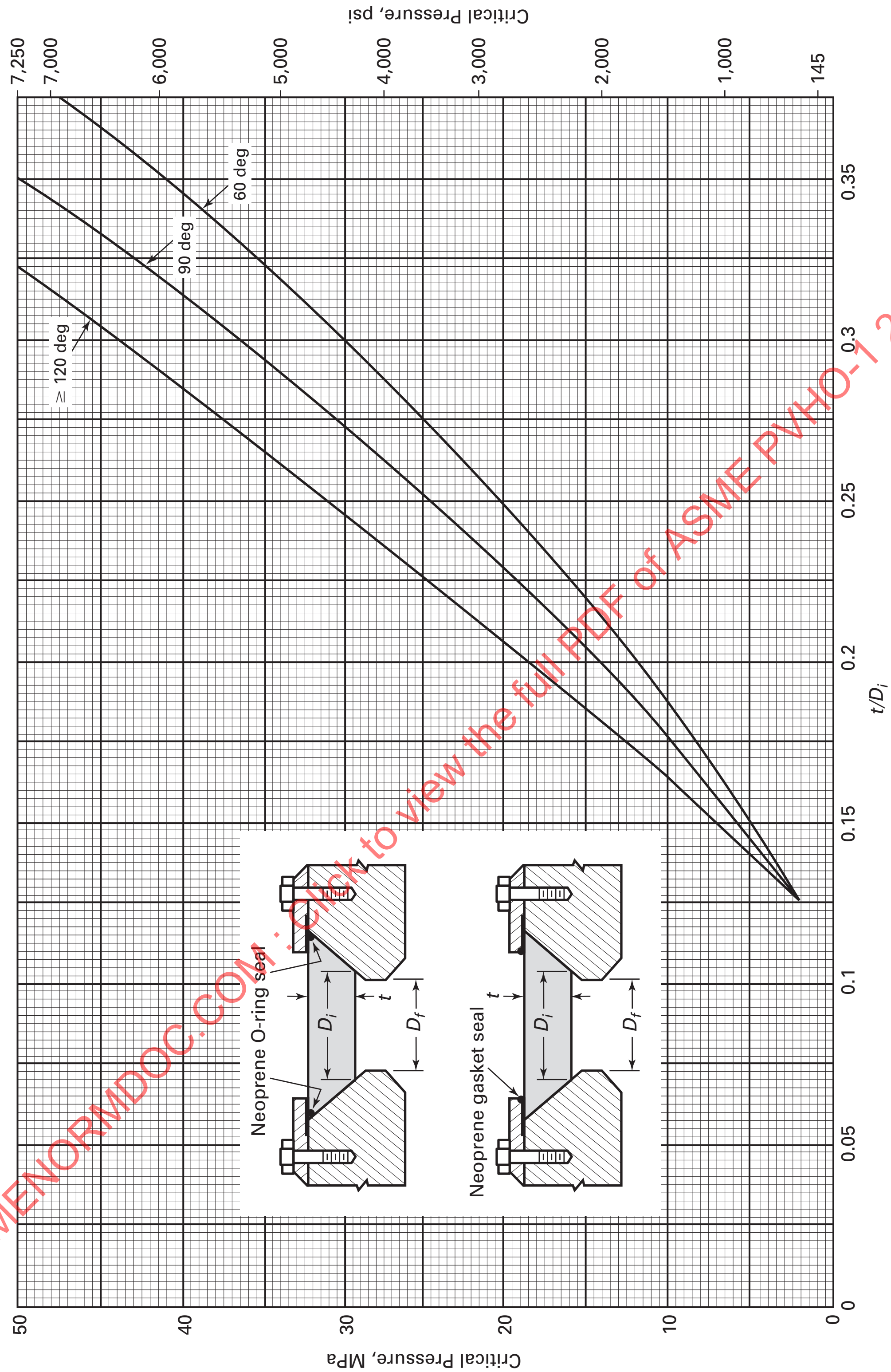


Fig. 2-2.5.1-5 Short-Term Critical Pressure of Conical Frustum Acrylic Windows

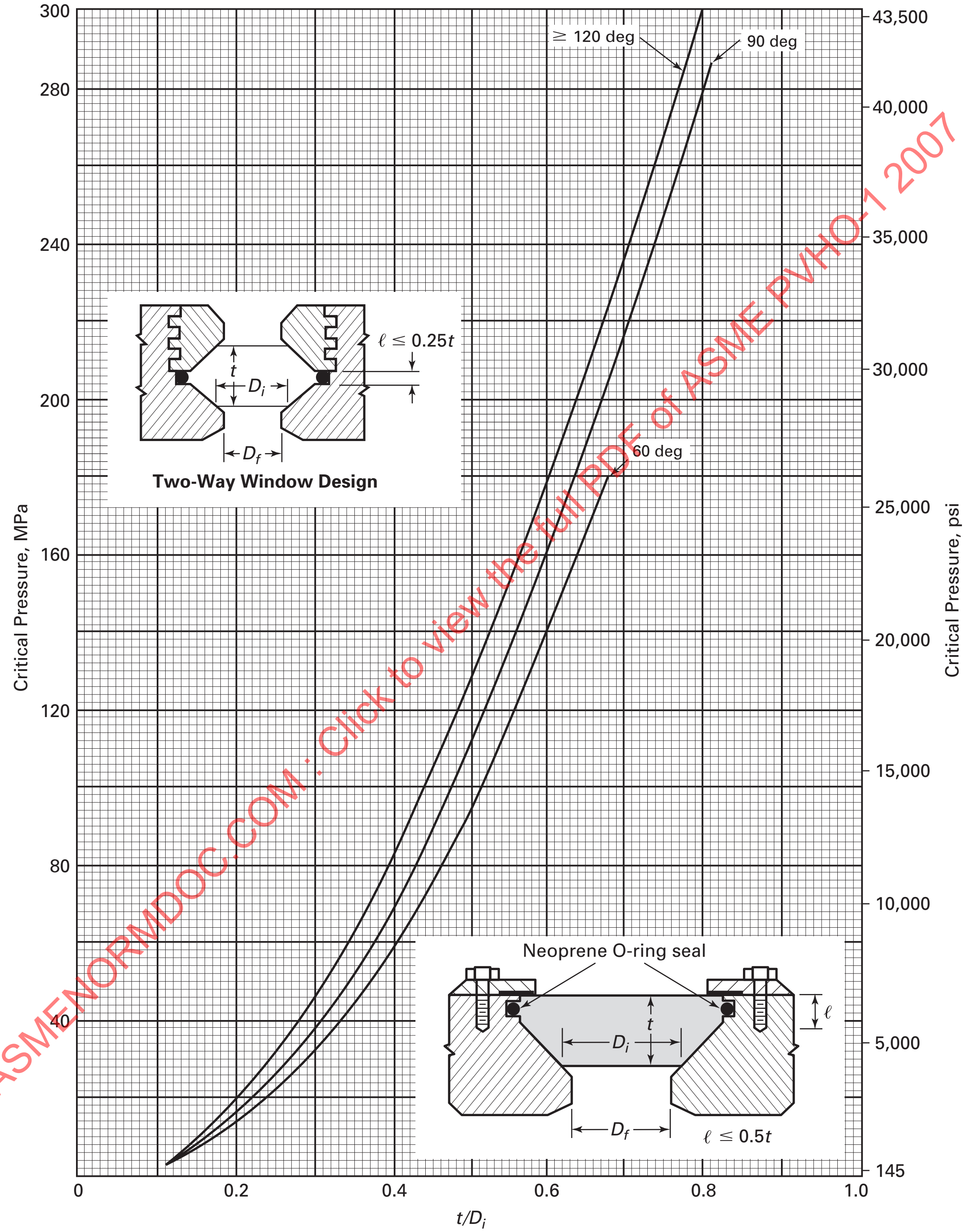


Fig. 2-2.5.1-6 Short-Term Critical Pressure of Spherical Sector Acrylic Windows

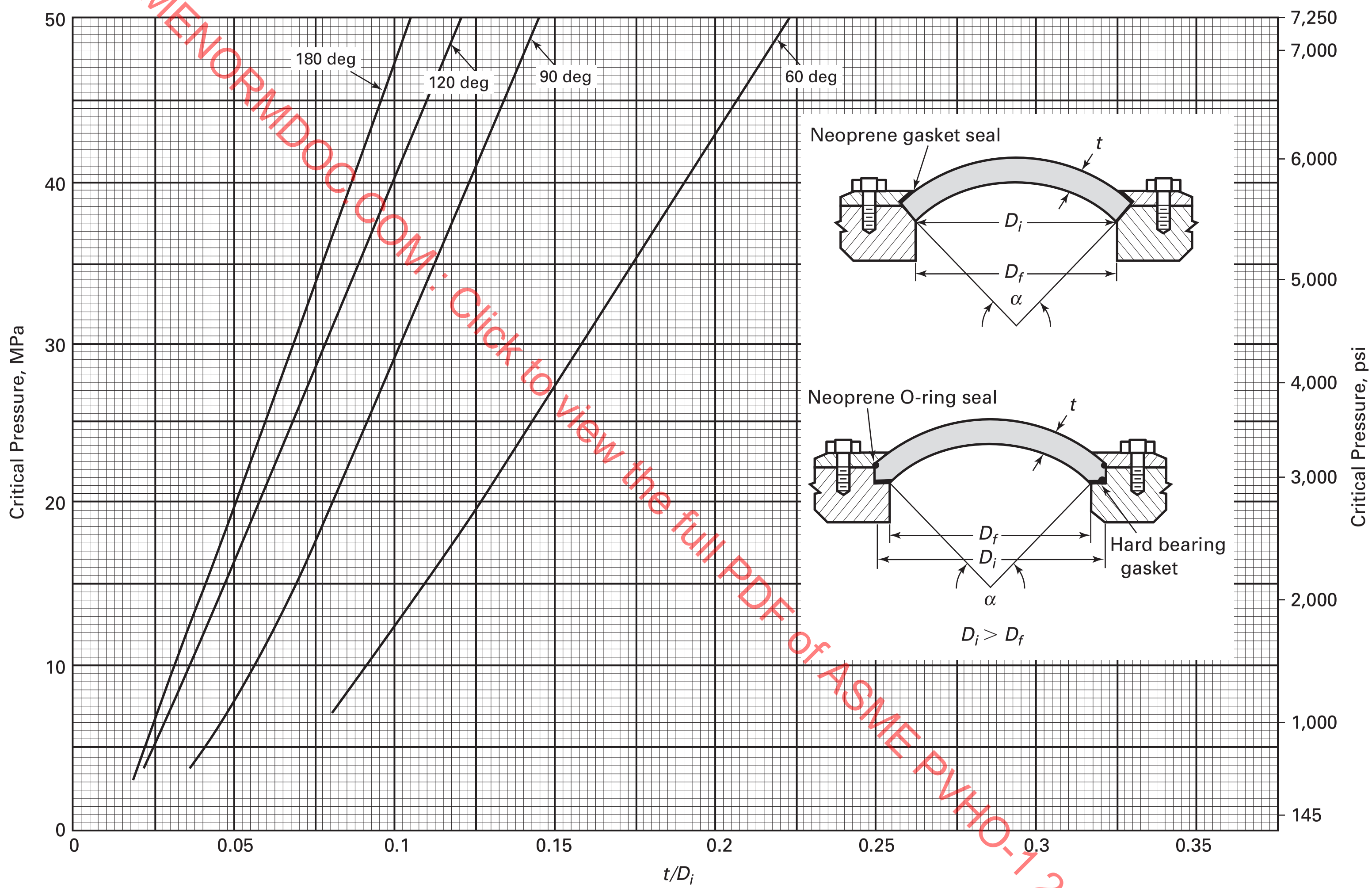


Fig. 2-2.5.1-7 Short-Term Critical Pressure of Spherical Sector Acrylic Windows

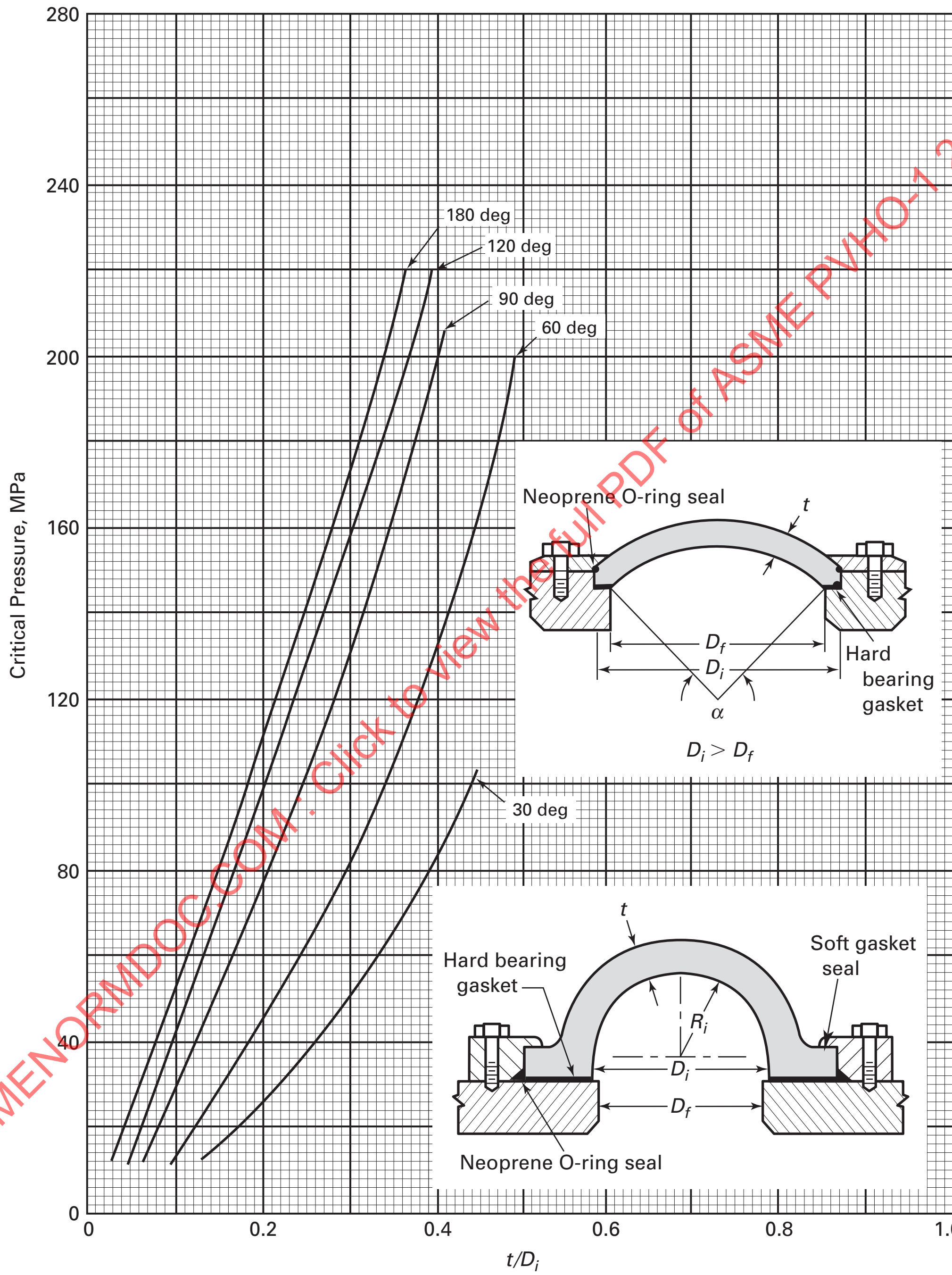


Fig. 2-2.5.1-8 Short-Term Critical Pressure of Cylindrical Acrylic Windows Pressurized Internally

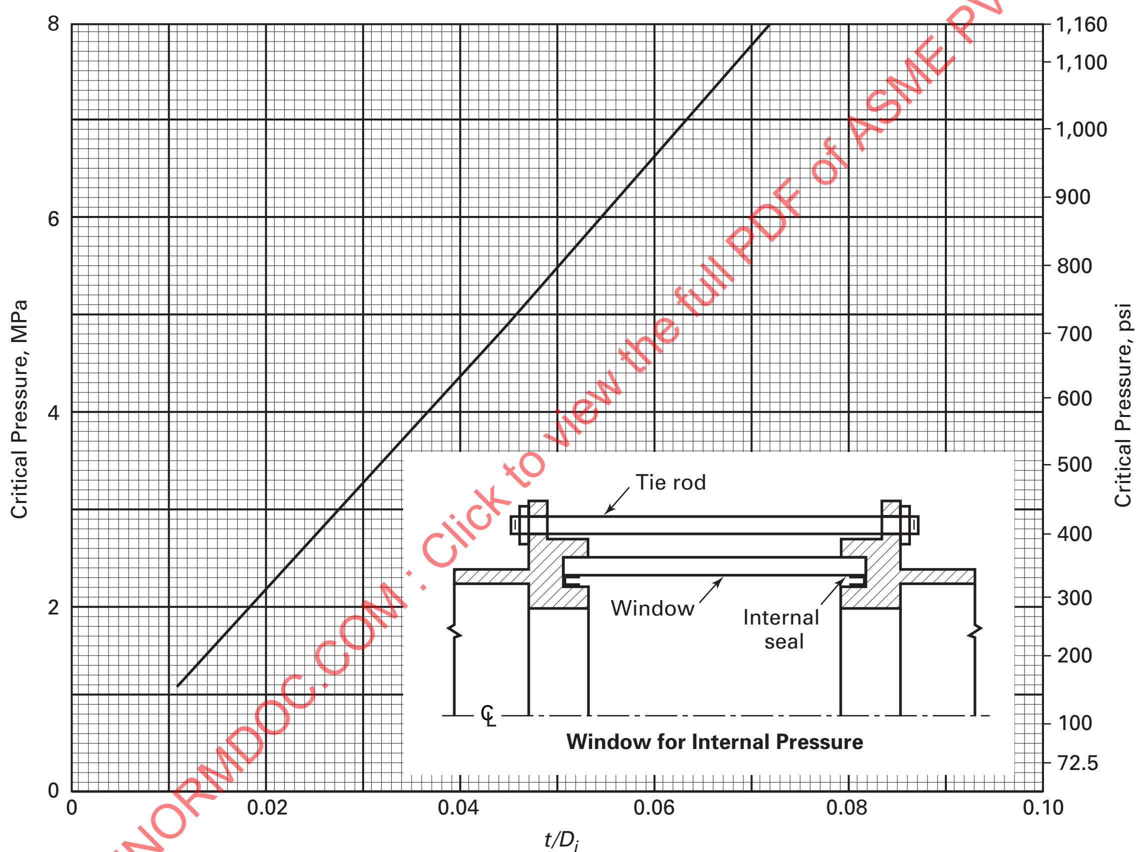


Fig. 2-2.5.1-9 Short-Term Critical Pressure of Cylindrical Acrylic Windows Pressurized Internally

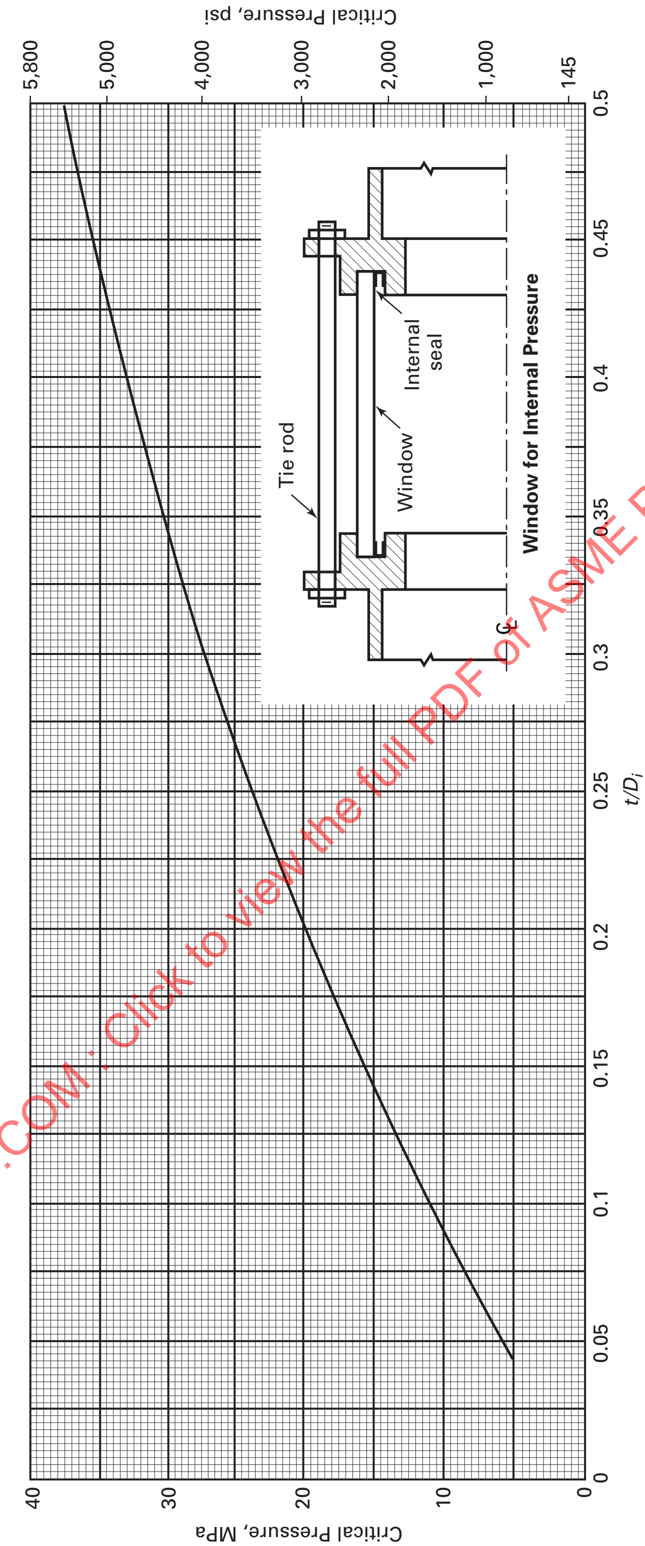


Fig. 2-2.5.1-10 Short-Term Critical Pressure of Cylindrical Acrylic Windows Pressurized Externally

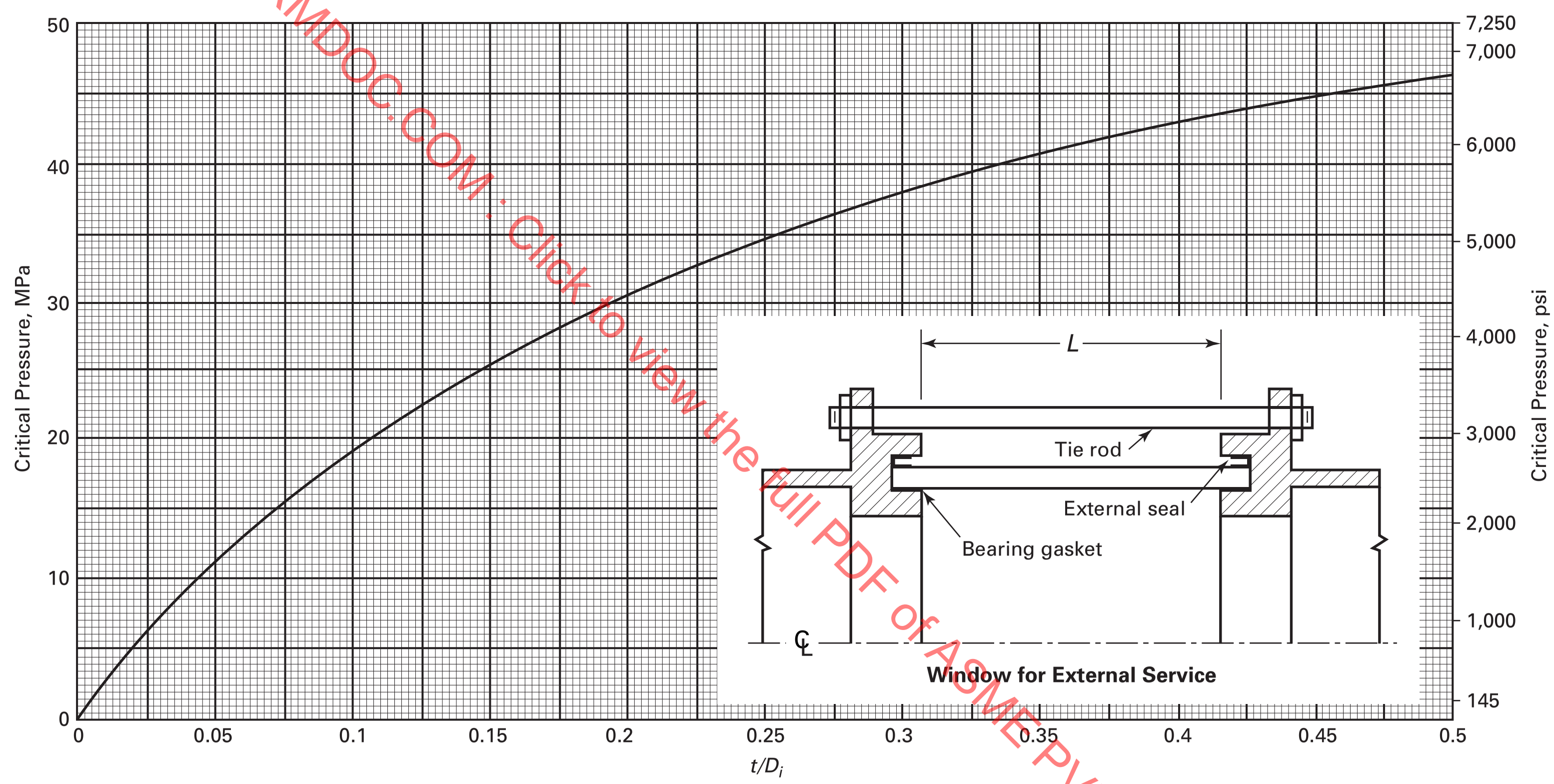
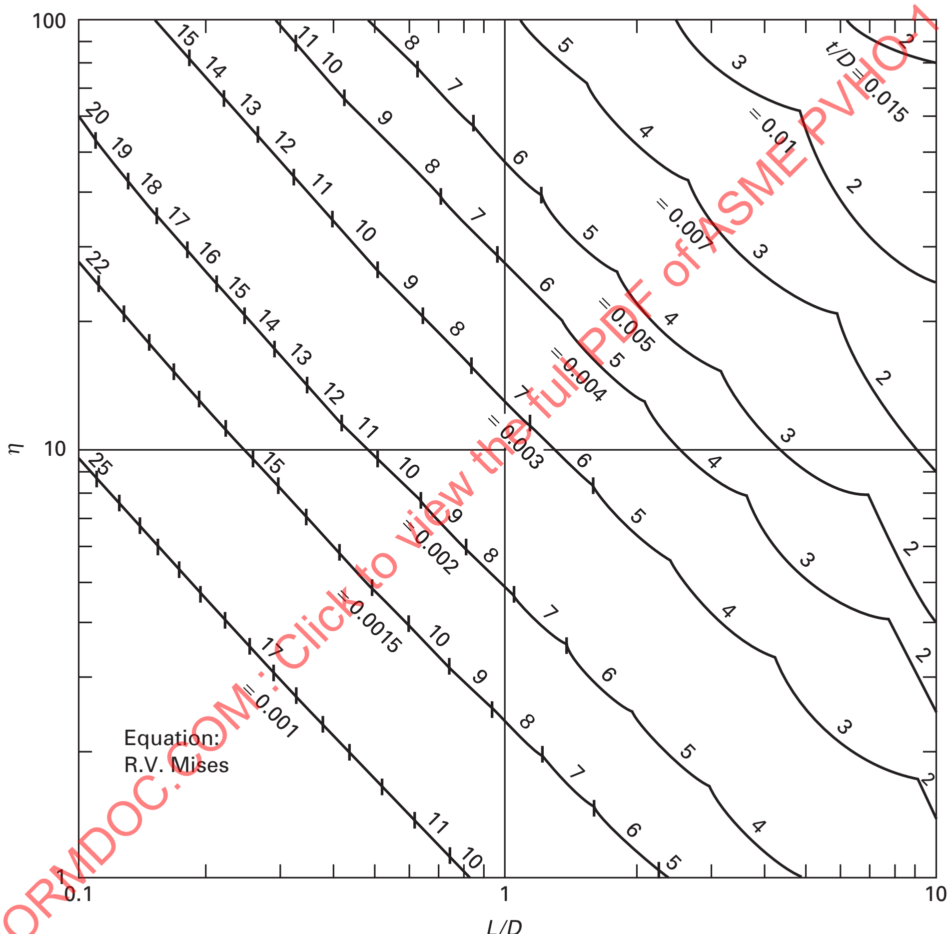


Fig. 2-2.5.1-11 Short-Term Elastic Buckling of Cylindrical Acrylic Windows Between Supports Under External Hydrostatic Pressure



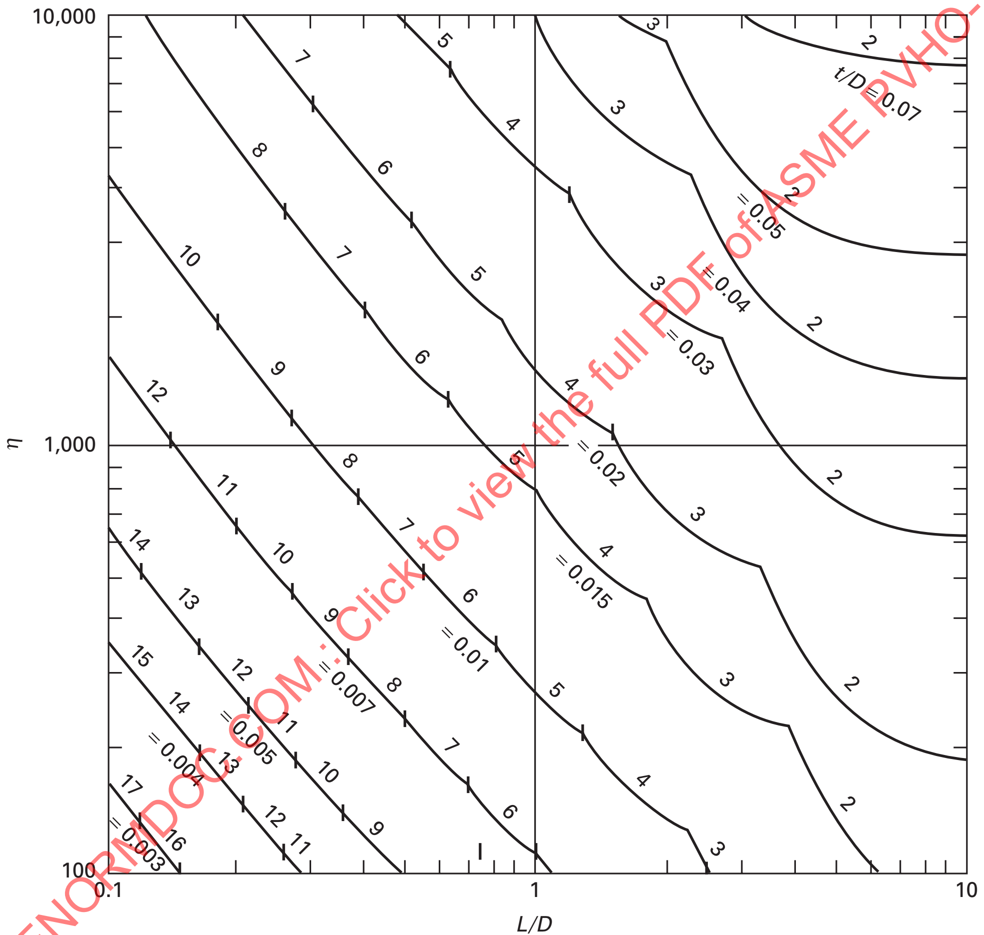
$D = \dfrac{D_i + D_o}{2}$

P_c = short term critical pressure

= $\eta \times 3.499 \times 10^{-2}$ (psi)

= $\eta \times 2.413 \times 10^{-4}$ (MPa)

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



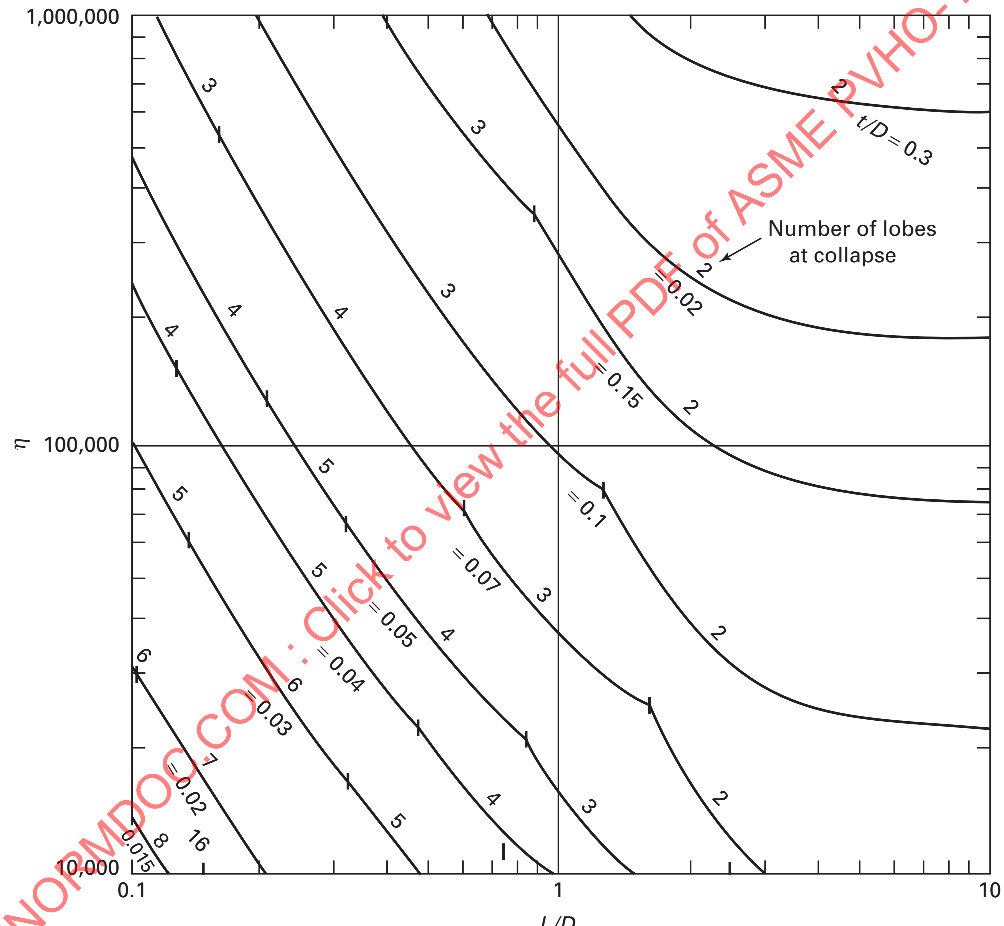
$D = \dfrac{D_i + D_o}{2}$

P_c = short term critical pressure

= $\eta \times 3.499 \times 10^{-2}$ (psi)

= $\eta \times 2.413 \times 10^{-4}$ (MPa)

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



$D = \frac{D_i + D_o}{2}$

P_c = short term critical pressure

= $\eta \times 3.499 \times 10^{-2}$ (psi)

= $\eta \times 2.413 \times 10^{-4}$ (MPa)

Fig. 2-2.5.1-14 Short-Term Critical Pressure of Hyperhemispherical and NEMO Type Acrylic Windows

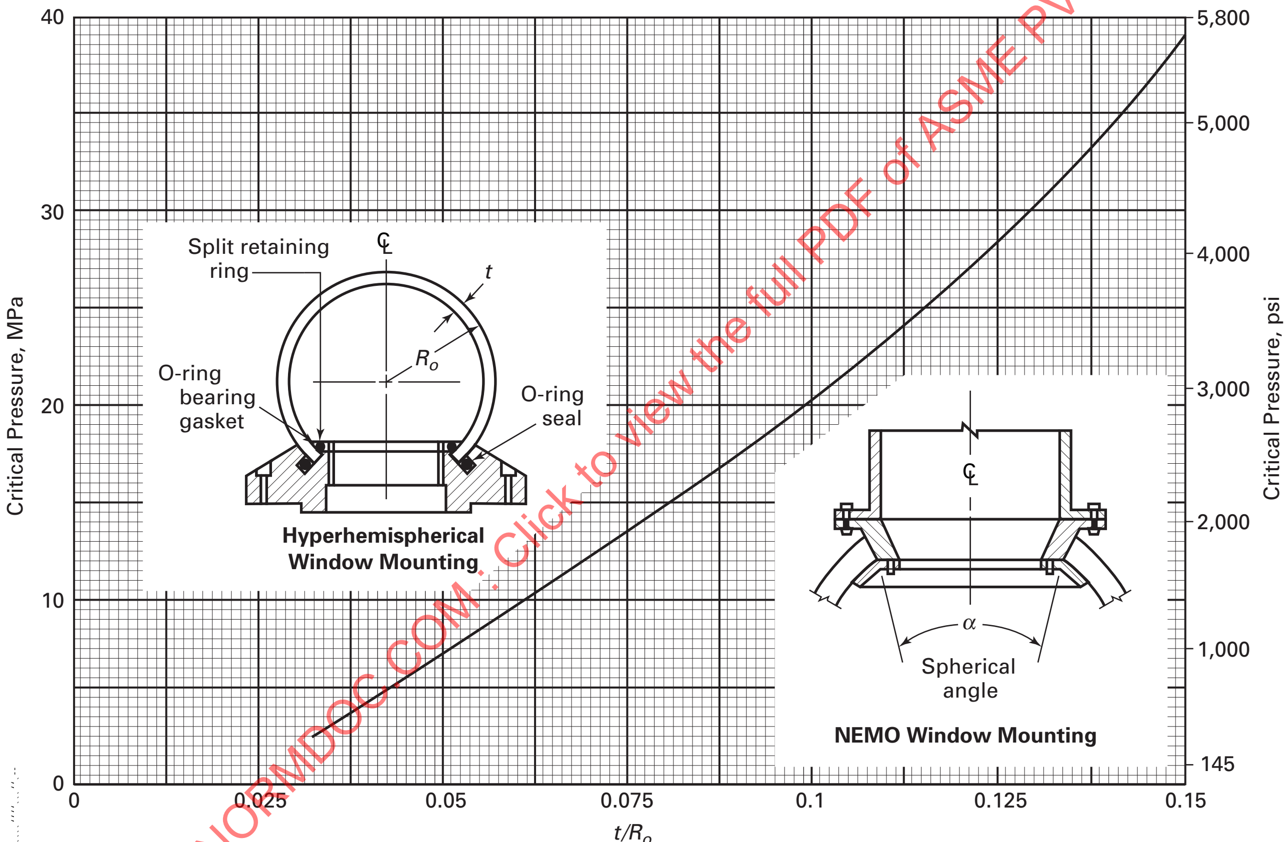


Fig. 2-2.5.1-15 Short-Term Critical Pressure of Hyperhemispherical and NEMO Type Acrylic Windows

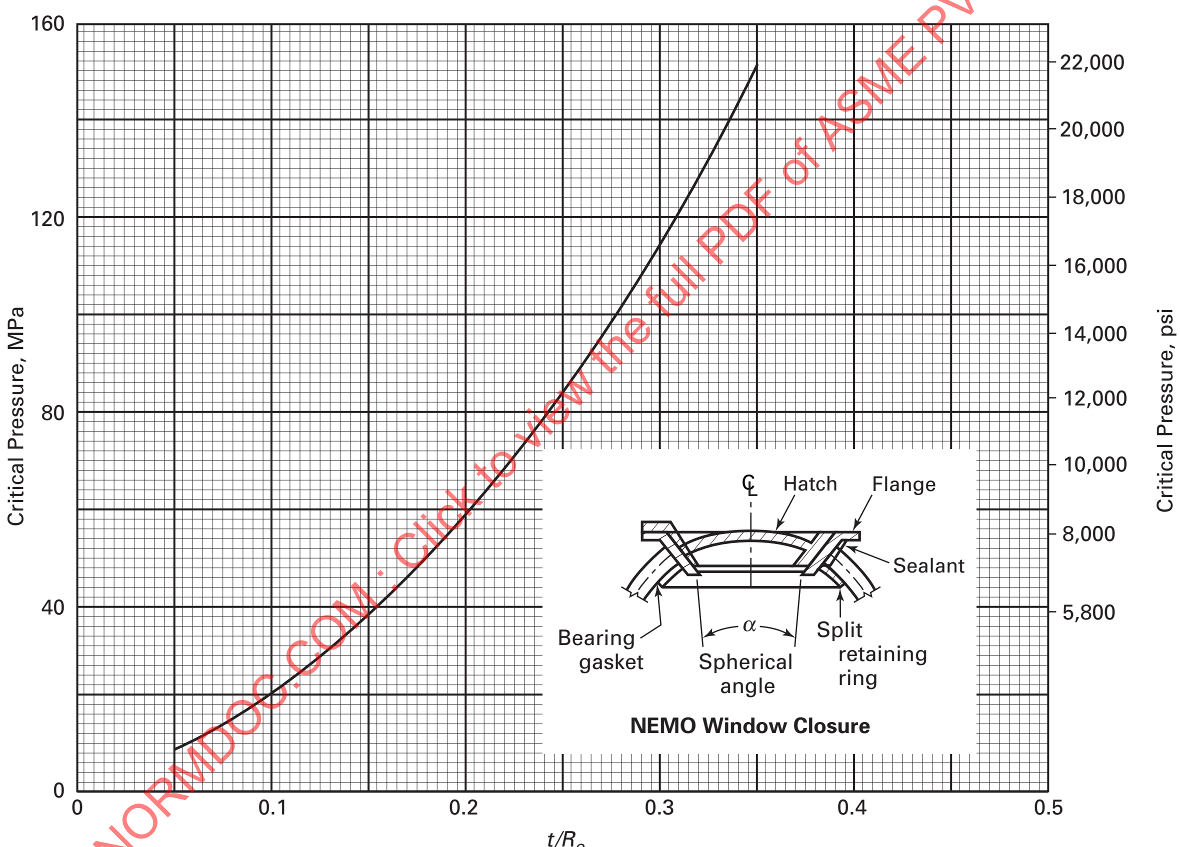
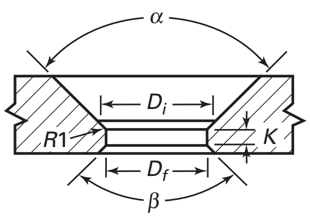


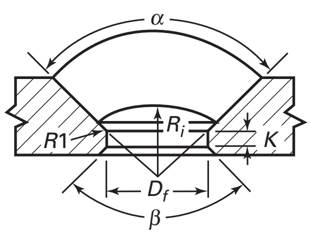
Fig. 2-2.10.1-1 Seat Cavity Requirements — Conical Frustum Window, Spherical Sector Window With Conical Edge, and Flat Disk Window



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	1.20	1.20	1.42

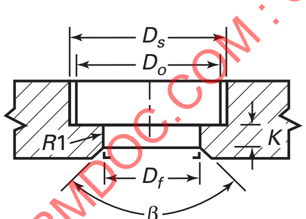
(a) Conical Frustum Window



$[2R_i \sin(\alpha/2)]/D_f$ Ratios (Spherical Sector With Conical Edge)

Operational Pressure Range	Included Angle, deg 30–180
$N = 1$	1.02
$N = 2$	1.03
$N = 3$	1.05

(b) Spherical Sector Window With Conical Edge



$1.250 \le D_o/D_f$

(c) Flat Disk Window

GENERAL NOTES:

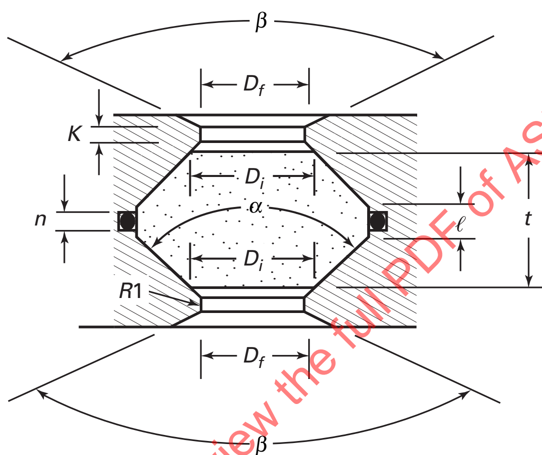
(a) For α between values shown, interpolation is required.

(b) $^1/_{32}$ in. (1.0 mm) ≤ $R1$ ≤ $^1/_{16}$ in. (2.0 mm).

(c) K is selected on the basis of structural analysis.

(d) β is selected on the basis of optical requirements.

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

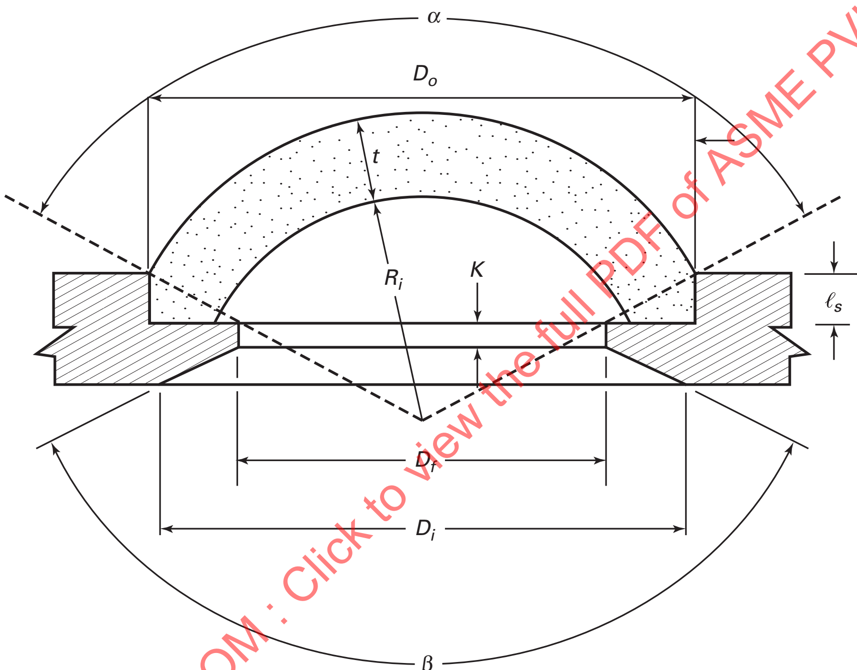


D_i/D_f Ratios

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:
(a) For α between values shown, interpolation is required.
(b) K is selected on the basis of structural analysis.
(c) β is selected on the basis of optical requirements.
(d) $\ell \leq 0.25t$
(e) $n \leq \ell$
(f) $^1/_{32}$ in. (1.0 mm) ≤ $R1$ ≤ $^1/_{16}$ 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.

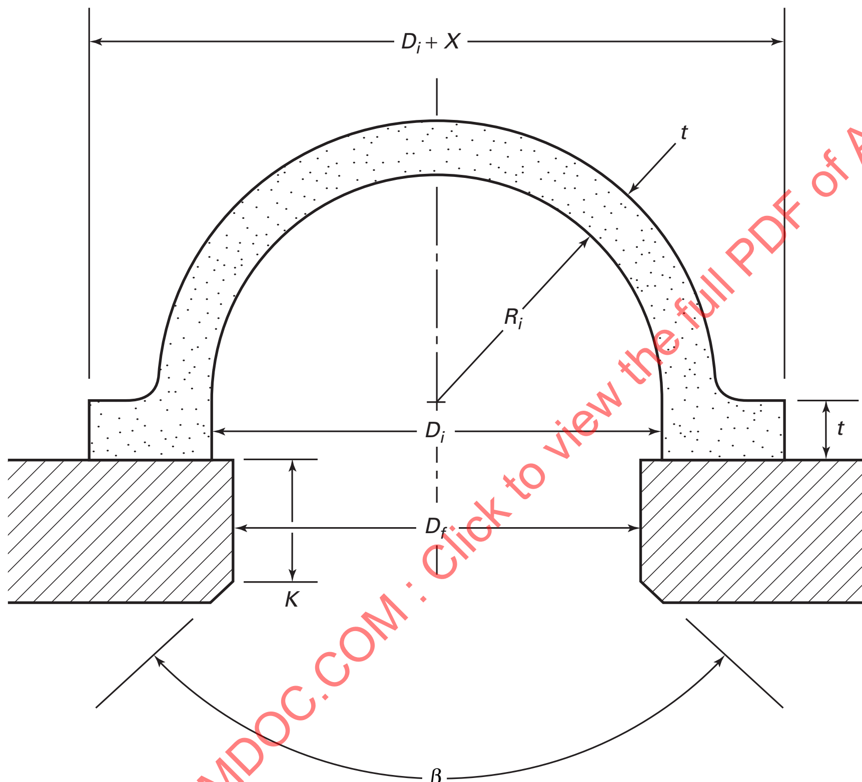
(c) $D_o = 2\ R_o \sin \alpha/2$.

(d) $D_i = 2\ R_i \sin \alpha/2$.

(e) $D_i - D_f \geq 1/8$ in. (3.0 mm).

(f) $\ell_s \geq t \sin (90\ \text{deg} - \alpha/2)$

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

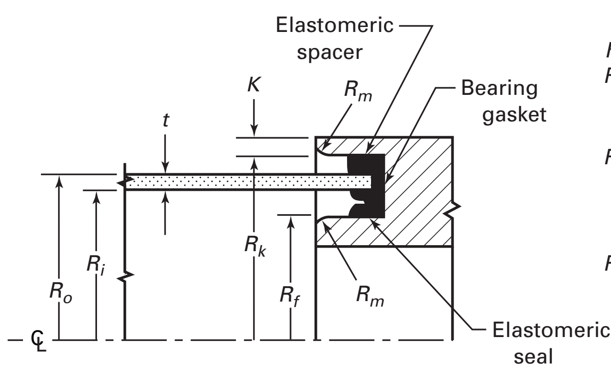


$3t \le X \le 4t$

Operational Pressure Range	D_i/D_f
$N = 1$	1.02
$N = 2$	1.03
$N = 3$	1.05

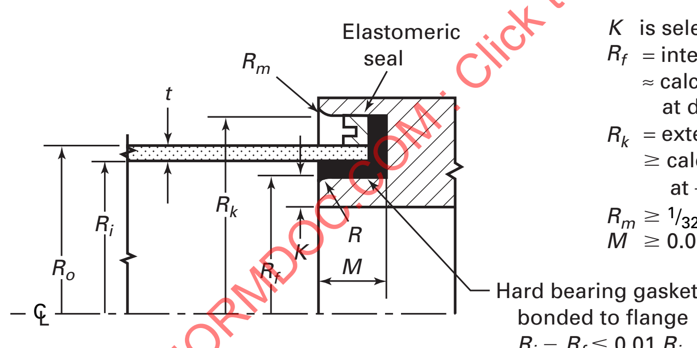
GENERAL NOTES:
(a) K is selected on the basis of structural analysis.
(b) β is selected on the basis of optical requirements.

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



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%
$R_m \geq {}^1/_{32}$ in. (1.0 mm)

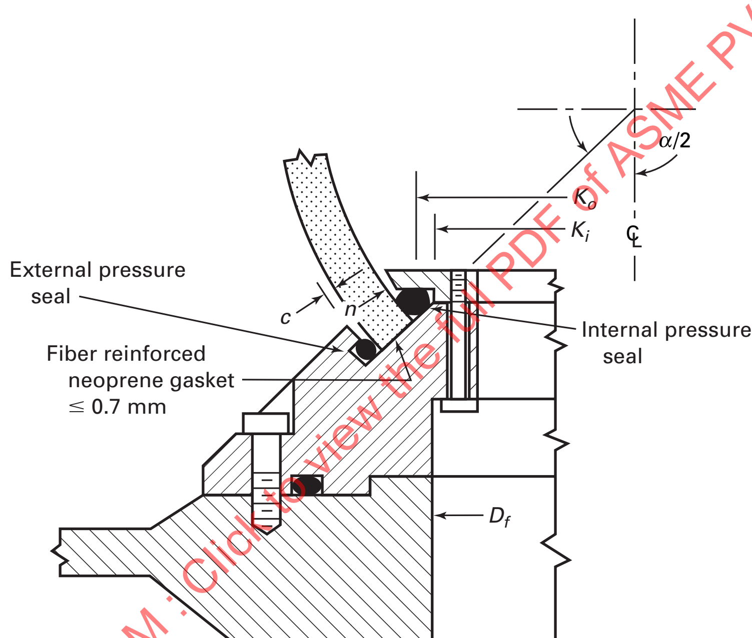
(a) Under Internal Pressure



K is selected on the basis of structural analysis
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°C plus gasket compressed 50%
$R_m \geq {}^1/_{32}$ in. (1.0 mm)
$M \geq 0.05R_i$

(b) Under External Pressure

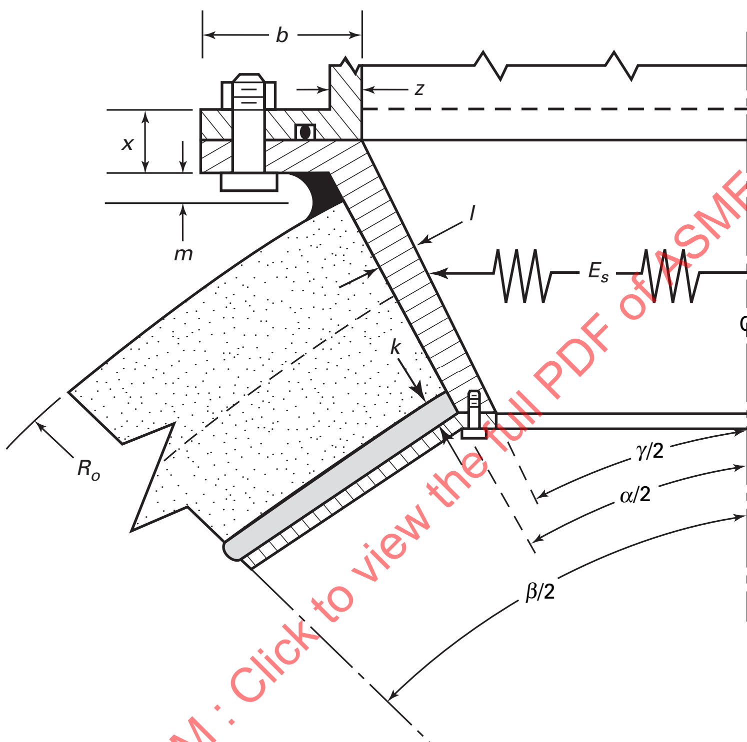
Fig. 2-2.10.1-6 Seat Cavity Requirements — Hyperhemispherical Window



$K_o - K_i \geq {}^1/_4$ in. (6.0 mm)
$n \geq {}^1/_{32}$ in. (1.0 mm)
$c \geq {}^1/_{16}$ in. (2.0 mm)
$\alpha \leq 100$ deg

where
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)



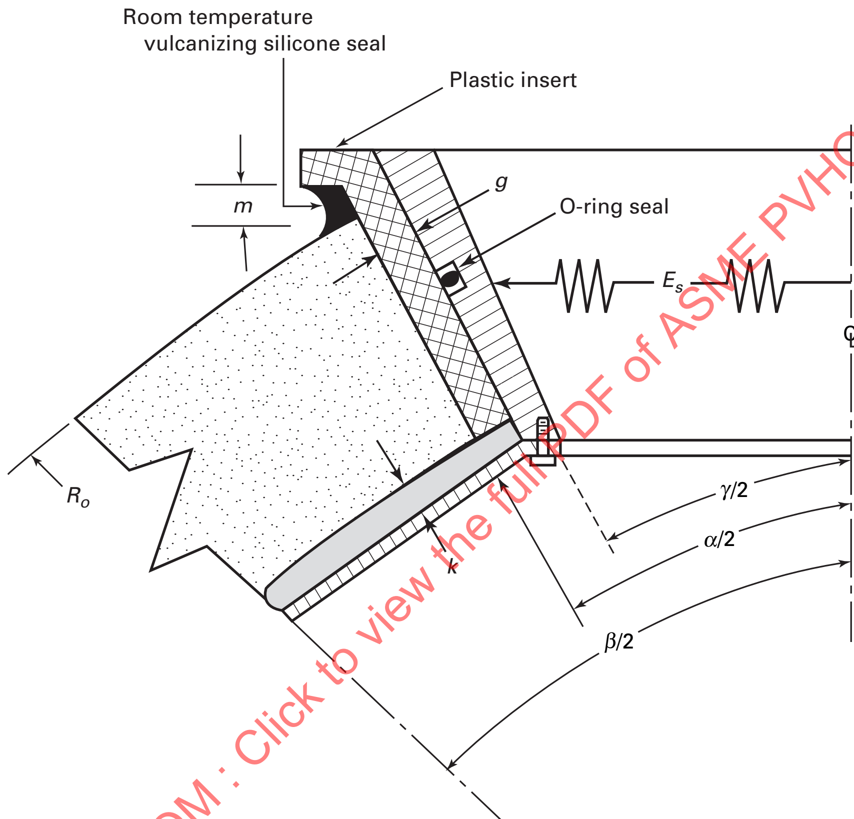
$k \geq 0.005\ R_o$
$m \geq 0.01\ R_o$
$\alpha \leq 50$ deg
$(\alpha + 8 \text{ deg}) \leq \beta \leq (\alpha + 12 \text{ deg})$

where

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

GENERAL NOTE: The variables *x, b, z,* and *l* must 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%.

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

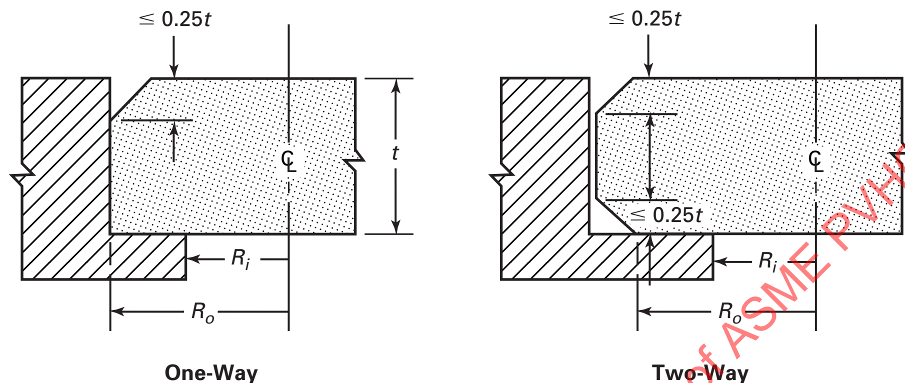


$g \geq 0.03\ R_o$
$k \geq 0.005\ R_o$
$m \geq 0.01\ R_o$
$\alpha \leq 50$ deg
$(\alpha + 8 \text{ deg}) \leq \beta \leq (\alpha + 12 \text{ deg})$

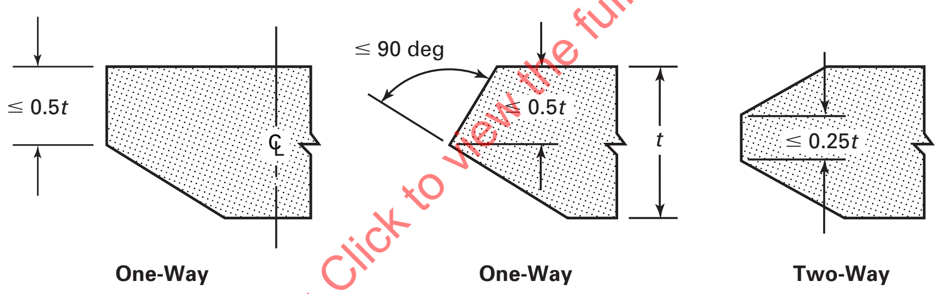
where
E_s = orientation of effective radial stiffness
g = thickness of plastic insert
k = thickness of compressed gasket (neoprene)
m = elevation of hatch ring
α = spherical angle of window penetration
β = spherical angle of split retaining ring
γ = spherical angle of hatch seat

GENERAL NOTE: The variables *x*, *b*, *z*, and *l* must 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%.

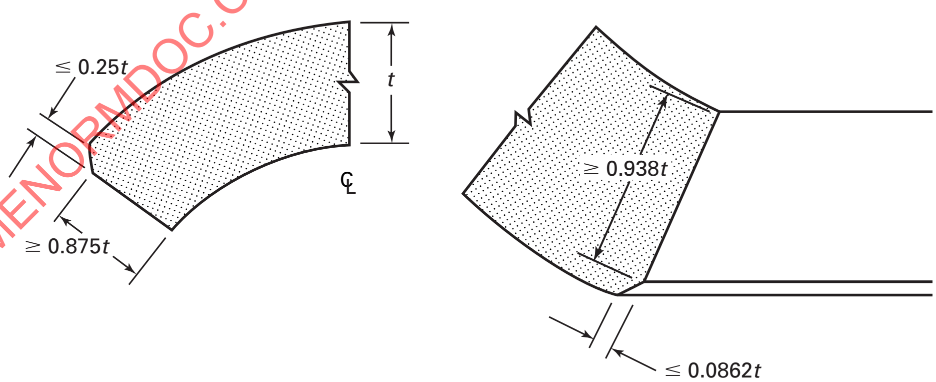
Fig. 2-2.11.10-1 Bevels on Window Edges — Flat Disk Windows, Conical Frustum Windows, Spherical Sector Windows, Hyperhemispheres



(a) Flat Disk Windows



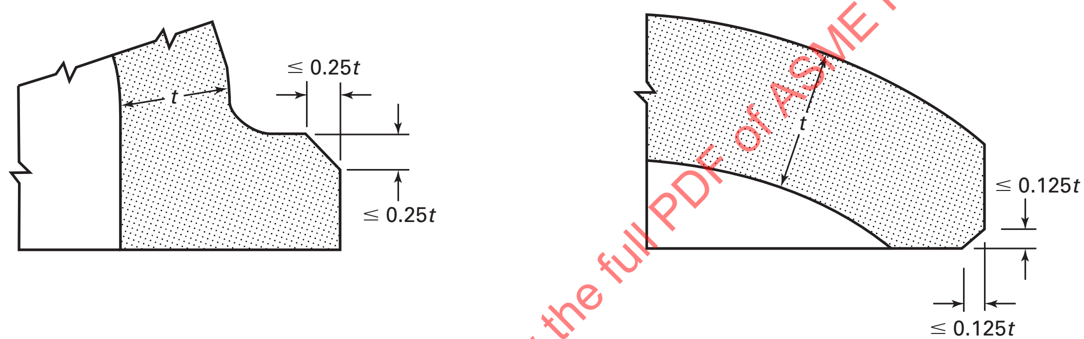
(b) Conical Frustum Windows



(c) Spherical Sector Windows

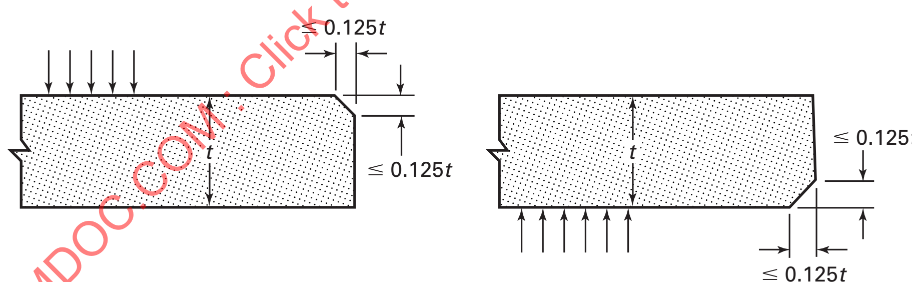
(d) Hyperhemispheres

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

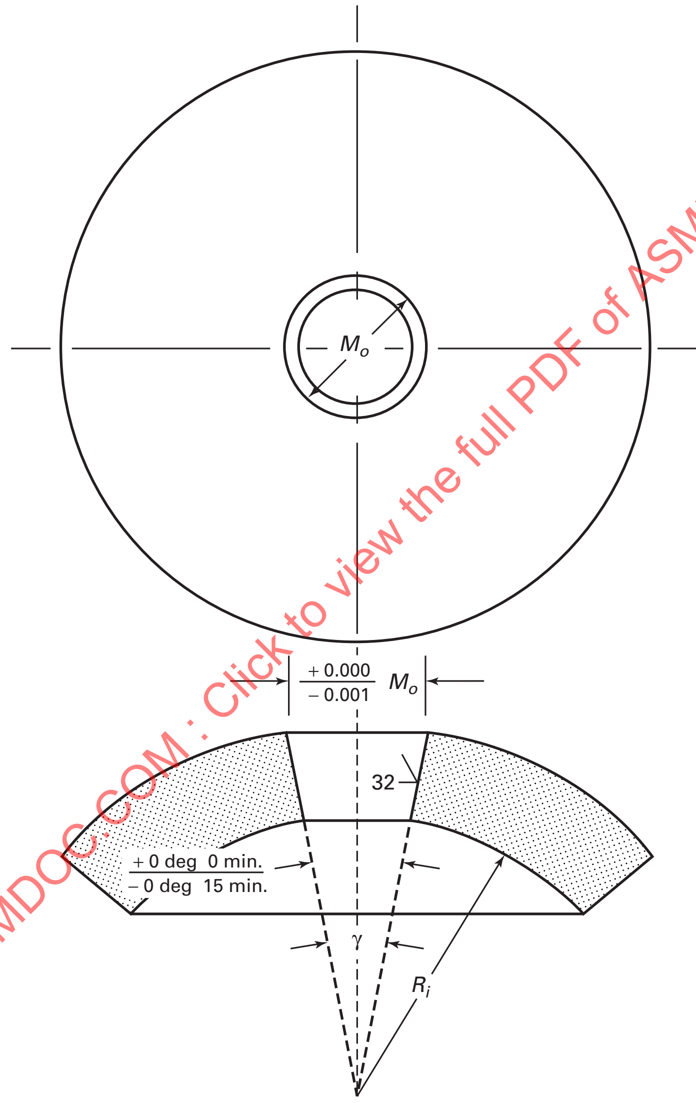


External Pressure

Internal Pressure

(c) Cylindrical Windows

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



M_o = outside diameter of penetrations
R_i = radius of convex curvature
γ = conical seat angle

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

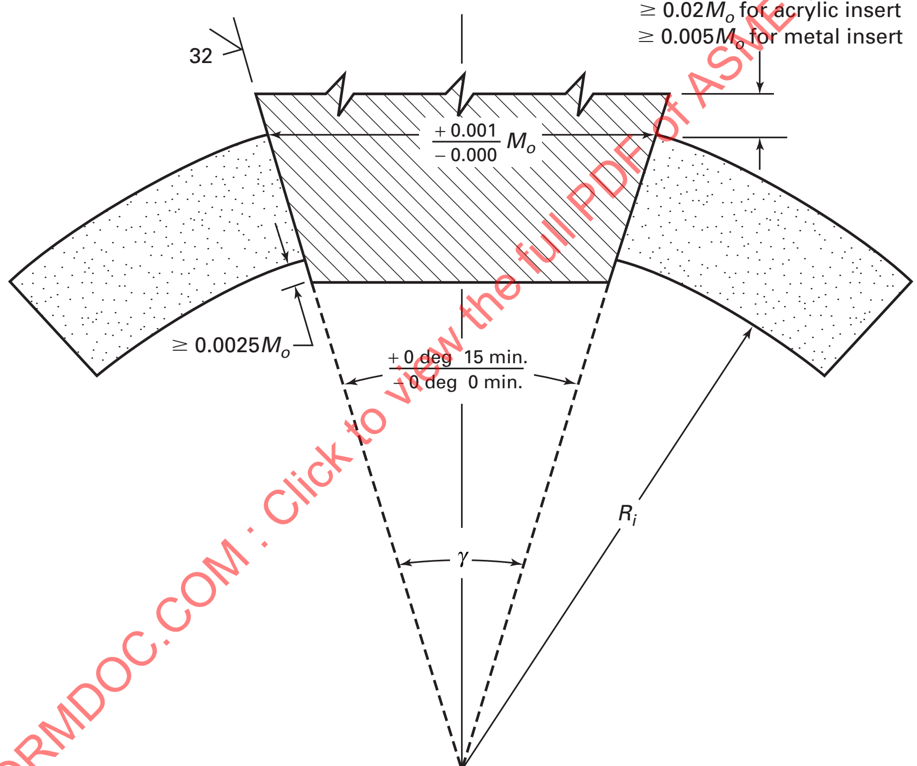
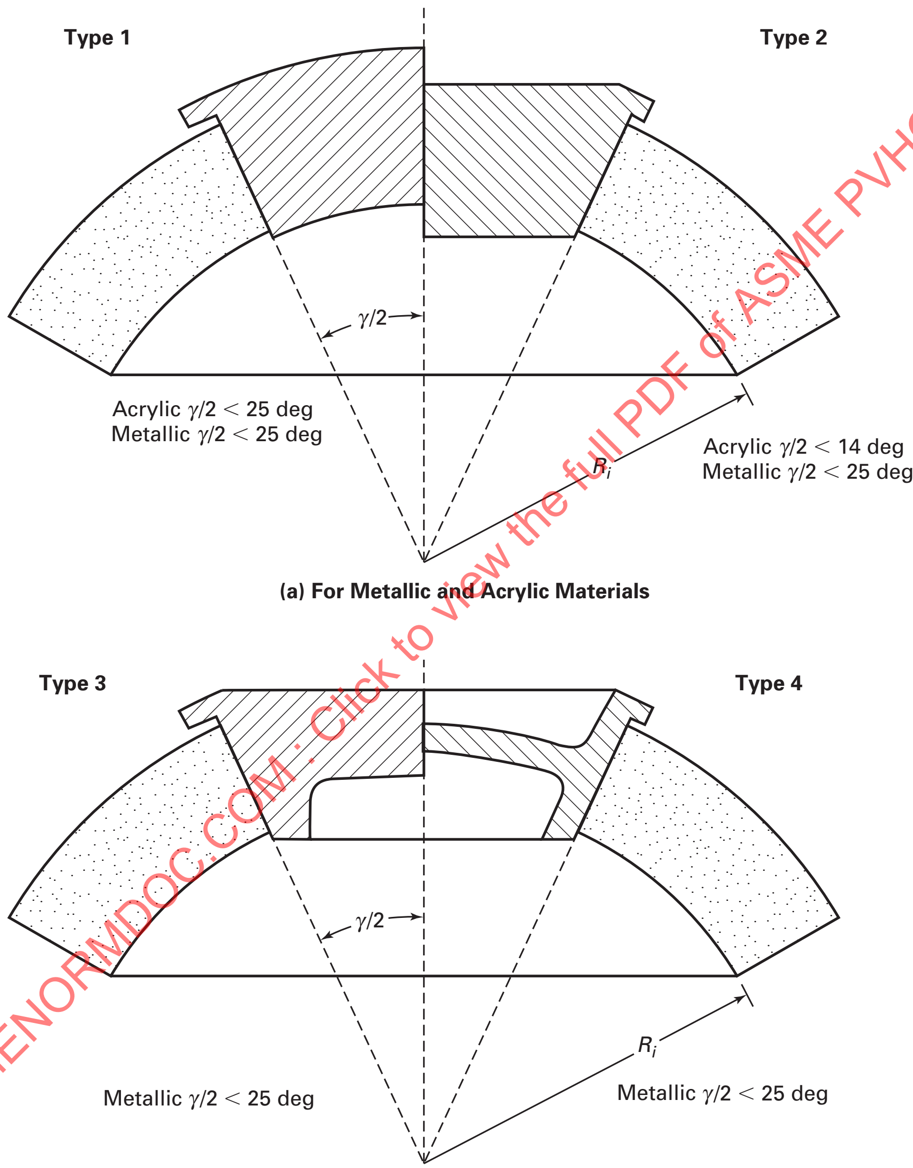


Fig. 2-2.14.16-1 Typical Shapes of Inserts



(b) For Metallic Materials

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

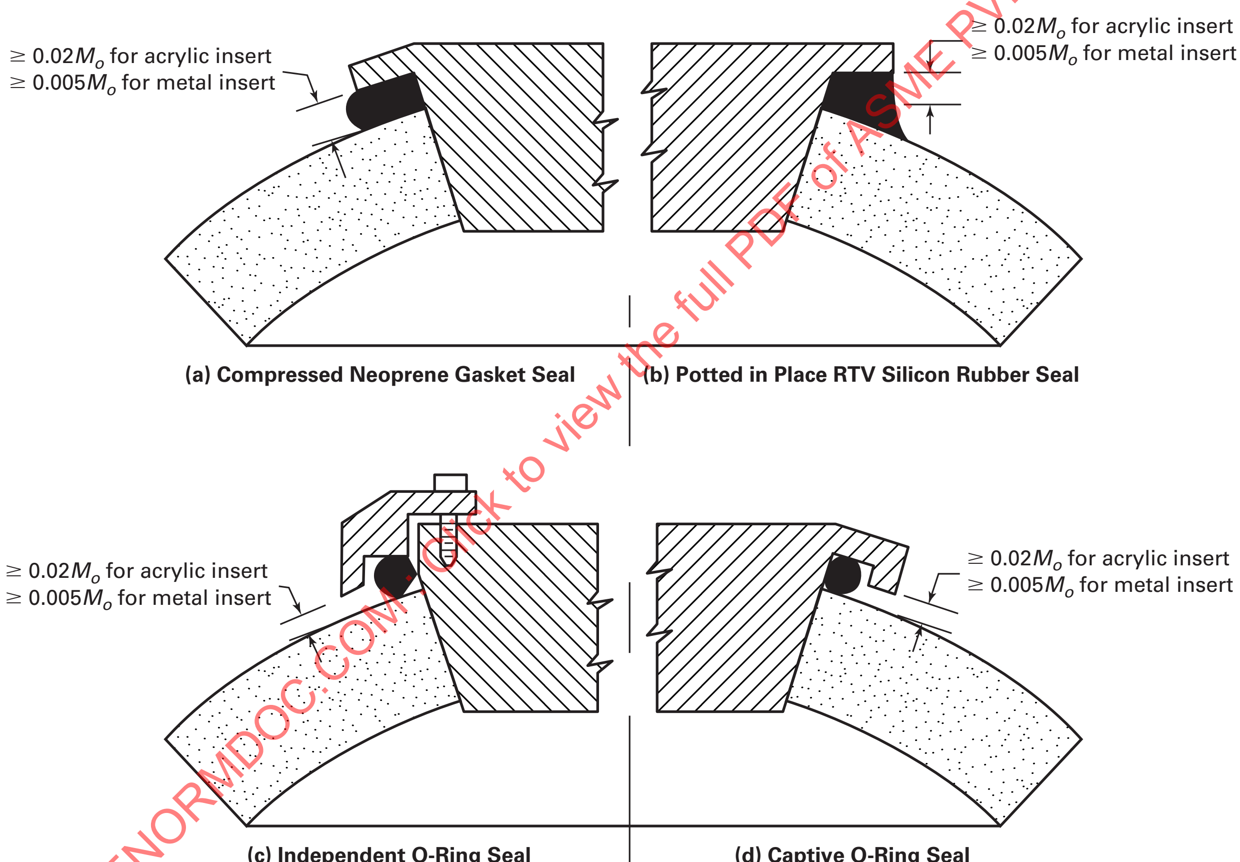


Fig. 2-2.14.24-1 Restraints for Inserts in Acrylic Windows

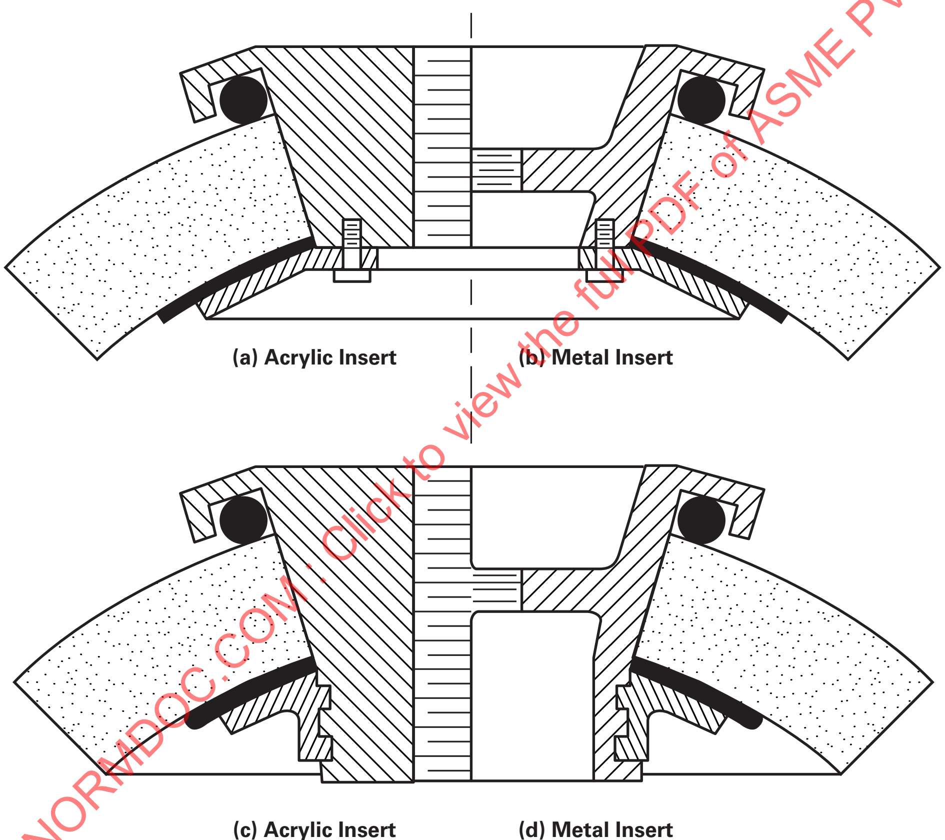


Table 2-2.3.1-1 Conversion Factors for Acrylic Flat Disk Windows

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, 2-2.5.1-2, and 2-2.5.1-3.
(b) Dotted lines refer to intermediate pressure ranges as indicated by the adjacent pressure figures.
(c) Interpolation between conversion factors (CF) is allowed.

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
	↕ Conversion factors for these pressures must be interpolated between the upper and lower values shown. ↕				4,500 psi (31 MPa)
N = 2 5,000 psi (34.5 MPa)	CF = 4	CF = 5	CF = 7	CF = 9	
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 conversion factors (CF) in this table apply only to short-term critical pressures (STCP) 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 conversion factors (CF) 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 conversion factors (CF) in this table apply only to short-term critical pressures (STCP) plotted in Figs. 2-2.5.1-6 and 2-2.5.1-7 (for spherical sector windows with conical edge), and 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 conversion factors (CF) 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 conversion factors (CF) in this table apply only to short-term critical pressures (STCP) 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 conversion factors (CF) 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 conversion factors (CF) in Part A of this table apply only to short-term critical pressures (STCP) plotted in Figs. 2-2.5.1-8 and 2-2.5.1-9.

(b) The conversion factors (CF) in Part B of this table apply only to short-term critical pressures (STCP) 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 must be considered in selection of t/D 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 short-term critical pressures. The mode of failure requiring a higher t/D_i ratio is chosen as the design criterion.

(c) Interpolation between conversion factors (CF) 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									
		≤50°F (10°C)					≤75°F (24°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.

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

Test Procedures	Physical Property	Specified Values: U.S. Customary Units	Specified Values: Metric Units
ASTM D 638 [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 D 695 [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 D 732 [Note (1)]	Shear, ultimate strength	≥9,000 psi	≥62 MPa
ASTM E 308	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 the table.

NOTE:

(1) These tests require testing of 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 will be used to meet the requirements of the minimum physical properties of this table.

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	Specified Values: Metric Units
ASTM D 638 [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 D 695 [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 D 732 [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 of 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 will be used to meet the requirements of the minimum physical properties of this table.

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

Test Procedures	Physical Property	Specified Values: U.S. Customary Units	Specified Values: Metric Units
ASTM D 256 [Note (1)]	Izod notched impact strength	≥0.25 ft-lb/in.-min	≥13.3 J/m
ASTM D 542	Refractive index	1.49 + 0.01	1.49 + 0.01
ASTM D 570 [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 D 638 [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 D 695 [Note (1)]	Compressive:		
	(a) yield strength	≥15,000 psi	≥103 MPa
	(b) modulus of elasticity	≥400,000 psi	≥2 760 MPa
ASTM D 732 [Note (1)]	Shear ultimate strength	≥8,000 psi	≥55 MPa
ASTM D 785 [Note (1)]	Rockwell hardness	≥M scale 90	≥M scale 90
ASTM D 790 [Note (1)]	Flexural ultimate strength	≥14,000 psi	≥97 MPa
ASTM D 792 [Note (1)]	Specific gravity	1.19 ± 0.01	1.19 ± 0.01
PVHO-1 method, para. 2-3.7(d)	Ultraviolet (290–330 nm) light transmittance	≤5%	≤5%
PVHO-1 method, para. 2-3.7(e)	Clarity, visually rated	Must have readability	Must have readability
ASTM D 696	Coefficient of linear thermal expansion at	$\leq 10^{-5}$ (in./in. °F)	$\leq 10^{-5}$ (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 D 648	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 of 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 will be used to meet the requirements of the minimum physical properties of this table.

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

Test Procedures	Physical Property	Specified Values: U.S. Customary Units	Specified Values: Metric Units
ASTM D 638 [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 D 695 [Note (1)]	Compressive:		
	(a) yield strength	≥15,000 psi	≥103 MPa
	(b) modulus of elasticity	≥400,000 psi	≥2 760 MPa
PVHO-1 method, para 2-3.7(c)	Compressive deformation at 4,000 psi (27.6 MPa) and 122°F (50°C), 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: Test coupons shall be taken from each casting or lot of material 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 of 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 will be used to meet the requirements of the minimum physical properties of this table.

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-Circulation Air Oven Maintained at a Set Temperature Within ±5°F (±2.8°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/hr)	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.

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 ______________________
(Name of Company and Designer)

Joint bonding (if applicable)

Manufacturer of acrylic cement ______________________

Trade name of cement ______________________

Curing means and duration ______________________

Average tensile strength (per ASTM D 638) ______________________

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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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)]

Thickness t (actual) ____________

D_o (actual) ____________

D_i (actual) ____________

Water temperature ________ °F ________ °C

No. 1 ________ No. 2 ________

No. 3 ________ No. 4 ________

No. 5 ________ STCP ________

(Note each test specimen FS for full scale and 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 t/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, section 2-2.

Viewport Designer	Date
Authorized representative of chamber manufacturer or owner	Date
Name and address of chamber manufacturer or owner	Date

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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.

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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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 ________

centimeters 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 D 638	Tensile:	
	(a) ultimate strength	________
	(b) elongation at break	________
	(c) modulus of elasticity	________
ASTM D 695	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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PVHO-1 Form VP-5 Pressure Testing Certification

Window Identification____________________

Window Description

Maximum allowable working pressure ____________________

Maximum design temperature ____________________

Test Arrangement

Windows tested in operational viewport/simulated viewport ____________________ (operational/simulated)

Operational/simulated viewport drawing no. ____________________

Window tested according to para. 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 section 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

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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 outisde 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 are to be provided and certified by the company/individual authorizing the repair of windows.
(b) The repair process information required by part 5 is to 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.

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 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 in Section 1, General Requirements.

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 section 1-4.

Piping systems constructed under the requirements contained in this Section are limited to design temperatures between 0°F (−17.8°C) and 150°F (65°C), inclusive.

This Section is to be used as an adjunctive document to B31.1 or B31.3. The user or an agent on behalf of the user is to specify the appropriate section of 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 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.

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 4-9-7.1(b)]

(c) conditions affecting the requirements for and amounts of stored gas reserves

(d) required number of breathing gas connections and their characteristics

(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. 4-1.2.3 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 and experienced in piping systems designs, 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 this Standard.

(c) Medical Use PVHO Certification. The piping system design for PVHOs intended for use as medical devices, designed and manufactured according to the manufacturers standard commercial design, shall comply with the U.S. Food and Drug Administration (FDA) Design Control Requirements as stated in 21 Code of Federal Regulations (C.F.R.) Part 820, Quality System Regulations. Standard Products meeting the requirements of the FDA are exempt from the requirements stated in para. 4-1.2 of this Standard.

(d) 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.

4-1.2.3 Data Retention. The fabricator shall retain a copy of the User's Design Specification, the Design Certification, and supporting data (test data, material test reports, as required by the User's Design Specification) for at least 5 years. 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. For Medical Use PVHOs, compliance with FDA data retention requirements shall be considered conforming with this paragraph.

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 Appendix A of ASME B31.1, Appendices A and B of ASME B31.3, or are listed in Table 4-2.1.1 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, water or steam service, and all components subject to the requirements of para. 4-9.3, Pressure Boundary Valve Requirements, shall not utilize 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 must 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 must 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 G 88.

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 must 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) 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 four times its rated MAWP. The effect of fittings on the burst pressure is to 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 para. 4-9.14 or they are rated by the manufacturer for breathing gas service. PTFE, nylon, and flexible metal liners meeting the requirements of para. 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 para. 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 either permanently printed 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 utilized.

(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 para. 4-9.14 need not be retested.

(b) Locally assembled hose assemblies shall be tested as prescribed in para. 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 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 B31.1, para. 104.1, or as specified in para. 304.1 of B31.3.

4-3.2.2 Additional Thickness Requirements. The thickness determined from the formulas in ASME B31.1 para. 104.1 and para. 304.1 of 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 B31.1 Table 102.4.5 or para. 332 of B31.3.

4-3.4 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 B31.1 or para. 332 of 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.

4-3.5 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.

4-3.6 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, B31.1 para. 104.3 or 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.

4-3.7 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.

4-3.8 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 (MAWP). 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 must 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 bi-directional 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 blowout 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 at 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 B31.3, subject to the following additional requirements:

Welded joints of NPS (nominal pipe size) 2½ in. pipe size or smaller may be socket welded or butt welded. Welded joints over NPS 2½ in. pipe size shall be butt welded.

4-5.2 Brazed Joints

Brazing shall be performed in accordance with para. 333 of B31.3.

(a) The Brazing Procedure Specification and the Procedure Qualification Record shall meet the Requirements of either ASME Section IX 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	Pressure
Over 3 in.	Not permitted
2½ to 3 in.	400 psig
2 in.	600 psig
1¼ to 1½ in.	800 psig
1 in.	1,500 psig
¾ in. or smaller	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 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 re-assembly 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 re-assembly 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 are found in B31.1, Table 121.5, or Part 5, para. 321 of 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. 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.

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) Pre-inserted 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 post assembly system leak test to operating pressure shall be performed.

Where a hydrostatic test is not possible or desirable, refer to para. 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 maximum allowable working pressure (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 one-half of the test pressure, after which the pressure shall be increased in steps of approximately one-tenth 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 totality for all PVHO piping systems but rather 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 section 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 section 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 must 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 is to 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 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, which 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 for the purpose of permitting 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 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 para. 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 in atmospheres absolute

F = factor, to be taken as 1.0 unless data is available to support a lower number. $F = 1$ 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, standard cubic feet per minute

RMV = maximum anticipated user respiratory minute volume, in cubic feet per minute at usage pressure. The minimum RMV that may be used is 1.41 ft^3/min (40 L/min) for a working diver and 0.7 ft^3/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 over pressure 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 one 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 on 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 (i.e., mask overboard dump lines, medical suction lines) shall be provided with vacuum relief valves capable of relieving under pressures 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 over pressure 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 Section VIII, Division 1 UG-125 through UG-136 or Section VIII, Division 2 Part AR

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 over pressurizing 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 utilizing oxygen enriched gases (greater than 25% oxygen), consideration must be given to the soft goods flammability in the oxygen enriched environment. ASTM G 63 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 and ASTM G 63 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 of this Section:

(a) A written cleaning procedure with well defined procedures, personnel responsibilities, and acceptance/re-cleaning 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 Offgassing 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 must be able to pass the off-gassing test described herein.

(a) *hydrocarbon:* for the purposes of 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 in Fig. 4-9.14. Before the air passes through the test hose, the air shall be clean and shall contain no more than 1 mg/m^3 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 air stream 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 shall not be acceptable.

4-9.14.3 MIL-H-2815 provides guidance in testing hoses.

Fig. 4-9.14 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

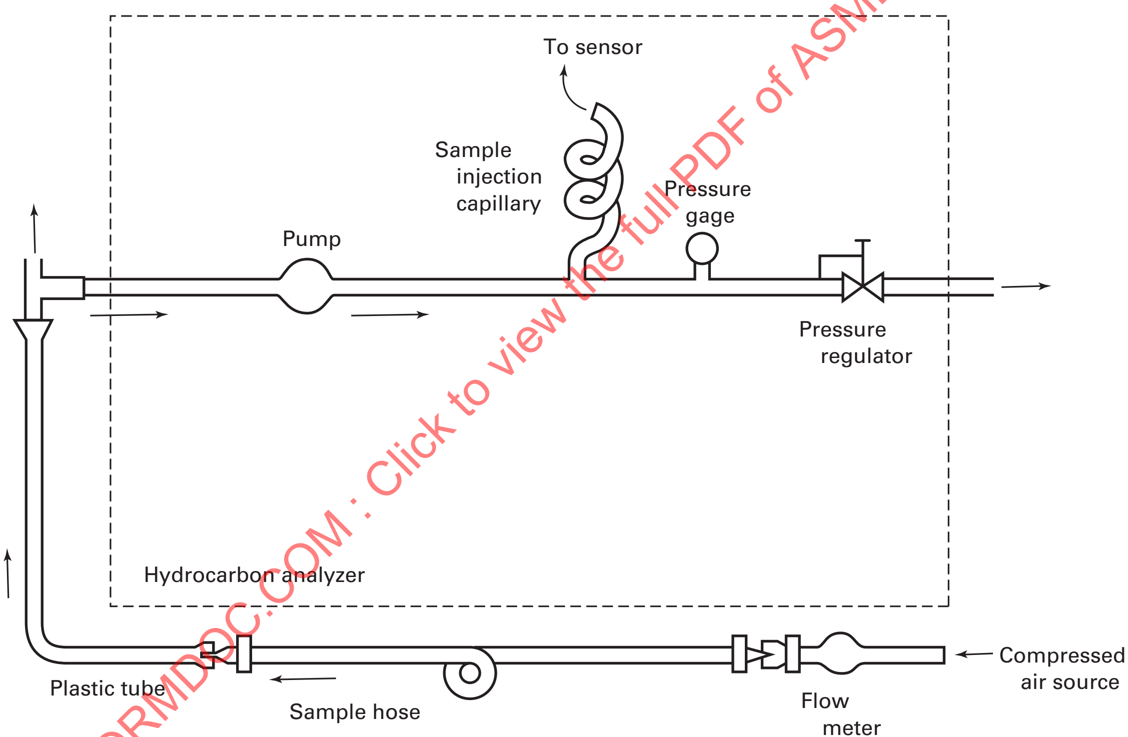

Table 4-2.1.1 Maximum Allowable Stress Values for Seamless Pipe and Tube Materials Not Listed in Nonmandatory Appendix A of ASME B31.1

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 B 88, Types K & L	Drawn	36	6.0

GENERAL NOTE: 1 ksi = 1,000 psi.

Table 4-7.1 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) For vent lines not subject to chamber pressure, MP or PT may be substituted for RT.
(b) All welds must be given a visual examination in addition to the type of specific nondestructive test specified.
(c) NPS = nominal pipe size.
(d) RT = radiographic examination; MT = magnetic particle examination; PT = liquid penetrant examination.
(e) 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.
(f) 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 B31.3.

Table 4-9.14 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

Section 5
Medical Hyperbaric Systems

5-1 GENERAL

5-1.1 Scope

This Section of the Standard provides minimum requirements for PVHO systems used specifically in medical hyperbaric therapy. The PVHO shall be designed, fabricated, assembled, inspected, tested, and certified in accordance with Section 1 of this Standard.

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 section 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, 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 LPM 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 are to 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 and around a chamber to see the patient(s), the chamber control console, and chamber support equipment.

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 accordance with Section 2 of this Standard.

5-5.5.2 Emergency Lighting. Emergency lighting shall be provided.

5-5.6 Access to Emergency Equipment

No permanent seat or stretcher shall block the aisles, hatches, doors, medical locks, hand held hoses, fire suppression controls, or any emergency equipment.

5-5.7 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.

5-5.8 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 section 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 designing, fabricating, 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 pressure
(*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, and 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 classing society certifications
(*g*) vessel drawings necessary for the maintenance, inspection, and repair of the PVHO

6-1.5 Useful References

The designer should be familiar with the references contained in Nonmandatory Appendix E.

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 must 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 back up 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 (i.e., 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 must consider the external forces transmitted to the PVHO.

For marine design purposes, these forces shall be at least 2.0 g vertical, 1.0 g transverse, and 1.0 g 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
Conponents 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 (i.e., viewports, emergency gas supplies), which 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 ft^3 (3.0 m^3) floodable volume

(c) diving bell (SDC)

(1) two occupants: 105 ft^3 (3.0 m^3) floodable volume

(2) three occupants: 160 ft^3 (4.5 m^3) 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 greater 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 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.

6-3 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 (i.e., passing food, medical, 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 installed as close to the PVHO hull penetration as possible

(b) have a MAWP equal to or greater than that of the PVHO

(c) shall 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 that is equal to or greater than the PVHO MAWP and temperature

(d) be gas/water tight 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 (i.e., diving bell)

6-3.9 Fiber Optic Penetrators

Fiber optic penetrators must meet the mechanical criteria as described for electrical penetrators.

Section 7 Submersibles

7-1 GENERAL

7-1.1 Scope

This Section and Section 1 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 Section 1 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 applies 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, the provinces of Canada, or the equivalent in other countries, and 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, material test reports, as required by the User's Design Specification, window certificates) for at least 5 years.

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 is to be provided. In addition to items listed in para. 7-1.3, the manual shall include

(a) systems description

(b) operational check-off lists (list is to 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

(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 (CO_2) level

(11) internal and external oxygen leaks

(12) 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 position.

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 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 are to 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 is to be applied to the side that will be under pressure in the actual application and is to 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 are to 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 are not to 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 section 1-8, General Requirements, 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, Piping, the following information shall be documented on the system assembly drawing, in the operations manual, and/or on 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. 4-2.4.6. Hose testing must be documented.

7-3.2 Internal and External Pressures

Systems, fittings, and equipment subject to internal or external pressures 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 non-return valve or shut-off 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), (d), (e), and (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 are to be effectively separated from each other.

7-4.3.3 Positive and Negative Conductors. Both positive and negative conductors from a power sources are not to pass through the same penetrator or connection in a pressure boundary and are to 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 are to 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 are to be able to withstand a hydrostatic pressure of 1.5 times the design pressure of the submersible. Submerged cable assemblies are to be tested by the continuous application of an alternating current voltage of at least 500 V for one minute. This is to be performed with the jacket exposed to seawater. The quality of the assembly is to 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 on-board 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 (CO_2) 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 on-board emergency life support system is to 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 is to be supplied through full-face masks, oral-nasal masks, self-contained rebreathers or by other means suitable for supporting life in a contaminated environment, including the byproducts 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 ft^3 (28.3 L) per hour per person and a carbon dioxide (CO_2) production rate of 0.115 lb (0.0523 kg)/hr per person, at one atmosphere.

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 (O_2) levels, carbon dioxide (CO_2) 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 (O_2) 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 on-board 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 operations under all design conditions. Equipment shall include, but not be limited to,

(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 Gages

Two independent instruments for registration of depth are to be provided. At least one of these instruments is to 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 are to be provided to render the submersible, while on the surface, readily visible to other vessels.

7-7.7 Submerged Detection

Means are to be provided to indicate the submersible's location while 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 must 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 in 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, 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(s) 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 must, 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 to be the greater of 1.5 in. (38 mm) or as determined by the following:

$$GB = nwNd / W \tan \alpha$$

where

d = the interior distance in inches (millimeters) within the main cabin accessible to onboard personnel

N = total number of persons onboard the submarine

n = 0.1 (10% of the people aboard moving simultaneously)

W = the total weight in pounds (kilograms) of the fully loaded submarine.

w = 175 lb (79.5 kg) per person
α = 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 2 g vertical (1 g static plus 1 g dynamic), 1 g transversal, and 1 g 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, is to be used.

ANSI/FCI 70-2, American National Standard for Control Valve Seat Leakage

Publisher: Fluid Controls Institute (FCI), 1300 Summer Avenue, Cleveland, OH 44115

ASME Boiler and Pressure Vessel Code
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

Publisher: The American Society of Mechanical Engineers (ASME), Three Park Avenue, New York, NY 10016-5990; Order Department: 22 Law Drive, Box 2300, Fairfield, NJ 07007-2300

ASTM B 88, Specification for Seamless Copper Water Tube
ASTM B 154, Method of Mercurous Nitrate Test for Copper and Copper Alloys
ASTM D 256, Test Methods for Impact Resistance of Plastics and Electrical Insulating Materials
ASTM D 542, Test Methods for Index of Refraction of Transparent Organic Plastics
ASTM D 570, Test Method for Water Absorption of Plastics
ASTM D 638, Test Method for Tensile Properties of Plastics
ASTM D 648, Test Method for Deflection Temperature of Plastics Under Flexural Load
ASTM D 695, Test Method for Compressive Properties of Rigid Plastics
ASTM D 696, Test Method for Coefficient of Linear Thermal Expansion of Plastics
ASTM D 732, Test Method for Shear Strength of Plastics by Punch Tool
ASTM D 785, Test Method for Rockwell Hardness of Plastics and Electrical Insulating Materials
ASTM D 790, Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials
ASTM D 792, Test Method for Specific Gravity (Relative Density) and Density of Plastics by Displacement
ASTM E 208, Method for Conducting Drop-Weight Test to Determine Nil-Ductility Transition Temperature of Ferritic Steels
ASTM E 308, Method for Computing the Colors of Objects by Using the CIE System
ASTM G 63, Standard Guide for Evaluating Nonmetallic Materials for Oxygen Service
ASTM G 88, 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), 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959

CGA G-4.4, Oxygen Pipeline Systems

Publisher: Compressed Gas Association (CGA), 4221 Walney Road, Chantilly, VA 20151-2923

ISO 9001, Quality Management Systems — Requirements
ISO 13485, Medical Devices — Quality Management Systems — Requirements for Regulatory Purposes

Publisher: International Organization for Standardization (ISO), ISO Central Secretariat, 1, ch. de la Voie-Creuse, Case Postale 56, CH-1211, Genève 20, Switzerland/Suisse

NASA Technical Manual TMX 64711, Compatibility of Materials with Liquid Oxygen, October 1, 1972

Publisher: Marshall Space Flight Center, Building 4200, Room 120, MSFC, Huntsville, AL 35812

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

NFPA 99, Standards for Health Care Facilities

Publisher: National Fire Protection Association (NFPA), 1 Batterymarch Park, Quincy, MA 02169-7471

21 CFR 820, Food and Drugs, Quality System Regulation
29 CFR 1910, Occupational Safety and Health Standards
Publisher: U.S. Government Printing Office, 732 North Capitol Street NW, Washington, DC 20401

Threshold Limit Values for Chemical Substances
Publisher: American Conference of Governmental Industrial Hygienists (ACGIH), 1330 Kemper Meadow Drive, Cincinnati, OH 45240-1634

MANDATORY APPENDIX II
DEFINITIONS

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.

component: consists of, but not limited to, items such as pipe, piping subassemblies, parts, valves, strainers, relief devices, fittings, etc.

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 inclusion 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 must 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, total chronological time from the date of initial manufacture.

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.

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).

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.

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 gasses 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.

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-windows: 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 lightweight PVHO designed to accommodate one person undergoing initial hyperbaric treatment during or while awaiting transport or transfer to a treatment chamber.

hyperhemispherical window: a spherical acrylic shell having an included angle greater than 180 deg, a single penetration, and a conical bearing surface.

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.

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.

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 than other connected compartments (e.g., inner lock, outer lock, entry lock, med/service lock).

long-term proof pressure (LTPP): pressure that a window must 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 utilized in PVHO systems.

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.

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).

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 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) is to 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.

operational temperature range: the range of ambient temperatures to which the chamber can be subjected while pressurized.

oxygen service: any portion of a piping system that may contain a gas containing oxygen over 25% by volume oxygen shall be considered to be in oxygen service.

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.

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 accordance 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 must withstand without catastrophic failure under short-term pressurization at 650 psi/min (4.5 MPa/min) rate in design temperature ambient environment. This Standard defines short-term proof pressure as equal to four 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, which 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.

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 to at least 1 000 mg/m^3 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.

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.

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 must meet the reinforcement and weld detail requirements of ASME PVHO-1 and ASME Code Section VIII, Division 1 or 2, as appropriate.

B-2 PENETRATOR DESIGNS

Figure B-2 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 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 gage penetrators.

(c) special forging. This category is intended for fully radiographable penetrators, generally to comply to 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, supply lock and tunnel equalizations, or in other applications where a flush internal mount is required.

B-3 COUPLING DETAILS

Figure B-3 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.