The American Society of Mechanical Engineers

SAFETY STANDARD FOR PRESSURE VESSELS FOR HUMAN OCCUPANCY

AN AMERICAN NATIONAL STANDARD

ASME PVHO-1-2002

(Revision of ASME PVHO-1-1997)

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Cases. Proposed new and revised Cases, as well as notices of their approval, issued by the PVHO Main Committee appear in *Mechanical Engineering*. Once approved, the Cases are published with the next regularly scheduled edition as a service to the subscribers. The Cases are not part of the Standard and are included for information only, following the Nonmandatory Appendices.

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(02)

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 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 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 Boiler and Pressure Vessel Code. However, a number of important considerations were not covered in those rules. Among these were requirements for viewports and the inservice 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 Code. The user is expected to be familiar with the principles and application of the Code sections.

Boiler and Pressure Vessel Code 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.

Subsystem design (e.g., life support) is not covered (with the exception of piping systems), nor are designs which fall outside of the scope of Section VIII.

Section 4 of this Standard has been added to provide design requirements for piping systems used in association with a pressure vessel for human occupancy (PVHO). The ASME B31.1 Power Piping Code is a required supporting document. This Standard represents a set of design requirements that have been found to give satisfactory service in circumstances appropriate to PVHO piping systems. It also reflects consideration of the requirements that relate specifically to operational aspects of PVHOs. These include, but are not limited to

(a) operation in marine and medical environments,

(b) transportability of the chamber system,

(c) materials compatibility with oxygen and gases intended for human respiration,

(d) unique functional requirements, and

(e) consistency with design rules required by other jurisdictions where systems built under this Standard may need to be operated.

The Committee still has important work under review in the following areas: design procedures for external pressure, dynamic and impact loadings, and design procedures for quick-acting, spherically dished, and flared and dished covers. As each part of this work is completed, the Committee will consider it for inclusion in this Standard.

This 2002 edition is a compilation of the 1997 edition and its addenda a and b. The 2002 edition emphasizes that the standard applies to all PVHOs exceeding a 2 psi differential

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pressure. In the 2002 edition, mandatory appendices have been renumbered using Roman numerals and nonmandatory appendices have been renumbered using alpha designations. For example, former Mandatory Appendix A is now Mandatory Appendix I. The 2002 edition was approved and adopted by the American National Standards Institute as meeting the criteria as an American National Standard on January 14, 2002. Previous editions were published in 1977, 1981, 1984, 1987, 1993, and 1997. The 1997 edition included the elimination of the ASME Accreditation for Window Fabricators.

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ASME PVHO-1–2002
SUMMARY OF CHANGES

ASME PVHO-1–2002 Edition is a compilation of ASME PVHO-1–1997 and its addenda a and b with the revisions and errata shown below. These revisions and errata are identified on the listed pages by a margin note, **(02)**, placed next to the affected area.

Page	*Location*	*Change*
iii	Contents	Updated to reflect 2002 edition
vi	Foreword	Last paragraph revised
1	1.1.1	Revised
5	1.4.9(d)	Revised
6	1.5.3	Revised
	1.5.6	Revised
17, 18	2-2.6.1(b)	Revised
24	Fig. 2-2.11	Corrected by errata
46	2-2.14.13(b)	Last paragraph editorially revised
55, 56	2-3.8(b)	Corrected by errata
57	Table 2-4.1	Revised
60	2-7.8	Revised

SPECIAL NOTE:

The cases and interpretations to PVHO-1 follow the last page of this edition. Neither the cases nor the interpretations, however, are part of the Standard itself.

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SAFETY STANDARD FOR PRESSURE VESSELS FOR HUMAN OCCUPANCY

SECTION 1 GENERAL REQUIREMENTS

1.1 Scope

1.1.1 This Standard provides requirements for the design, fabrication, inspection, testing, marking, and stamping of pressure vessels for human occupancy, having an internal or external pressure differential exceeding 2 psi, hereafter called PVHOs or chambers. This Standard also provides requirements for the design, fabrication, inspection, testing, cleaning, and certification of piping systems for PVHOs. A PVHO is a pressure vessel that encloses a human being within its pressure boundary while it is under internal or external pressure that exceeds a 2 psi differential pressure. PVHOs include, but are not limited to, submersibles, diving bells, personnel transfer capsules, decompression chambers, recompression chambers, hyperbaric chambers, high altitude chambers, and medical hyperbaric oxygenation facilities. This does not include nuclear reactor containments, pressurized airplane and aerospace vehicle cabins, and caissons.

1.1.2 The requirements contained in this Standard are supplemented by the ASME Boiler and Pressure Vessel Code, hereafter referred to as the Code, and the ASME Code for Pressure Piping, B31.1 Power Piping, also referred to herein as ASME B31.1.

1.1.3 In relation to the geometry of pressure containing parts, the following are considered to be parts of chambers:

(a) shells of revolution;

(b) openings and their reinforcement;

(c) nozzles and other connections;

(d) flat heads;

(e) quick-actuating closures;

(f) attachments and supports, including method of attachment;

(g) access openings;

(h) windows;

(i) where external piping is to be connected to the vessel:

(1) the welding end connection for the first circumferential joint for welded connections;

(2) the first threaded joint for screwed connections;

(3) the face of the first flange for bolted, flanged connections; and

(4) the first sealing surface for proprietary connections or fittings;

(j) pressure retaining covers for vessel openings;

(k) the first sealing surface for proprietary fittings for which rules are not provided by this Standard; and

(l) devices providing pressure relief to a chamber.

1.1.4 Piping systems, as covered by this Standard, include all pressure piping and component parts which fall under the definition of breathing gas systems and life-sensitive systems as defined in mandatory appendix IV. Piping systems subject to the requirements of this Standard include, but are not necessarily limited to, the following:

(a) piping systems communicating with chamber pressure,

(b) breathing gas supply systems,

(c) ballast blow systems in submersibles, and

(d) hydraulic systems in diving bell or submersible handling systems.

Piping that is part of personal breathing equipment and cylinders and other containers used for the storage of gases are excluded from the requirements of this Standard.

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1.2 General

1.2.1 The PVHOs shall be designed, fabricated, inspected, tested, marked, and stamped in accordance with the requirements of this Standard and Section VIII of the Code. The user, or the user's agent, shall specify which Division of Section VIII of the Code shall be used.

1.2.2 PVHO manufacturers shall hold a valid Certificate of Authorization for use of the ASME U or U2 Code Symbol Stamp, and shall complete Form PVHO-1, Manufacturer's Data Report for Pressure Vessels for Human Occupancy, to certify that each PVHO meets the requirements of this Standard and the applicable Division of Section VIII of the Code.

1.2.3 PVHO window fabricators shall complete Form PVHO-2, Fabrication Certification for Acrylic Windows, to certify that each window meets the requirements of this Standard.

1.2.4 Piping systems shall meet the requirements of Section 4 of this Standard.

1.2.5 Revisions to this Standard, published in addenda, may be utilized upon publication and shall become mandatory 6 months after the date of issuance of the addenda.

1.3 PVHO Materials

1.3.1 All chamber materials shall meet the requirements of this Standard and the specified division of Section VIII of the Code. The following materials shall not be used for pressure parts: SA-36, SA-283, SA-515, and cast and ductile iron.

1.3.2 Ferrous materials of chambers shall also comply with the following requirements.

(a) Except as provided for in 1.3.2(b), (c), (d), or (e), 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 heat 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 design minimum temperature for seamless and postweld heat-treated chambers, and 50°F (28°C) lower for as-welded chambers. 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-204.3, as applicable, in all respects, except the test temperature shall not be higher than that specified in 1.3.2(a).

(c) As an alternative to the provisions of 1.3.2(a), 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 1.3.2(a) regardless of the temperature shown in Table A1.15 of SA-20.

(d) Ferrous materials which are 0.625 in. (16 mm) or less in thickness are exempted from the additional toughness tests of 1.3.2(a), (b), and (c) above provided these materials are

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

(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 1.3.2(a), (b), and (c) 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 minimum temperature, regardless of the value of the design minimum temperature.

1.3.3 PVHOs constructed of ferrous materials which are exposed to the corrosive effects of seawater or seawater atmosphere shall have provision 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. In no case shall the corrosion allowance be less than that specified in Section VIII, Part UCS, of the Code for Division 1 vessels or less than that specified in the User's Design Specification for Division 2 vessels.

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1.4 Design and Fabrication of PVHOs

The design and fabrication of PVHOs shall be in accordance with the specified division of Section VIII of the Code and the following requirements.

1.4.1 Joint Design. All PVHOs shall be designed with joints as follows.

(a) All joints of Categories A, B, and C shall be Type No. 1 of Table UW-12 for Division 1 vessels or shall comply with AF-221 for Division 2 vessels, except as permitted in 1.4.1(c).

(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 installed in accordance with Fig. UW-13.1(f), and per UW-13(c)(1) and UW-13(c)(2) for Division 1 vessels only, provided that all of the following conditions are met:

(1) the maximum allowable working pressure is less than or equal to 135 psig;

(2) the allowable stress used in the calculations for the two shells and intermediate head is 70% of the allowable stress found in Section II, Part D;

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

(4) the allowable shear stress value of the butt weld and the fillet weld shall be 20% of the stress value for the vessel material [see UW-13(c)(2)].

1.4.2 Temperature Limit. The design temperature shall not be below 0°F (−18°C) or above 150°F (66°C).

1.4.3 Drain Openings. Drain openings shall be provided.

1.4.4 Opening Reinforcements. All opening reinforcement shall be integral with the nozzle and/or shell. Reinforcement pads are not permitted.

1.4.5 Supports and Attachments

(a) The design must consider the external local forces transmitted to the chamber. For marine design purposes, these forces shall be at least 2.0g (19.6 m/s^2) vertical, 1.0g (9.8m/s^2) transverse, and 1.0g (9.8 m/s^2) longitudinal, all acting simultaneously while the chamber is pressurized.

NOTE: The term 2.0g (19.6 m/s^2) indicates a force which is equal to two times the weight of the component. The term 1.0g (9.8 m/s^2) is a force equal to one times the weight of the component.

(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.

(c) Lifting attachments for submersible PVHOs are to be designed for the maximum anticipated load, given in 1.4.5(a), including shock. Weld details shall conform to the requirements of AD-910 of Section VIII, Division 2, of the Code.

1.4.6 Brazed or Riveted Construction. Brazed or riveted construction is prohibited.

1.4.7 External Pressure Design of Spheres and Spherical Segments

(a) Nomenclature

C = a factor used to determine minimum shell thickness and length of the template used in checking local shell deviations

E = modulus of elasticity for the material at design temperature, psi (MPa). (For this value, for Division 1 vessels, see the applicable material chart in Subpart 3 of Section II, Part D of the Code; for Division 2 vessels, see Tables TM-1 through TM-5 in subpart 2 of Section II, Part D.)

L_c = chord length of template used to measure deviation from nominal circulatory, in. (mm)

P_e = external design pressure, psi (MPa)

PT = external test pressure, equal to 1.25 P_e, psi (MPa)

R_o = nominal outside radius of spherical shell, in. (mm)

S_y = minimum yield strength for the material at design temperature, psi (MPa). (For yield strength values, see Table Y-1, Section II, Part D, of the Code.)

t = required minimum thickness of spherical shell exclusive of corrosion allowances, in. (mm)

(b) Thickness. The minimum required thickness for the spherical shell under external pressure exclusive of corrosion allowance shall be determined by the following procedure.

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

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

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

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

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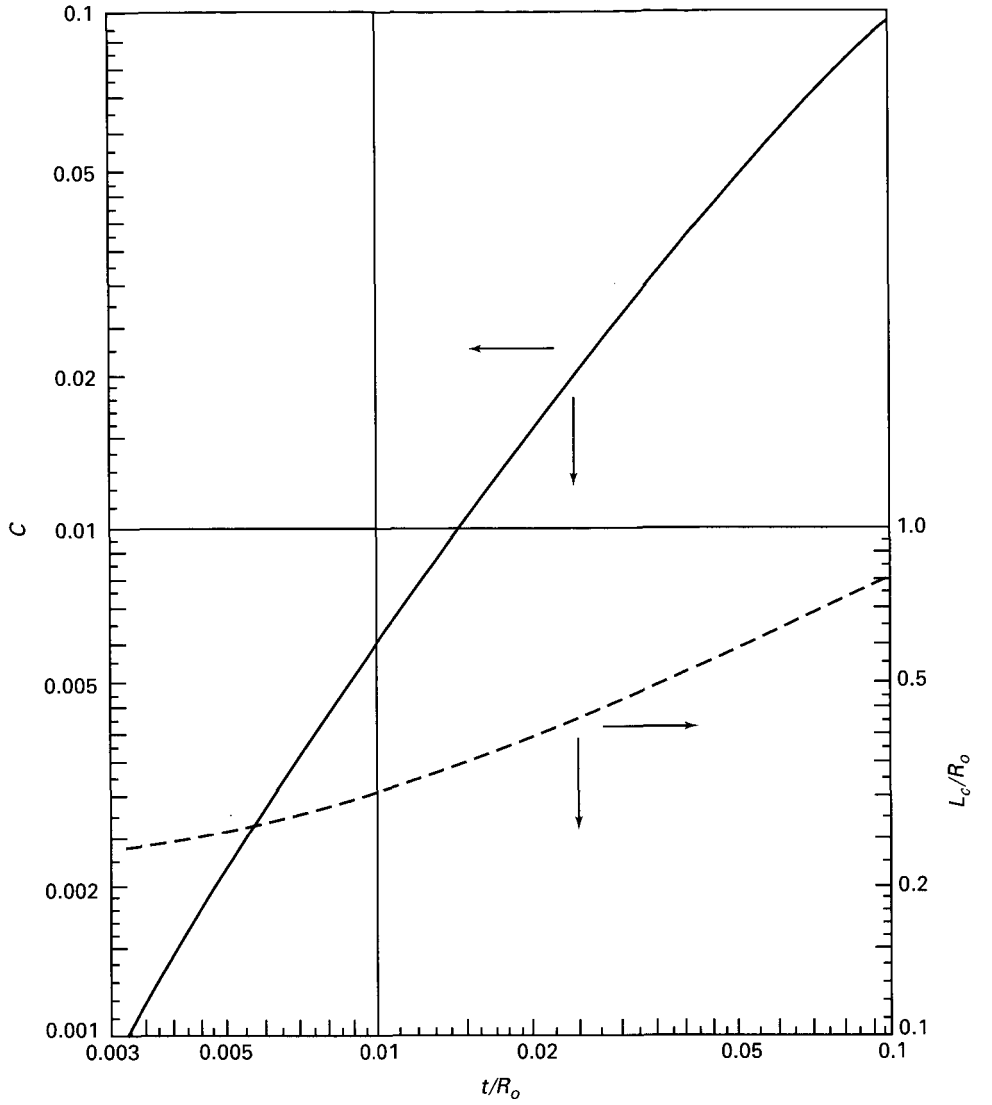


FIG. 1.4-1 VALUES OF t/R_o AND L_c/R_o

Step 2. Enter the left ordinate of Fig. 1.4-1 with the value of C calculated in step 1. Move horizontally to an intersection with the solid curve. Extrapolation beyond the upper or lower limit of the curve is prohibited. When values of C fall outside the limits of Fig. 1.4-1, 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 not be less than $^3/_8$ 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.

(c) Tolerances

(1) Out-of-Roundness. The difference between the maximum and minimum inside diameters at any cross

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

(2) Local Shell Tolerances

(a) The maximum plus or minus deviation from the 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.

(b) From the required minimum ratio of thickness to outside radius t/R_o obtained in Step 3 of (b), move vertically upward on Fig. 1.4-1 to the intersection of the dashed line. Move horizontally to the right from the dashed line and determine the ratio of critical arc length to outside radius L_c/R_o. The chord length L_c is obtained by multiplying this ratio by the outside radius R_o.

(d) Limitations. The following limitations apply to PVHOs designed in accordance with para. 1.4.7. 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 maximum outside radius R_o shall not exceed 60 in. (1500 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 $^3/_8$ in. (10 mm).

(4) The maximum external design pressure shall not exceed 900 psig (6.2 MPa gage).

(5) The fabricated vessel, regardless of thickness, shall be postweld heat treated in accordance with the requirements of Section VIII, Part UCS (Division 1 design) or Article F-4 (Division 2 design). The PWHT shall be accomplished prior to conducting the external pressure test.

(6) Materials of construction are limited to ferrous materials.

(7) These rules are applicable only for spheres and spherical segments and are not applicable to cylindrical vessel parts and forms of other shapes.

(e) External Pressure Test

(1) Test Pressure. All spherical vessels and vessels with spherical segments designed in accordance with para. 1.4.7 shall be subjected to an external hydrostatic pressure test that subjects every part of the vessel to an external pressure PT not less than $1.25P_e$ to be marked on the vessel.

(2) Post Test Measurements. Measurements for determining the deviations specified in (c), *Tolerances*, shall be taken after the external pressure hydrostatic test. Any deviations exceeding the limits of (c) *Tolerances*, shall be corrected and the external pressure test repeated.

1.4.8 Windows

(a) The design pressure and temperature of the transparent materials shall meet, or exceed, the design pressure and temperature of the chamber.

(b) The design of transparent materials and their attachments to the chamber shall meet the requirements of Section 2 of this Standard.

(c) The transparent materials shall be fabricated by processes specified in Section 2 of this Standard.

(d) The designer shall consider all loadings, including, but not limited to, internal, external, hydrodynamic, hydrostatic, and thermal forces on the vessel.

1.4.9 Hatch Design. Hatches that do not use bolts for attachments may be designed in accordance with the requirements of Division 1, appendix 1-6(g) with the following conditions: **(02)**

(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 ferrous materials that meet ASME/PVHO requirements; and

(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 para. 1.4.7.

1.4.10 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 relevant 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,

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appendix 4 of Division 2 may be used as a guide using the allowable stress values of Division 1.

1.5 Inspection and Tests of PVHOs

1.5.1 All Categories A, B, C, and D butt welds shall be 100% radiographed.

1.5.2 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.

(02) **1.5.3** After hydrostatic tests, all pressure retaining, fillets, and/or seal welds that meet the requirements of para. 1.4.1 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.

1.5.4 All PVHOs designed for external pressure service shall be subjected to an external pressure hydrostatic test at 1.25 times the design pressure.

PVHOs designed for both internal and external pressure shall also be subjected to the internal hydrostatic test required by the specified Division of Section VIII of the Code.

1.5.5 PVHOs which incorporate viewports in their pressure boundary shall be subjected to the required internal and/or external pressure tests with the transparent materials mounted in their seats per Section 2, Article 7, at the time of the original chamber certification by the PVHO manufacturer.

(02) **1.5.6** In PVHO vessels which incorporate an intermediate head per 1.4.1(c), the following examinations shall be conducted.

(a) The butt weld joint shall be 100% radiographed and 100% ultrasonic examined per the requirements of Division 1.

(b) The butt weld and fillet weld shall be examined after hydrotest in accordance with para. 1.5.3.

1.6 Stamping and Reports of PVHOs

1.6.1 Each PVHO shall be marked with the following:

(a) the designation of this Standard, PVHO-1;

(b) name of the manufacturer of the pressure vessel, preceded by the words "certified by";

(c) maximum allowable working pressure ____ psi (internal) and/or ____ psi (external) at _____°F maximum and/or _____°F minimum;

(d) manufacturer's serial number; and

(e) year built.

PVHO-1

Certified by

_____
(Name of manufacturer)

_____ psi internal _____ psi external
(Max. allowable working pressures)

_____°F maximum _____°F minimum
(Design temperature range)

_____ _____
(Manufacturer's serial number) (Year built)

FIG. 1.6-1 FORM OF NAMEPLATE

1.6.2 The marking described in para. 1.6.1 shall be on a nameplate substantially as shown in Fig. 1.6-1. Nameplates shall be metal suitable for the intended service. Required nameplates shall be located in a conspicuous place on the vessel.

1.6.3 Nameplates may have markings produced by either casting, etching, embossing, debossing, stamping, or engraving, except that the PVHO-1 lettering shall be stamped on the nameplate.

(a) The required markings on a nameplate shall be in characters not less than $^5/_{32}$ in. high, except the lettering PVHO-1 shall be not less than $^3/_8$ in. high.

(b) Characters shall be either indented or raised at least 0.004 in. and shall be legible and readable.

1.6.4 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.

1.6.5 The nameplate shall be attached to the vessel or to a pad, bracket, or structure which is welded or soldered directly to the vessel. The nameplates shall be located within 30 in. of the vessel. Removal shall require the willful destruction of the nameplate or its attachment system.

(a) Nameplates may be attached either by welding, brazing, or soldering.

(b) Nameplates may be attached by tamper-resistant mechanical fasteners of suitable metal construction.

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FORM PVHO-1 MANUFACTURER'S DATA REPORT FOR PRESSURE VESSELS FOR HUMAN OCCUPANCY
As Required by the Provisions of ASME PVHO-1

1. Manufactured and certified by _____
2. Manufactured for _____
3. Location of installation _____
4. Type _____ _____ _____ _____
(drawing no.) (mfr. serial no.) (year built)
5. 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. _____.
6. 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).
7. Service: Fatigue analysis required _____ _____
(yes or no) (describe service)
8. *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

9. Manufacturer's Data Reports/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-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 _____ Signed _____
(PVHO mfr.) (representative)

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FORM PVHO-1S MANUFACTURER'S DATA REPORT SUPPLEMENTARY SHEET
As Required by the Provisions of ASME PVHO-1

1. Manufactured and certified by _____
2. Manufactured for _____
3. Location of installation _____
4. Type _____ _____ _____ _____
(drawing no.) (mfr. serial no.) (year built)

Data Report	Remarks (name of part, manufacturer's name, and identifying stamp)

1.6.6 In addition to the requirements of paras. 1.6.1 through 1.6.5, the stamping requirement of the specified Division of Section VIII of the Code shall be met.

1.6.7 The data report form from the specified Division of Section VIII of the Code shall be attached to the Manufacturer's Data Report, Form PVHO-1.

1.6.8 Windows in the PVHO shall be marked as required by Section 2 of this Standard.

1.7 PVHO Pressure Relief Devices

1.7.1 The need to maintain control of the pressure within chambers necessitates the inclusion of in-service operational requirements for pressure relief devices. Pressure excursions can be hazardous to individuals undergoing decompression, and there shall always be persons in attendance to monitor the PVHO in the event of an accident. Therefore, the following requirements shall be met for pressure relief devices installed on chambers.

(a) The applicable provisions 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 chamber 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 chamber.

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

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SECTION 2
VIEWPORTS

ARTICLE 1 GENERAL

2-1.1

The term *viewport* is defined, for the purpose of this Standard, as a penetration in the pressure vessel including the window, flange, retaining rings, and seals. The term *window* shall refer to the transparent, impermeable, and pressure resistant insert in the viewport.

2-1.2

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; and

(c) pressure cycles at design pressure and temperature.

2-1.3

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 contained 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 megarads.

(g) The design life of the windows shall not exceed the time limits specified in para. 2-2.7.

2-1.4

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

2-1.5

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

2-1.6

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

2-1.7

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, Article 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 2-3.1 for each lot and verify for each casting or lot (see Section 2, Article 3, for material certification requirements);

(c) a *material certification* for each window shall certify that the material meets the minimum values specified in Table 2-3.2 and that these properties have been experimentally verified. Average values specified in Table 2-3.2 shall be reported (see Section 2, Article 3, for material certification requirements); and

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FORM PVHO-2 FABRICATION CERTIFICATION FOR ACRYLIC WINDOWS
As Required by the Provisions of ASME PVHO-1

Window Drawing No. _____

Window Identification _____

Material Stock Descriptions

Manufacturer of acrylic _____

Trade name _____

Casting shape _____

Nominal thickness _____

Lot number _____

Casting number _____

Certified for conformance to Table 2-3.1 by _____

Date _____

Certified for conformance to Table 2-3.2 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 _____

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Fabrication Process Data

First annealing temperature _____

Duration _____

Cooling rate _____

Intermediate annealing temperature (if any) _____

Duration _____

Cooling rate _____

Final annealing temperature _____

Duration _____

Cooling rate (chart required) _____

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 pressure-tested windows _____Yes _____No

Window fabricator has completed Enclosure 4 _____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, Addenda _____, and company _____ drawing number _____, revision _____, dated _____.

_____ _____

Authorized representative of window fabricator Date

_____

Name and address of window fabricator

_____

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(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, Article 7, for pressure testing requirements).

ARTICLE 2 DESIGN

2-2.1 General

The manufacturer of the chamber shall be responsible 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 Acrylic windows in chambers must have one of the standard geometries shown in Figs. 2-2.1 through 2-2.4. Minimum acceptable thickness ratios shall comply with the requirements of Figs. 2-2.1 through 2-2.4 for the specific window geometry. (For acceptance of nonstandard window geometries, see para. 2-2.6.)

2-2.2.2 Calculations of the short-term critical pressure (STCP), on the basis of Figs. 2-2.1 through 2-2.4, satisfy the requirements of the design certification required by this Standard under para. 2-1.7(a).

2-2.2.3 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 The dimensions of a standard window in the 0 to 10,000 psi (0 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 through 2-2.16. Conversion factor values for standard window geometries are given in Tables 2-2.1 through 2-2.5.

2-2.3.2 The dimensions of windows in the 10,000 to 20,000 psi (69 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 2-2.6. 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 When selecting the conversion factors from Tables 2-2.1 through 2-2.5, 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 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.

2-2.5 Determination of Short-Term Critical Pressure

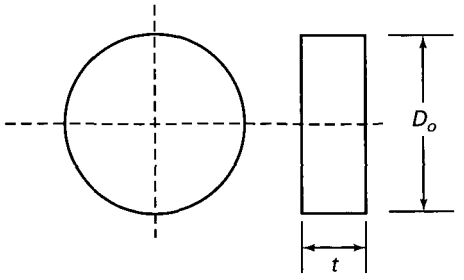
2-2.5.1 The STCP of a window accepted for service in chambers, without the use of experimental data, shall not be less than

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

where CF and P are the conversion factor and design pressure, respectively.

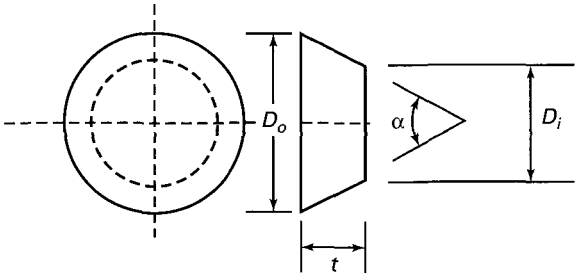
(a) For *flat disk acrylic windows*, shown in Fig. 2-2.1, use conversion factors from Table 2-2.1 and STCPs from Figs. 2-2.5, 2-2.6, and 2-2.7. Figure 2-2.5 shall be utilized for determination of critical pressures in the 72.5 to 1,160 psi (0.5 to 8 MPa) range. Figure

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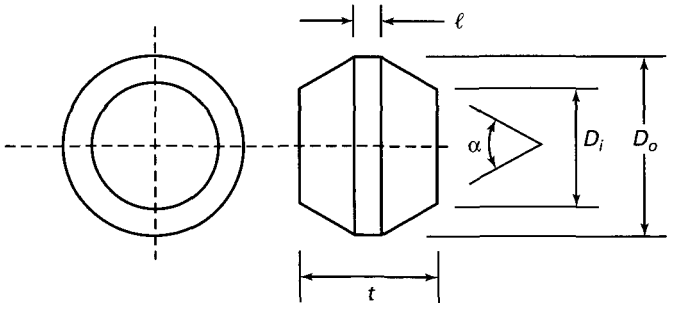
For Sketch (a):
$t \geq 1/2$ in. (12.5 mm)
$t/D_o \geq 0.125$

(a) Flat Disk Window



For Sketch (b):
$t \geq 1/2$ in. (12.5 mm)
$t/D_i \geq 0.125$
$\alpha \geq 60$ deg

(b) Conical Frustum Window



For Sketch (c):
$t \geq 1/2$ in. (12.5 mm)
$t/D_i \geq 0.250$
$\alpha \geq 60$ deg
$\ell \leq 0.25\ t$

(c) Double Beveled Disk Window

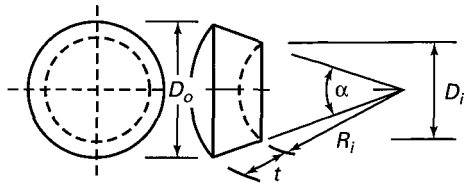
FIG. 2-2.1 STANDARD WINDOW GEOMETRIES

2-2.6 shall be used for the 1,160 to 7,250 psi (8 to 50 MPa) range, and Fig. 2-2.7 shall be used for the 7,250 to 43,500 psi (50 to 300 MPa) range. 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. 2-2.1, use conversion factors from Table 2-2.2 and STCPs from Figs. 2-2.8 and 2-2.9. Figure 2-2.8 shall be utilized for determination of critical pressures in the 290 to 7,250 psi (2 to 50 MPa) range, while Fig. 2-2.9 shall be used for the 7,250 to 43,500 psi (50 to 300 MPa) range. 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.

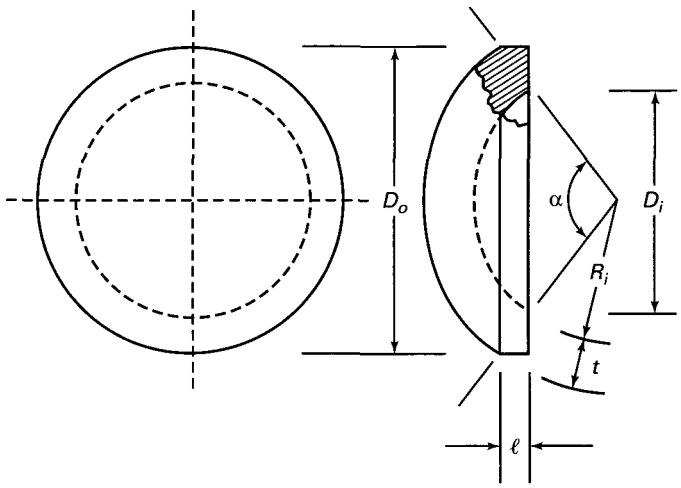
(c) For *double beveled disk acrylic windows*, shown in Fig. 2-2.1, use conversion factors from Table 2-2.2 and STCPs from Figs. 2-2.8 and 2-2.9. Figure 2-2.8 shall be utilized for determination of critical pressures in the 290 to 7,250 psi (2 to 50 MPa) range, while Fig. 2-2.9 shall be used for the 7,250 to 43,500 psi

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For Sketch (a):
$t \geq 1/2$ in. (12.5 mm)
$\alpha \geq 60$ 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



For Sketch (b):
$t \geq 1/2$ in. (12.5 mm)
30 deg $\leq \alpha$ 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 STANDARD WINDOW GEOMETRIES

(50 to 300 MPa) range. Short-term critical pressures may also be experimentally determined according to the procedure in para. 2-2.5.2.

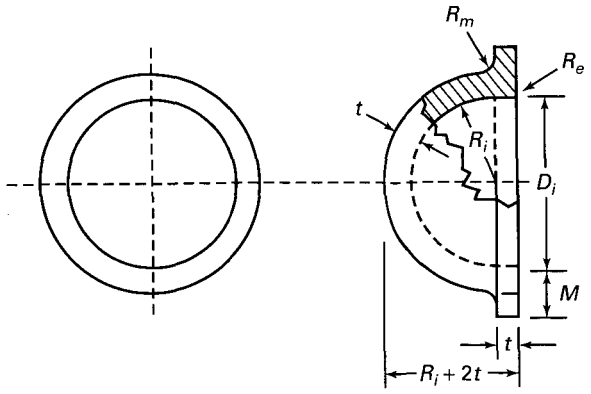
(d) For *spherical sector acrylic windows with conical edge*, shown in Fig. 2-2.2, use conversion factors from Table 2-2.3 and STCPs from Figs. 2-2.10 and 2-2.11. Figure 2-2.10 shall be utilized for determination of critical pressures in the 725 to 7,250 psi (5 to 50 MPa) range, while Fig. 2-2.11 shall be used for the 7,250 to 34,800 psi (50 to 240 MPa) range. 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, use conversion factors from Table 2-2.4 and STCPs from Figs. 2-2.10 and 2-2.11. Figure 2-2.10 shall be utilized for determination of critical pressures in the 725 to 7,250 psi (5 to 50 MPa) range, while Fig. 2-2.11 shall be used for the 7,250 to 34,800 psi (50 to 240 MPa) range. 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. 2-2.3, use conversion factors from Table 2-2.4 and short-term critical pressures from Figs. 2-2.10 and 2-2.11. Figure 2-2.10 shall be utilized for determination of critical pressures in the 725 to 7,250 psi (5 to 50 MPa) range, while Fig. 2-2.11 shall be used for the 7,250 to 34,800 psi (50 to 240 MPa) range. Short-term critical pressures may also be experimentally determined according to the procedure in para. 2-2.5.2. Windows of this type are accepted for service only where the hydrostatic pressure is applied to the convex surface.

(g) For *cylindrical acrylic windows*, shown in Fig. 2-2.3, use conversion factors from Table 2-2.5 and STCPs from Figs. 2-2.12 through 2-2.17. Table 2-2.5, Part A, and Figs. 2-2.12 and 2-2.13 shall be utilized only in determination of conversion factors and critical pressures for internal pressure service. Figure 2-2.12 shall be utilized for determination of critical pressures

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For Sketch (a):

$t \geq 1/2$ in. (12.5 mm)

$t/R_i > 0.03$

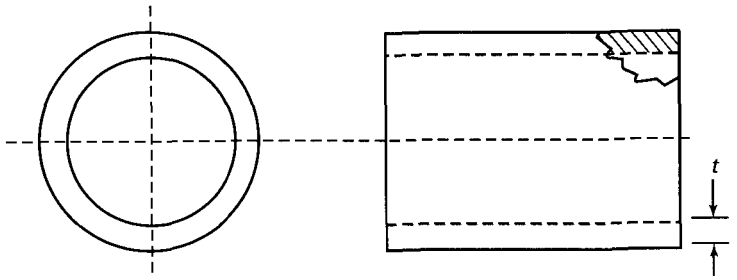
$D_o = (D_i + 4t)$

$R_m \geq 1/8$ in. (3.0 mm)

0.5 mm $\leq R_e \leq 0.125t$

$1.5t \leq M \leq 2.0t$

(a) Hemispherical Window With Equatorial Flange



For Sketch (b):

$t \geq 1/2$ in. (12.5 mm)

(b) Cylindrical Window

FIG. 2-2.3 STANDARD WINDOW GEOMETRIES

in the 145 to 1,160 psi (1 to 8 MPa) range, while Fig. 2-2.13 shall be used for the 1,160 to 5,800 psi (8 to 40 MPa) range. Table 2-2.5, Part B, and Figs. 2-2.14 through 2-2.17 shall be utilized only in determination of conversion factors and critical pressures for external pressure service. Short-term critical pressures may also be experimentally determined according to the procedure in para. 2-2.5.2.

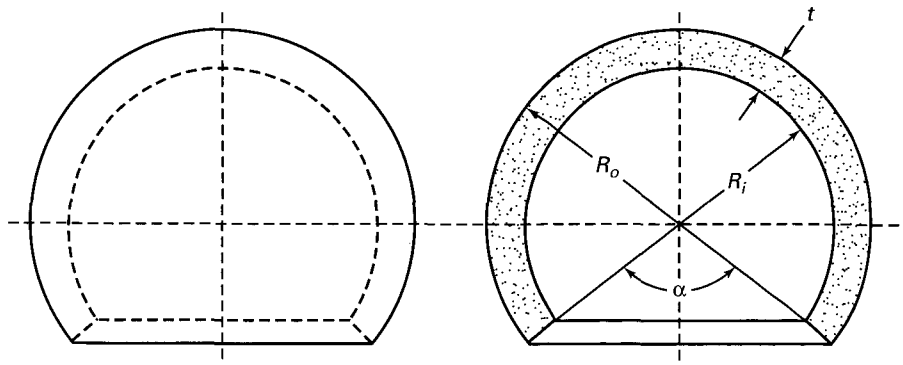
(h) For *hyperhemispherical acrylic windows*, shown in Fig. 2-2.4, use conversion factors from Table 2-2.3 and STCPs from Figs. 2-2.18 and 2-2.19. Figure 2-2.18 shall be utilized for determination of critical pressures in the 435 to 5,800 psi (3 to 40 MPa) range, while Fig. 2-2.19 shall be used for the 5,800 to 23,200 psi (40 to 160 MPa) range. 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. 2-2.4, use CFs from Table 2-2.3 and STCPs from Figs. 2-2.18 and 2-2.19. Figure 2-2.18 shall be utilized for determination of critical pressures in the 435 to 5,800 psi (3 to 40 MPa) range, while Fig. 2-2.19 shall be used for the 5,800 to 23,200 psi (40 to 160 MPa) range. 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 The experimental determination of STCP of an acrylic window shall be conducted by subjecting the window to hydrostatic pressure which 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 to 77°F (21 to 25°C) in a flange that satisfies the requirements of para. 2-2.9.

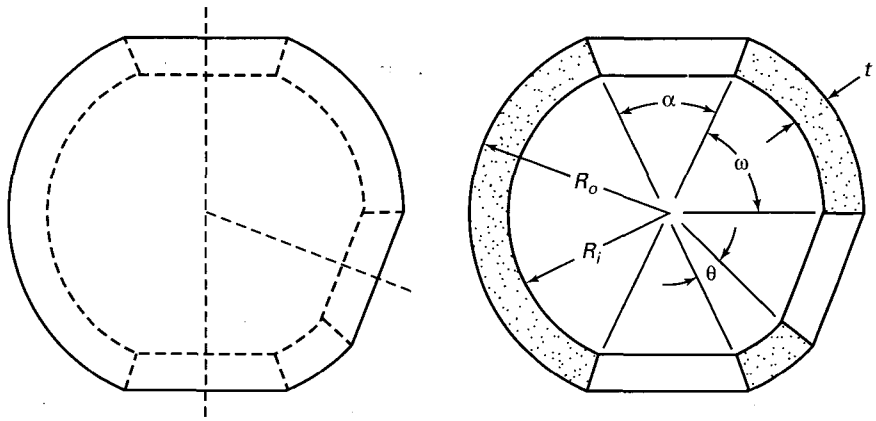
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For Sketch (a):
$t \geq 1/2$ in. (12.5 mm)
$0.03 \leq t/R_o \leq 0.355$
$\alpha \leq 100$ deg

(a) Hyperhemispherical Window



For Sketch (b):
$t \geq 1/2$ in. (12.5 mm)
$0.03 \leq t/R_o \leq 0.355$
$\alpha \leq 50$ deg
ω, θ = spacing between adjacent penetrations shall exceed $\alpha/2$ of the larger penetrations

(b) NEMO Window

FIG. 2-2.4 STANDARD WINDOW GEOMETRIES

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.

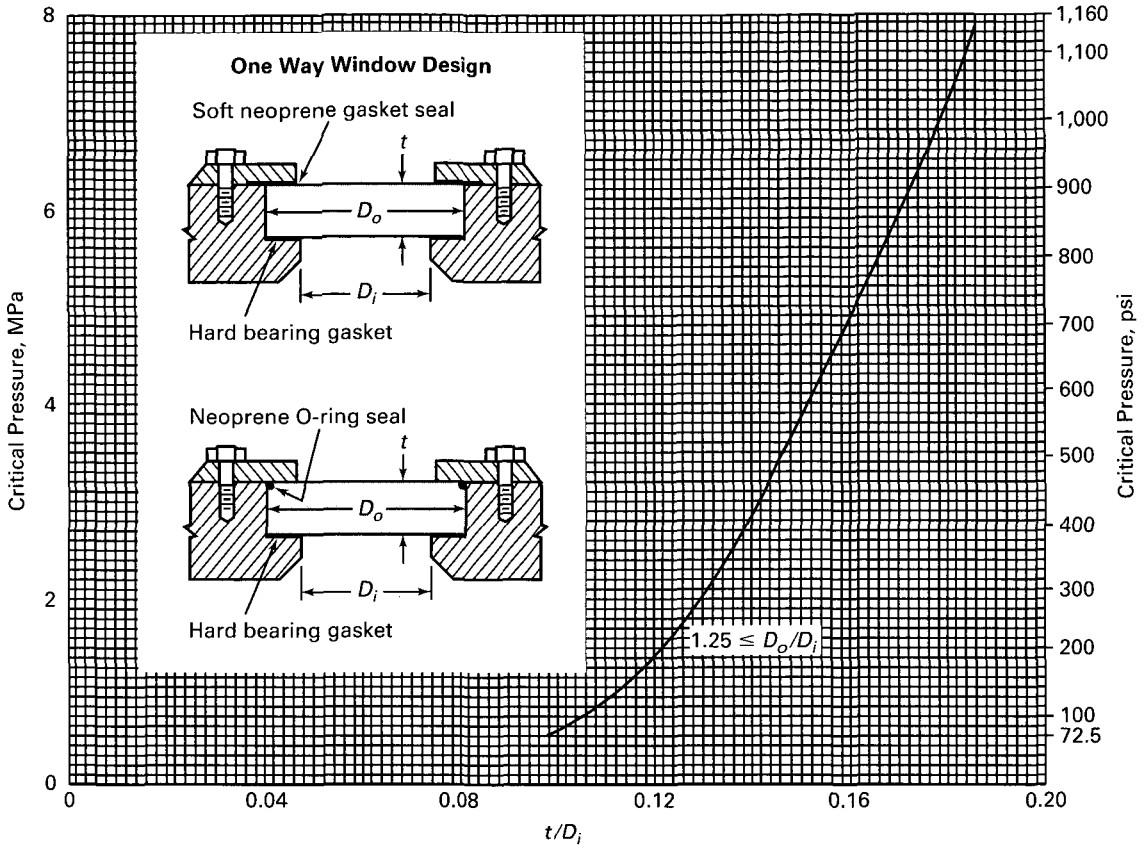
(b) For tests conducted on model-scale windows, the results will be considered acceptable only if the STCP of the full-scale window is equal to or above the single lowest STCP among the five model-scale windows. In case the STCP of the single full-scale window does not meet this criterion, four more full-scale windows shall be tested and the STCP value of the window design shall be calculated according to para. 2-2.5.2(a) 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 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 para. 2-1.3. **(02)**

(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 experimen-

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GENERAL NOTE: See Technical Report R 527, "Windows for External or Internal Hydrostatic Pressure Vessels — Part III," J.D. Stachiw et al., Naval Civil Engineering Laboratory, Port Hueneme, CA, 1967.

FIG. 2-2.5 SHORT-TERM CRITICAL PRESSURE OF FLAT DISK ACRYLIC WINDOWS [For Pressures in the 72.5–1,160 psi (0.5–8 MPa) Range]

tal 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 Windows with nonstandard geometries, or with standard geometries and lower conversion factors (CF), 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 Windows with nonstandard geometries, or with standard geometries and lower conversion factors (CF), must meet the following mandatory requirements:

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

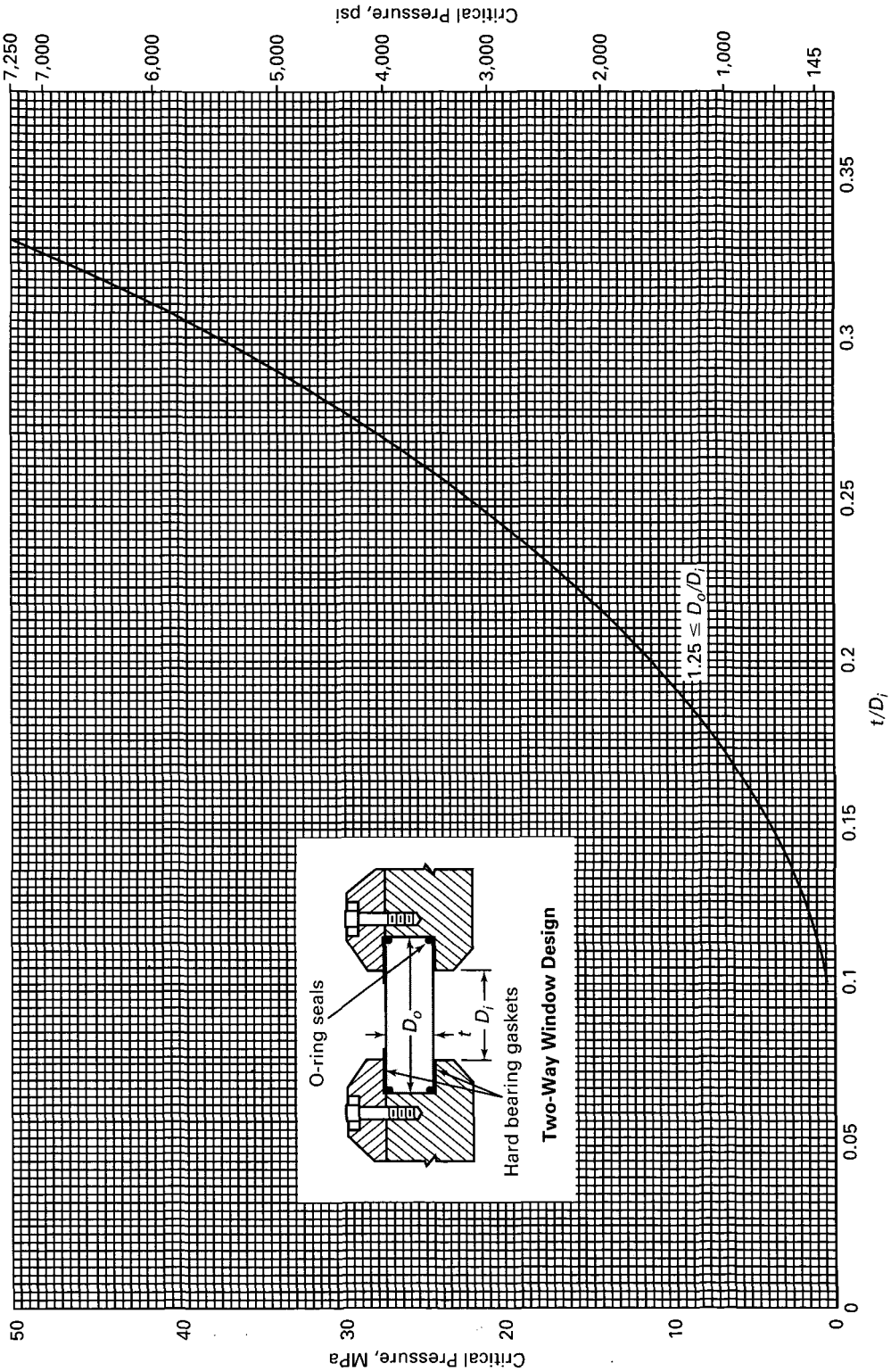
(b) long-term proof pressure (LTPP) = design pressure sustained continuously for 80,000 hr in design temperature environment without catastrophic failure;

(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 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.

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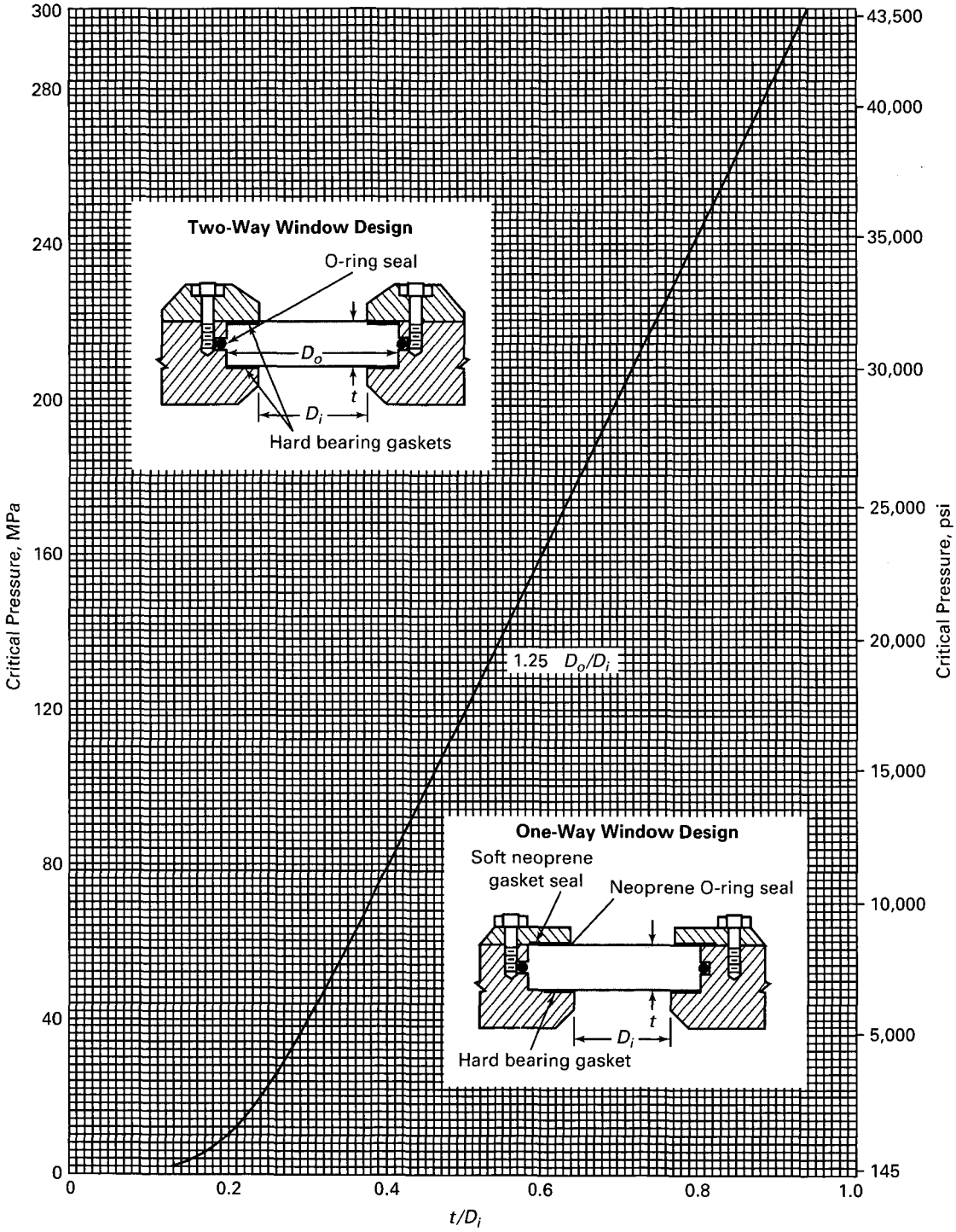


GENERAL NOTE: See Technical Report R 527, "Windows for External or Internal Hydrostatic Pressure Vessels — Part II," J. D. Stachiw et al., Naval Civil Engineering Laboratory, Port Hueneme, CA, 1967.

FIG. 2-2.6 SHORT-TERM CRITICAL PRESSURE OF FLAT DISK ACRYLIC WINDOWS
[For Pressures in the 1,160–7,250 psi (8–50 MPa) Range]

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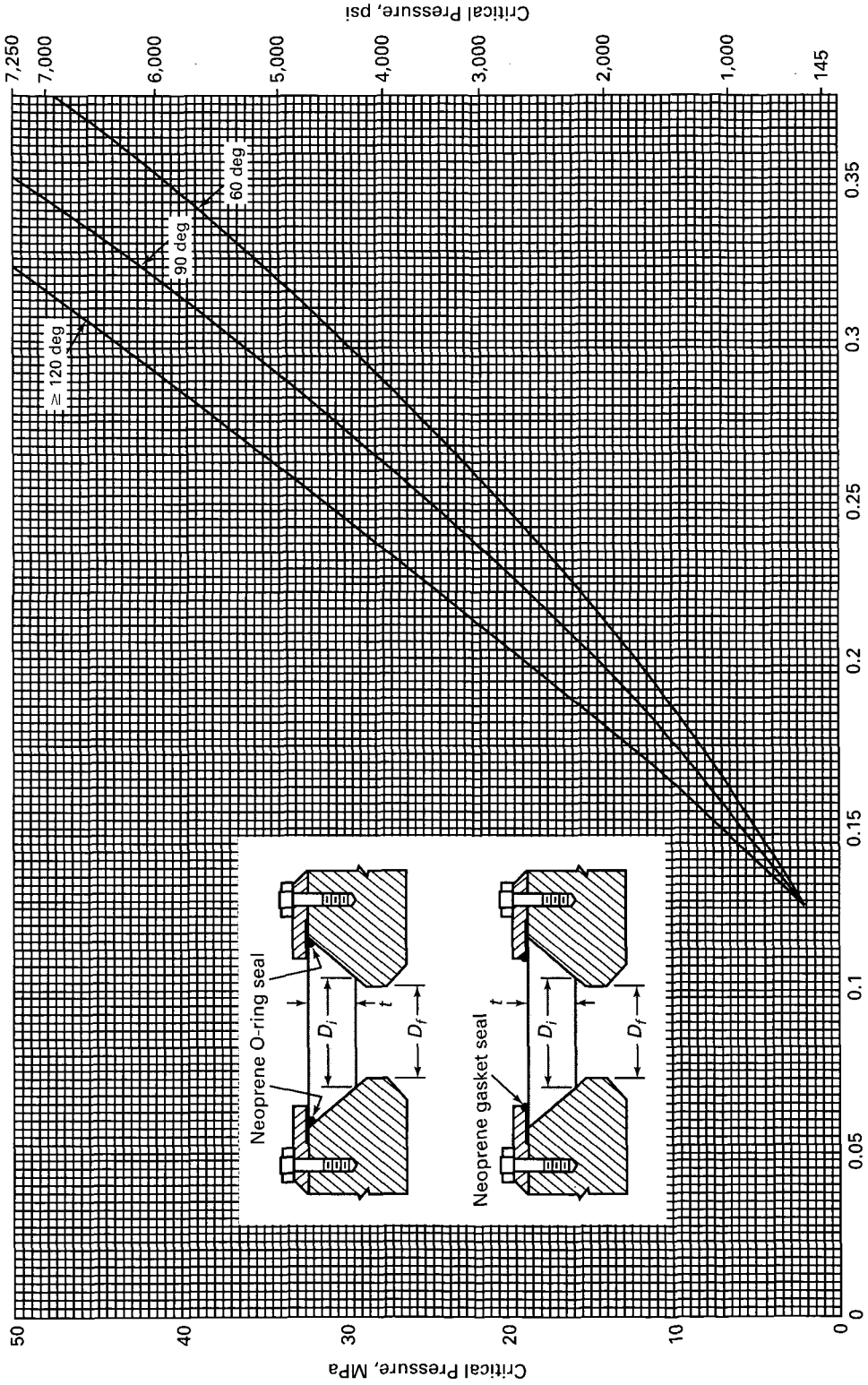
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GENERAL NOTE: See Technical Report R 527, "Windows for External or Internal Hydrostatic Pressure Vessels — Part III," J. D. Stachiw et al., Naval Civil Engineering Laboratory, Port Hueneme, CA, 1967.

FIG. 2-2.7 SHORT-TERM CRITICAL PRESSURE OF FLAT DISK ACRYLIC WINDOWS [For Pressures in the 7,250–43,500 psi (50–300 MPa) Range]

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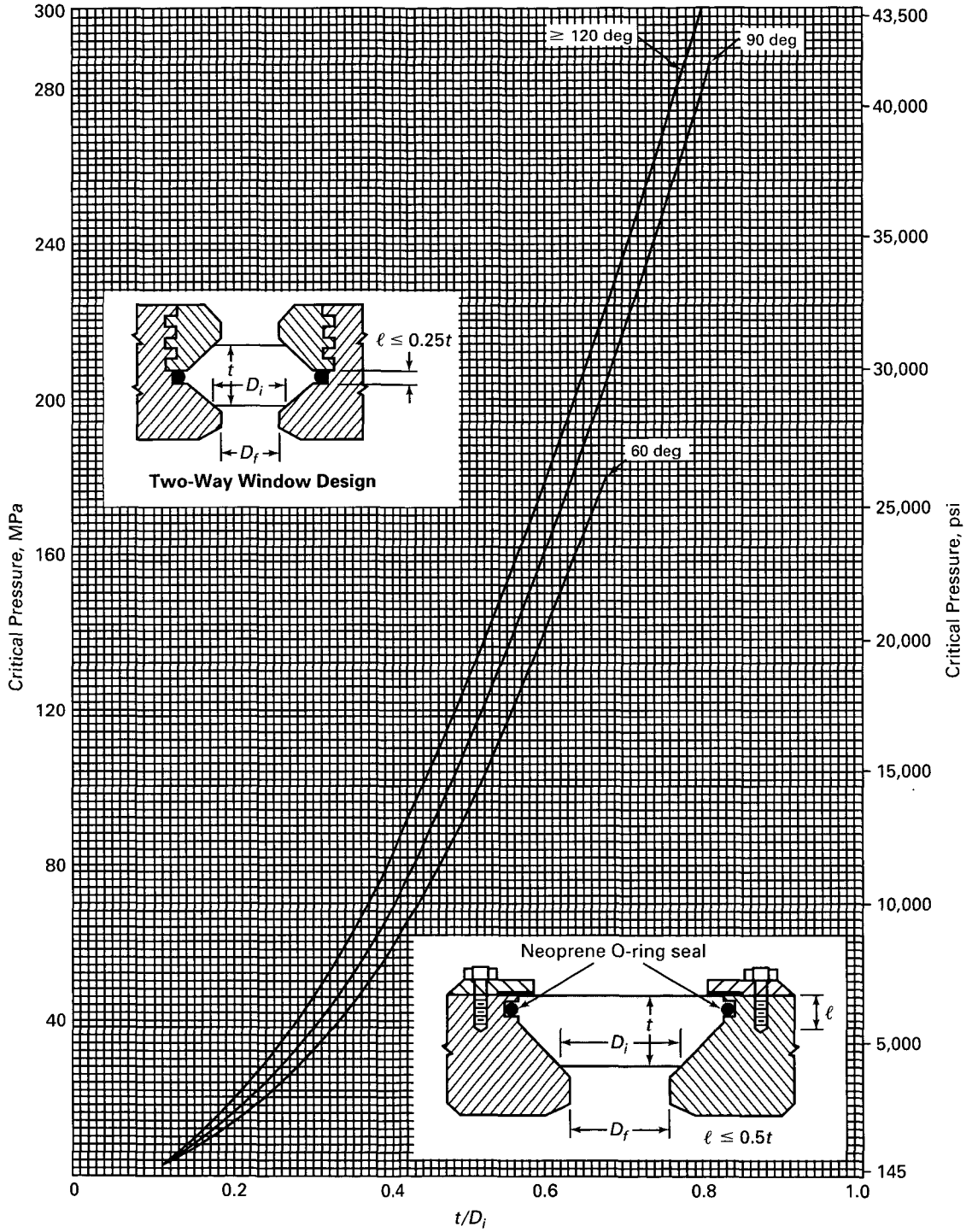


GENERAL NOTE: See Technical Report R 512, "Windows for External or Internal Hydrostatic Pressure Vessels — Part I," J. D. Stachiw and K. O. Gray, Naval Civil Engineering Laboratory, Port Hueneme, CA, 1967.

FIG. 2-2.8 SHORT-TERM CRITICAL PRESSURE OF CONICAL FRUSTUM ACRYLIC WINDOWS [For Pressures in the 290–7,250 psi (2–50 MPa) Range]

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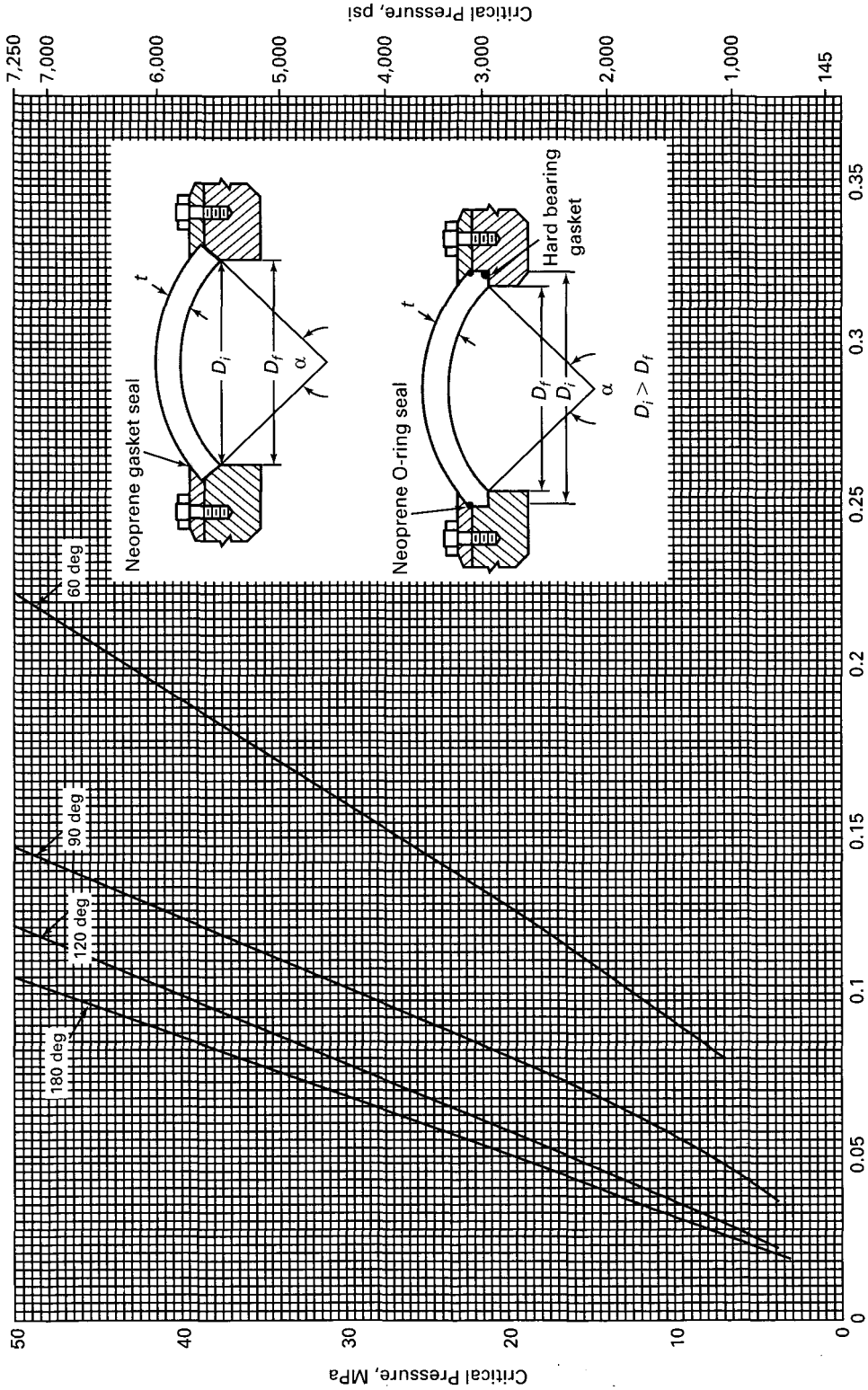
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GENERAL NOTE: See Technical Report R 512, "Windows for External or Internal Hydrostatic Pressure Vessels — Part I," J. D. Stachiw and K. O. Gray, Naval Civil Engineering Laboratory, Port Hueneme, CA, 1967.

FIG. 2-2.9 SHORT-TERM CRITICAL PRESSURE OF CONICAL FRUSTUM ACRYLIC WINDOWS [For Pressures in the 7,250–43,500 psi (50–300 MPa) Range]

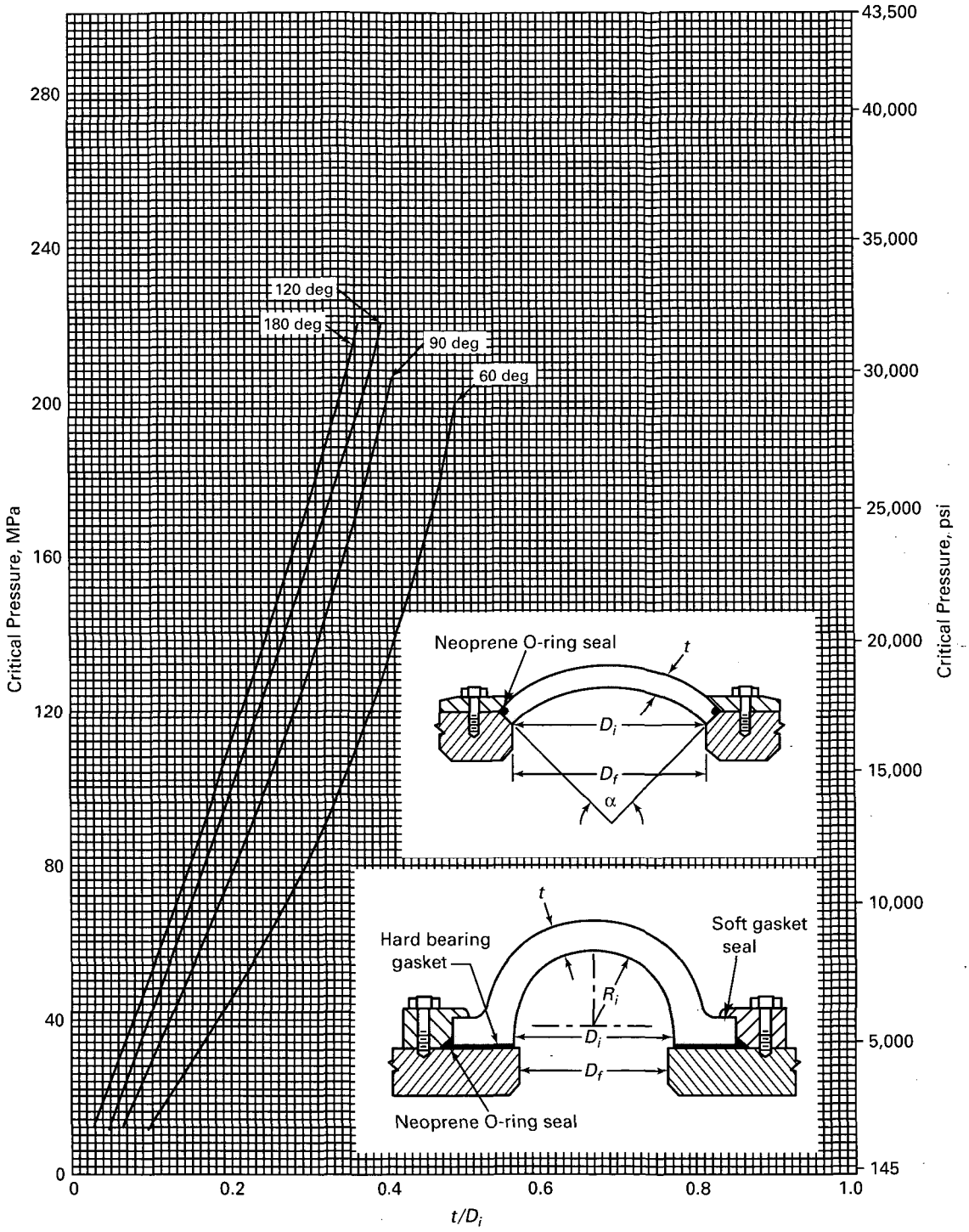
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GENERAL NOTE: See Technical Report R 631, "Windows for External or Internal Hydrostatic Pressure Vessels — Part III," J. D. Stachiw and F. Brier, Naval Civil Engineering Laboratory, Port Hueneme, CA, 1969.

FIG. 2-2.10 SHORT-TERM CRITICAL PRESSURE OF SPHERICAL SECTOR ACRYLIC WINDOWS [For Pressures in the 725–7,250 psi (5–50 MPa) Range]

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(02) FIG. 2-2.11 SHORT-TERM CRITICAL PRESSURE OF SPHERICAL SECTOR ACRYLIC WINDOWS [For Pressures in the 7,250–34,800 psi (50–240 MPa) Range]

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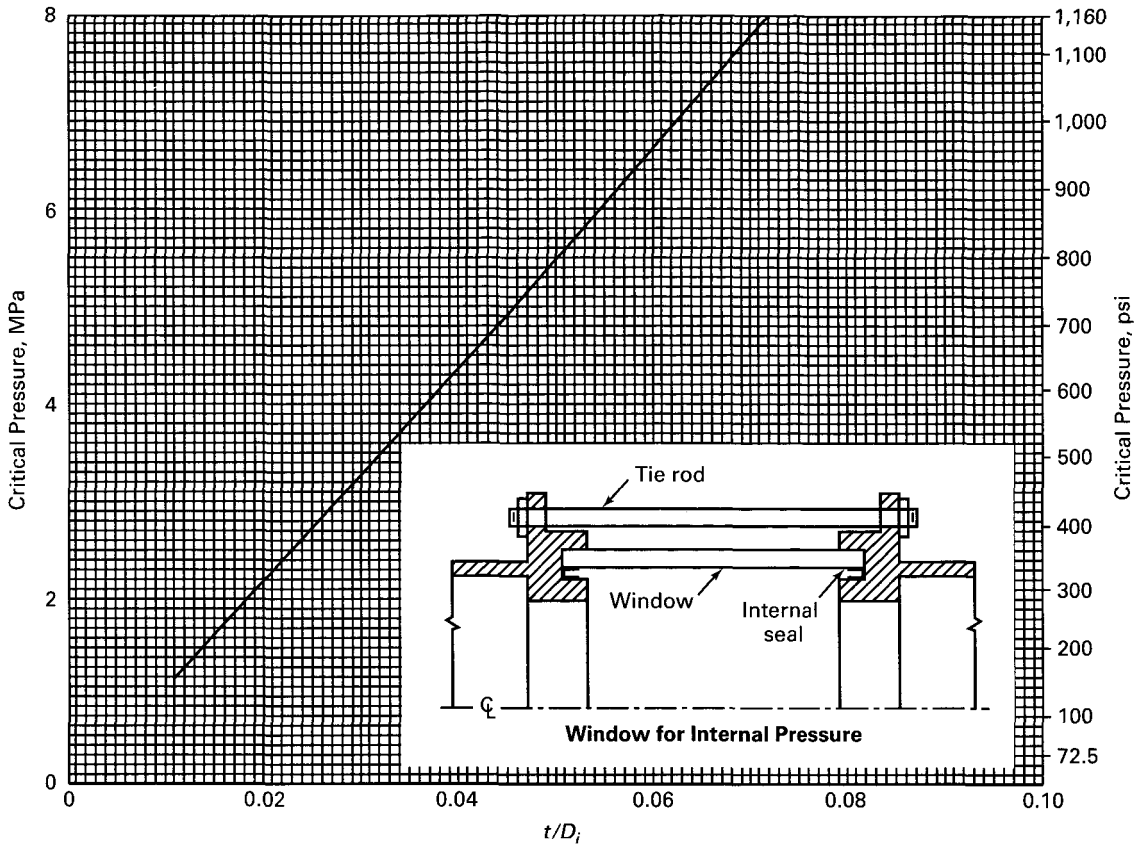


FIG. 2-2.12 SHORT-TERM CRITICAL PRESSURE OF CYLINDRICAL ACRYLIC WINDOWS PRESSURIZED INTERNALLY
[For Pressures in the 145–1,160 psi (1–8 MPa) Range]

(a) The windows shall be individually pressurized at 650 ±100 psi/min (4.5 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 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 STPP established experimentally in para. 2-2.6.4.

(d) The experimental data points of (c) 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-minute sustained loading duration shall also be 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 2-2.6.5(b), (c), (d), and (e) shall be sustained pressure loading of individual windows for a duration of 10,000 hr at design temperature per one on the following test programs.

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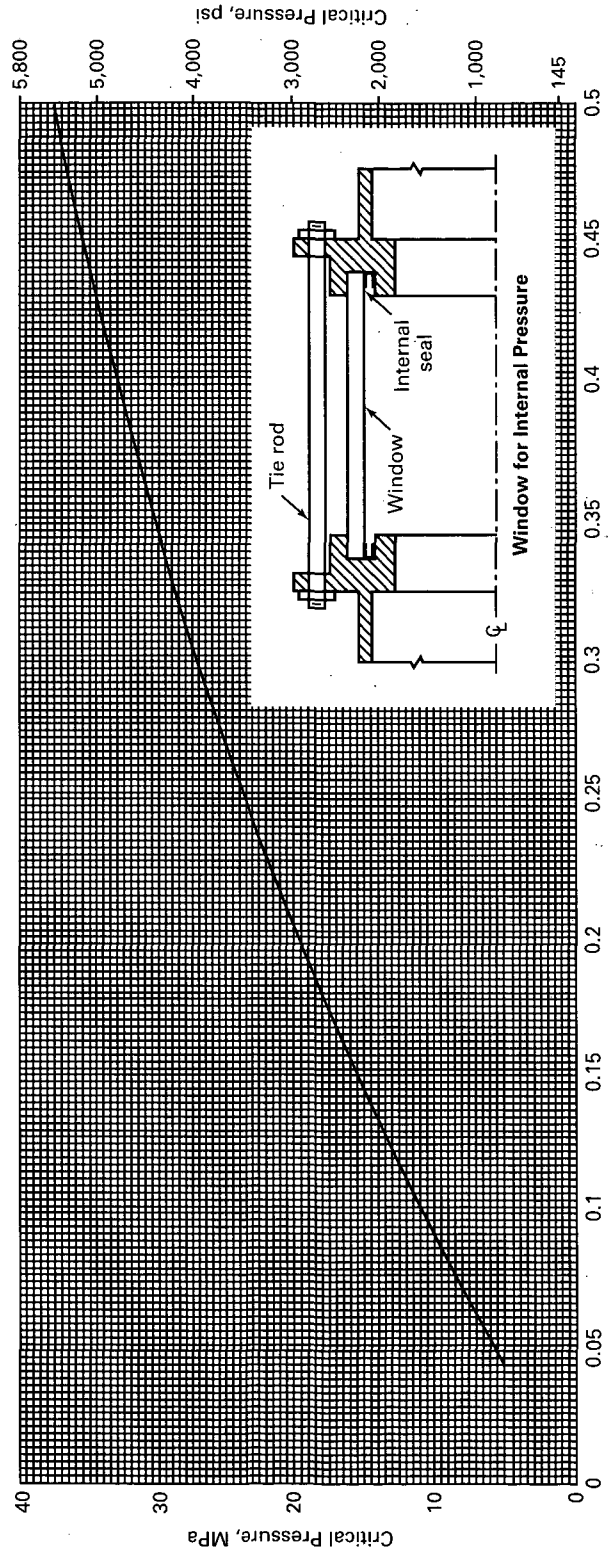


FIG. 2-2.13 SHORT-TERM CRITICAL PRESSURE OF CYLINDRICAL ACRYLIC WINDOWS PRESSURIZED INTERNALLY
[For Pressures in the 1,160–5,800 psi (8–40 MPa) Range]

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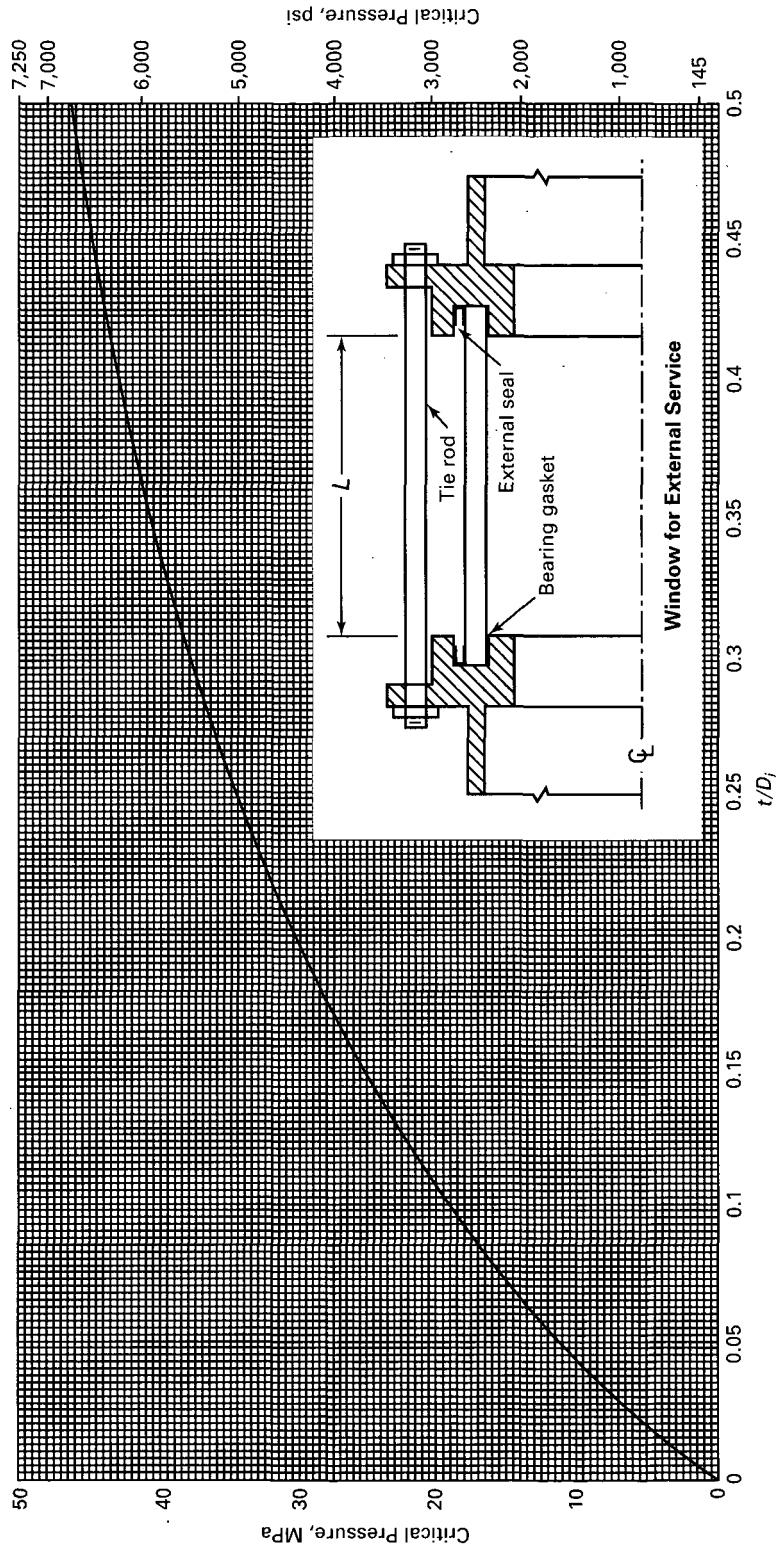
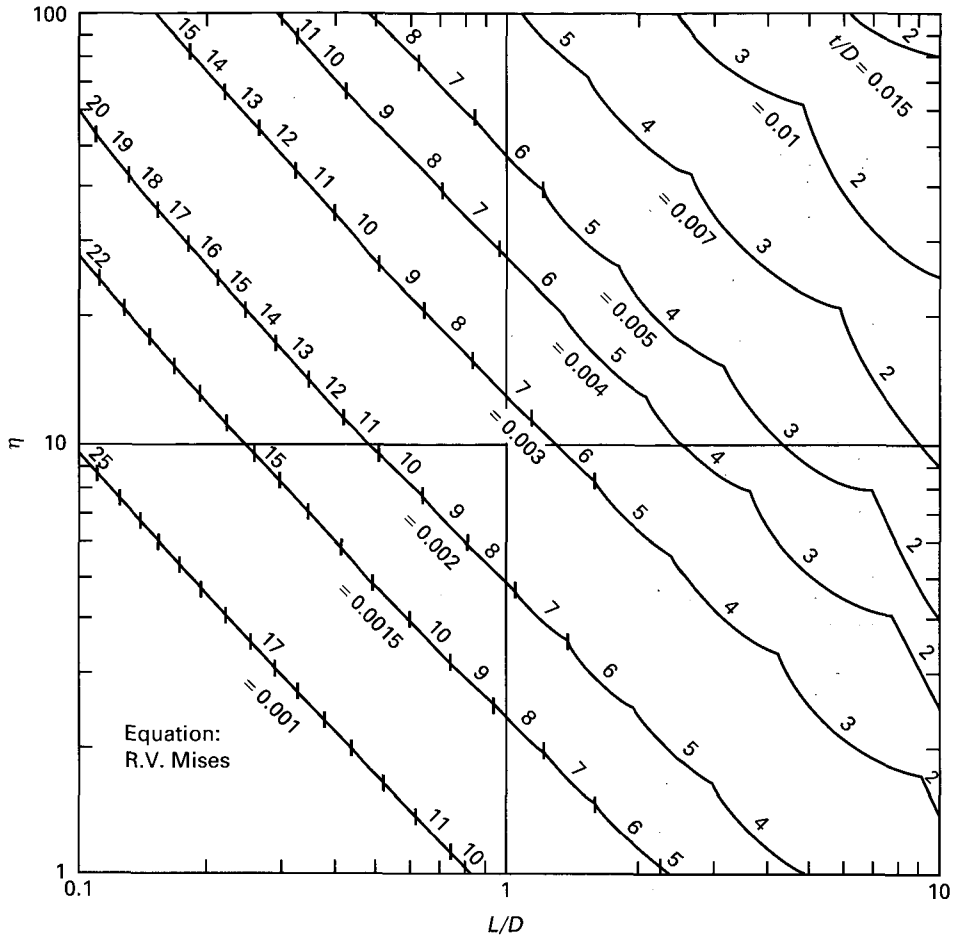


FIG. 2-2.14 SHORT-TERM CRITICAL PRESSURE OF CYLINDRICAL ACRYLIC WINDOWS PRESSURIZED EXTERNALLY

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GENERAL NOTES:
(a) P_c = short term critical pressure
$P_c = \eta \times 3.499 \times 10^{-2}$ psi
$P_c = \eta \times 2.413 \times 10^{-4}$ MPa

(b) $D = \frac{D_i + D_o}{2}$

FIG. 2-2.15 SHORT-TERM ELASTIC BUCKLING OF CYLINDRICAL ACRYLIC WINDOWS BETWEEN SUPPORTS UNDER EXTERNAL HYDROSTATIC PRESSURE (*t/D* Range of 0.001–0.015)

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

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

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

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

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

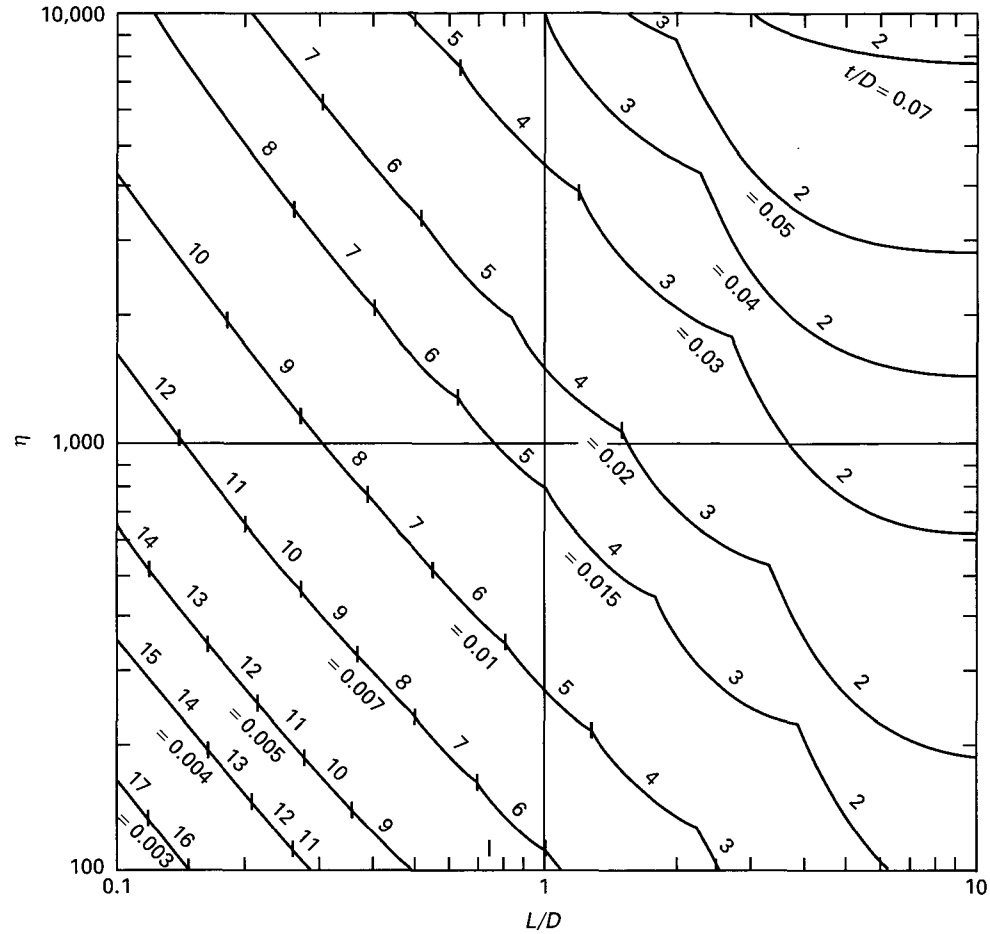
If all windows of any one of the five test programs above survives sustained pressurization for 10,000 hr without catastrophic failure, the window design is considered to have satisfied fully all requirements of the LTPP test.

2-2.6.6 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

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GENERAL NOTES:
(a) P_c = short term critical pressure
$P_c = \eta \times 3.499 \times 10^{-2}$ psi
$P_c = \eta \times 2.413 \times 10^{-4}$ MPa

(b) $D = \frac{D_i + D_o}{2}$

FIG. 2-2.16 SHORT-TERM ELASTIC BUCKLING OF CYLINDRICAL ACRYLIC WINDOWS BETWEEN SUPPORTS UNDER EXTERNAL HYDROSTATIC PRESSURE (*t/D* Range of 0.003–0.07)

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 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).

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TABLE 2-2.1 CONVERSION FACTORS FOR ACRYLIC FLAT DISK WINDOWS

Operational Pressure Ranges	Temperature Ranges				
	≤ 50°F (10°C)	≤ 75°F (24°C)	≤ 100°F (38°C)	≤ 125°F (52°C)	≤ 150°F (66°C)
N = 1 2500 psi (17.2 MPa)	CF = 5	CF = 6	CF = 8	CF = 10	CF = 16
N = 2 5000 psi (34.5 MPa)	CF = 5	CF = 6	CF = 8	CF = 10	4000 psi (27.6 MPa)
N = 3 7500 psi (51.7 MPa)	CF = 5	CF = 6	7000 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, 2-2.6, and 2-2.7.
(b) Dotted lines refer to intermediate pressure ranges as indicated by the adjacent pressure figures.

TABLE 2-2.2 CONVERSION FACTORS FOR ACRYLIC CONICAL FRUSTUM AND DOUBLE BEVELED DISK WINDOWS

Operational Pressure Ranges	Temperature Ranges				
	≤ 50°F (10°C)	≤ 75°F (24°C)	≤ 100°F (38°C)	≤ 125°F (52°C)	≤ 150°F (66°C)
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. 2-2.8 and 2-2.9.
(b) Dotted lines refer to intermediate pressure ranges as indicated by the adjacent pressure figures.

2-2.6.8 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 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 windows with the same geometry and higher t/D_i ratios for the same design pressure and temperature.

2-2.7 Design Life

2-2.7.1 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

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TABLE 2-2.3 CONVERSION FACTORS FOR ACRYLIC SPHERICAL SECTOR AND HYPERHEMISPHERICAL WINDOWS WITH CONICAL EDGE, AND NEMO-TYPE WINDOWS WITH CONICAL PENETRATIONS

Operational Pressure Ranges	Temperature Ranges				
	≤ 50°F (10°C)	≤ 75°F (24°C)	≤ 100°F (38°C)	≤ 125°F (52°C)	≤ 150°F (66°C)
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. 2-2.10 and 2-2.11 (for spherical sector windows with conical edge), and 2-2.18 and 2-2.19 (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.

TABLE 2-2.4 CONVERSION FACTORS FOR ACRYLIC SPHERICAL SECTOR WINDOWS WITH SQUARE EDGE AND HEMISPHERICAL WINDOWS WITH EQUATORIAL FLANGE

Operational Pressure Ranges	Temperature Ranges				
	≤ 50°F (10°C)	≤ 75°F (24°C)	≤ 100°F (38°C)	≤ 125°F (52°C)	≤ 150°F (66°C)
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. 2-2.10 and 2-2.11.
(b) Dotted lines refer to intermediate pressure ranges as indicated by the adjacent pressure figures.

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TABLE 2-2.5 CONVERSION FACTORS FOR ACRYLIC CYLINDRICAL WINDOWS

Part A — Internal Pressure

Operational Pressure Ranges	Temperature Ranges				
	≤ 50°F (10°C)	≤ 75°F (24°C)	≤ 100°F (38°C)	≤ 125°F (52°C)	≤ 150°F (66°C)
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 Ranges				
	≤ 50°F (10°C)	≤ 75°F (24°C)	≤ 100°F (38°C)	≤ 125°F (52°C)	≤ 150°F (66°C)
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. 2-2.12 and 2-2.13.

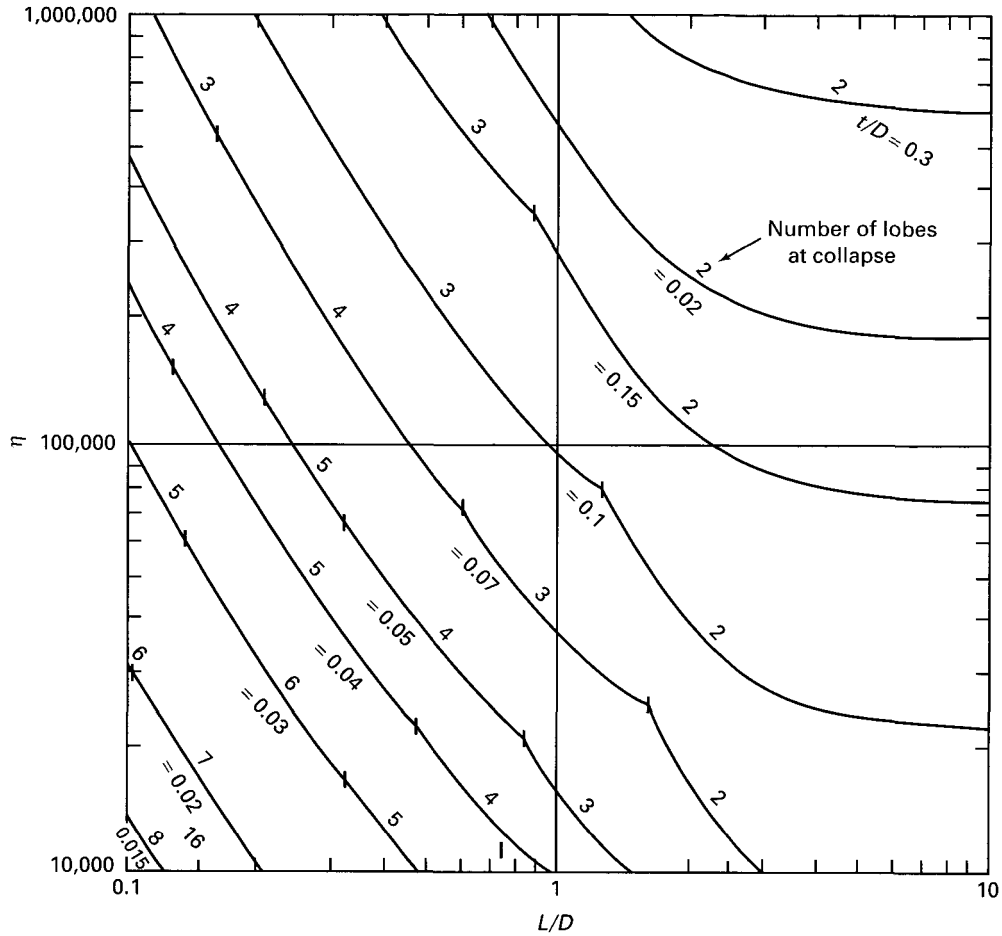
(b) The conversion factors (CF) in Part B of this table apply only to short-term critical pressures (STCP) plotted in Figs. 2-2.14 through 2-2.17. Since the tube may fail due to yielding of material (Fig. 2-2.12) or elastic buckling (Figs. 2-2.13 through 2-2.15), both modes of failure must be considered in selection of t/D ratio. Which mode of failure 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.

TABLE 2-2.6 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. 2-2.20.

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GENERAL NOTES:
(a) P_c = short term critical pressure
$P_c = \eta \times 3.499 \times 10^{-2}$ psi
$P_c = \eta \times 2.413 \times 10^{-4}$ MPa

(b) $D = \frac{D_i + D_o}{2}$

FIG. 2-2.17 SHORT-TERM ELASTIC BUCKLING OF CYLINDRICAL ACRYLIC WINDOWS BETWEEN SUPPORTS UNDER EXTERNAL HYDROSTATIC PRESSURE (*t/D* Range of 0.015–0.3)

category it shall be 10 years. Paragraphs 2-2.7.2 through 2-2.7.8 define the design life of windows under this Standard.

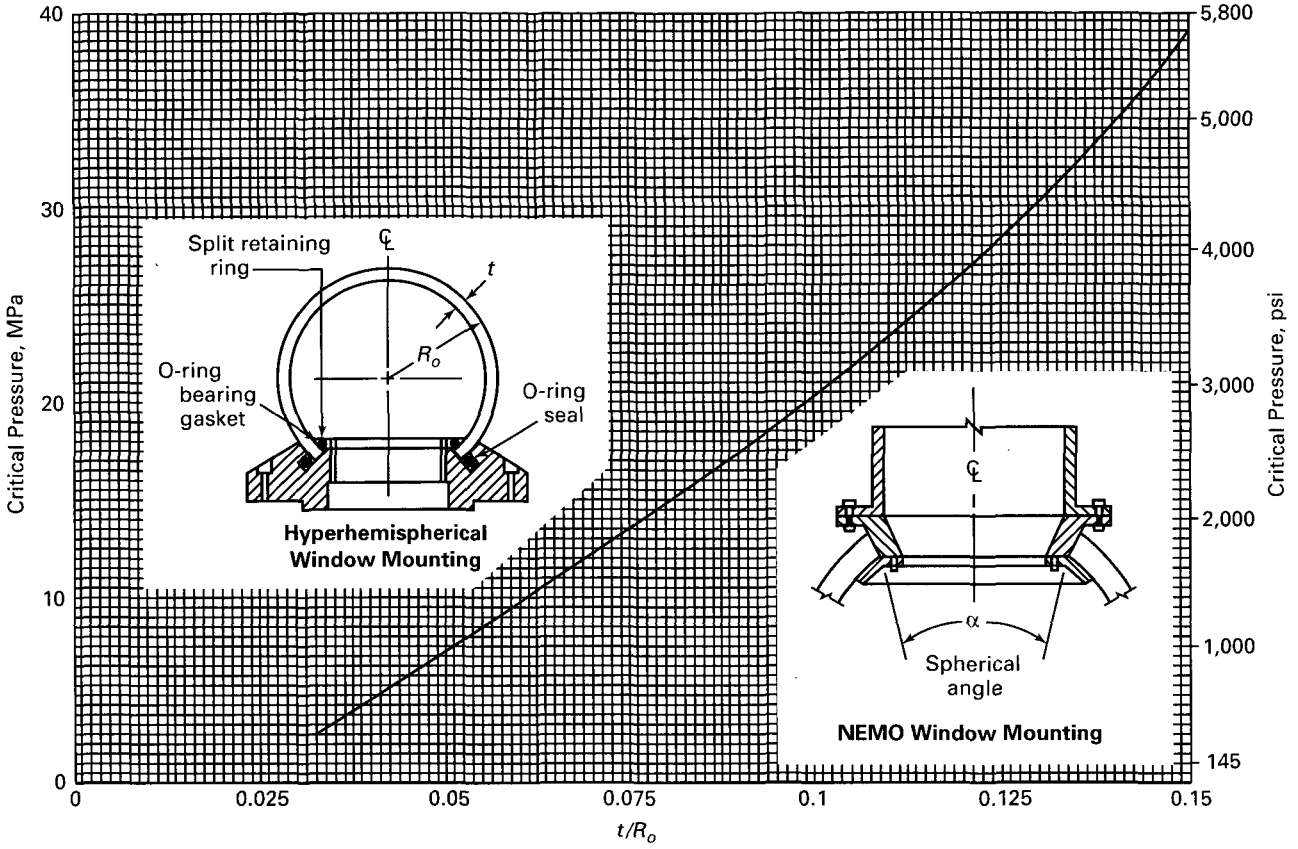
2-2.7.2 The design life of flat disk windows shown in Fig. 2-2.1 and meeting the requirements of this Standard shall be 10 years from the date of fabrication.

2-2.7.3 The design life of conical frustum windows shown in Fig. 2-2.1 and meeting the requirements of this Standard shall be 10 years from the date of fabrication for $t/D_i \leq 0.5$ and 20 years for $t/D_i \geq 0.5$.

2-2.7.4 The design life of double beveled disk windows shown in Fig. 2-2.1 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 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 and 2-2.4 and meeting the requirements of this Standard shall be 20 years from the date of fabrication.

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GENERAL NOTE: See technical article, "Spherical Acrylic Pressure Hulls for Undersea Exploration," J. D. Stachiw, TRANSACTIONS of ASME/Journal of Engineering for Industry, Volume 94, Series B, Number 4, November 1972.

FIG. 2-2.18 SHORT-TERM CRITICAL PRESSURE OF HYPERHEMISPHERICAL AND NEMO-TYPE ACRYLIC WINDOWS [For Pressures in the 435–5,800 psi (3–40 MPa) Range]

2-2.7.6 The design life of spherical sector windows with square edge and hemispherical windows with equatorial flange, shown in Figs. 2-2.2 and 2-2.3 and meeting the requirements of this Standard, shall be 10 years from the date of fabrication.

2-2.7.7 The design life of cylindrical windows for internal pressure applications shown in Fig. 2-2.3 and meeting the requirements of this Standard shall be 10 years from the date of fabrication.

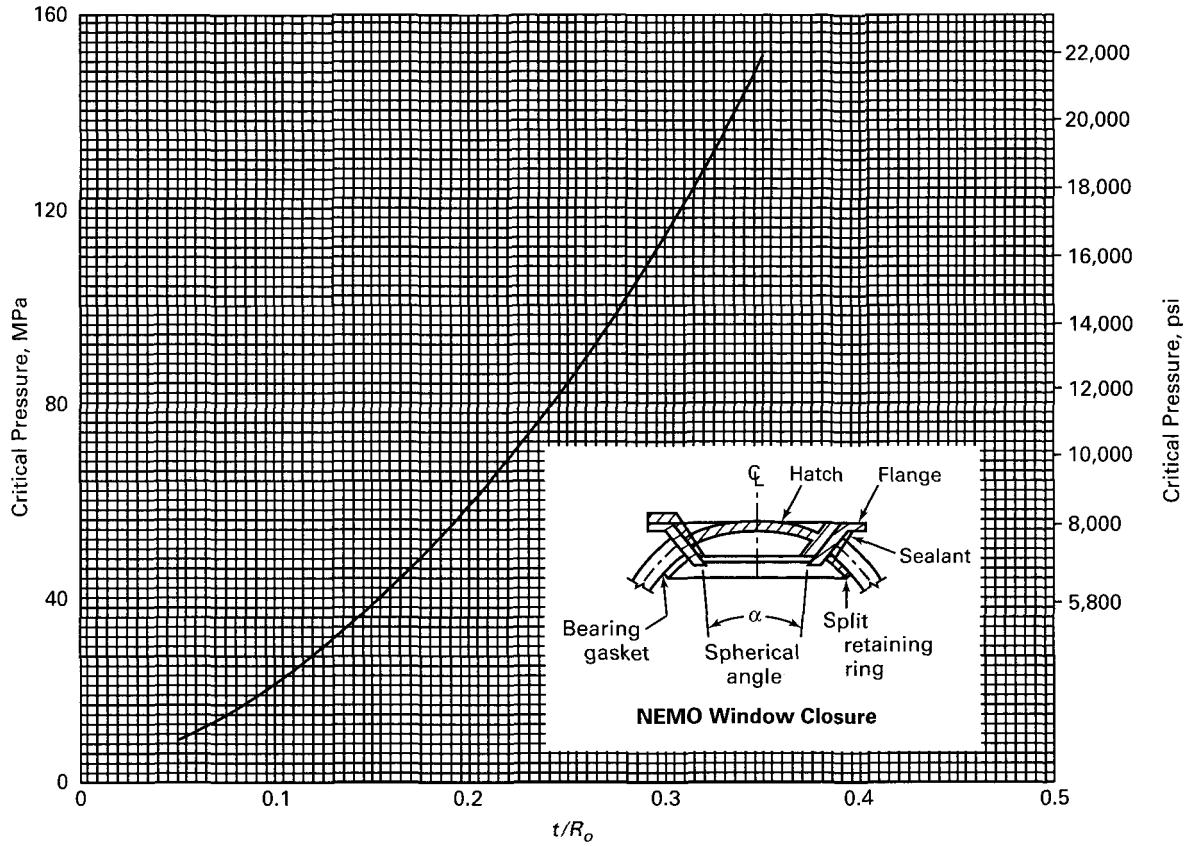
2-2.7.8 The design life of cylindrical windows for external pressure applications shown in Fig. 2-2.3 and meeting the requirements of this Standard shall be 20 years from the date of fabrication.

2-2.8 Temperature Considerations

2-2.8.1 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 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

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GENERAL NOTE: See Technical Report R 631, "Windows for External or Internal Hydrostatic Pressure Vessels — Part III," J. D. Stachiw and F. Brier, Naval Civil Engineering Laboratory, Port Hueneme, CA, 1967.

FIG. 2-2.19 SHORT-TERM CRITICAL PRESSURE OF HYPERHEMISPHERICAL AND NEMO-TYPE ACRYLIC WINDOWS
[For Pressures in the 5,800–23,200 psi (40–160 MPa) Range]

the change in window diameter over the operational temperature range results in a diametral clearance greater than 0.020 in. (greater than 0.5 mm) between the window and its seat.

2-2.8.3 The diametral interference 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.

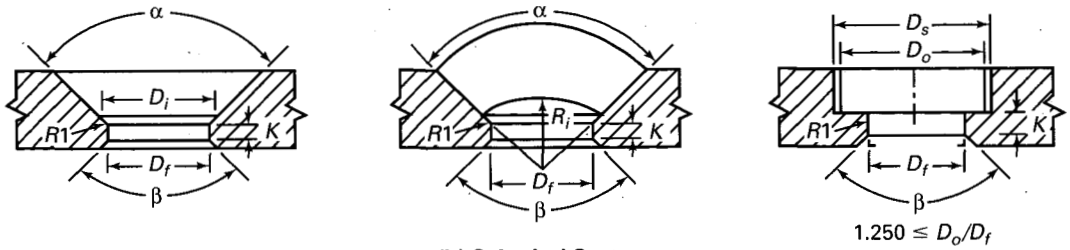
2-2.8.4 The nominal diameters of the window and of the window seat in the flange shall be identical. The actual diameters at standard temperature will differ, but still will be within the dimensional tolerances specified in para. 2-2.12.

2-2.9 Viewport Flanges

2-2.9.1 Due to the 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 Any of the analytical or empirical methods for stress and displacement calculations acceptable to the applicable Division of Section VIII of the Code

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(a) Conical Frustum Window

(b) Spherical Sector Window With Conical Edge

(c) Flat Disk Window

D_i/D_j 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

$[2R_i \sin(\alpha/2)]/D_j$ RATIOS

Operational Pressure Range	Included Angle, deg				
	60	90	120	150	180
$N = 1$	1.02	1.02	1.02	1.02	1.02
$N = 2$	1.03	1.03	1.03	1.03	1.03
$N = 3$	1.05	1.05	1.05	1.05	1.05

GENERAL NOTES:
(a) For α between values shown, interpolation is required.
(b) $\frac{1}{32}$ in. (1.0 mm) ≤ $R1$ ≤ $\frac{1}{16}$ 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. 2-2.20 SEAT CAVITY REQUIREMENTS — CONICAL FRUSTUM WINDOW, SPHERICAL SECTOR WINDOW WITH CONICAL EDGE, AND FLAT DISK WINDOW

may be used for dimensioning the thickness, width, and location of the flange around the viewport penetration.

2-2.9.3 Reinforcement for penetrations of chambers must meet the requirements of para. 1.4.5 and the requirements of the applicable Division of Section VIII of the Code.

2-2.9.4 The following minimum requirements shall be met by viewport flanges shown in Figs. 2-2.20 through 2-2.23, 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.

2-2.9.5 Viewport flanges shown in Figs. 2-2.24 through 2-2.27 do not have to meet the radial and angular deformation limits stated in paras. 2-2.9.4(a) and (b) above.

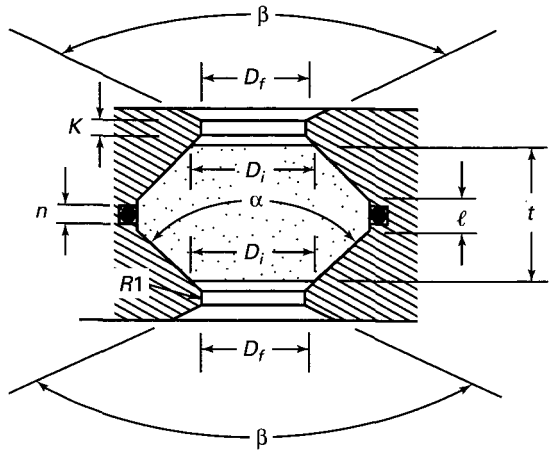
2-2.10 Window Seats

2-2.10.1 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. 2-2.20 through 2-2.27.

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

2-2.10.3 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.

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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

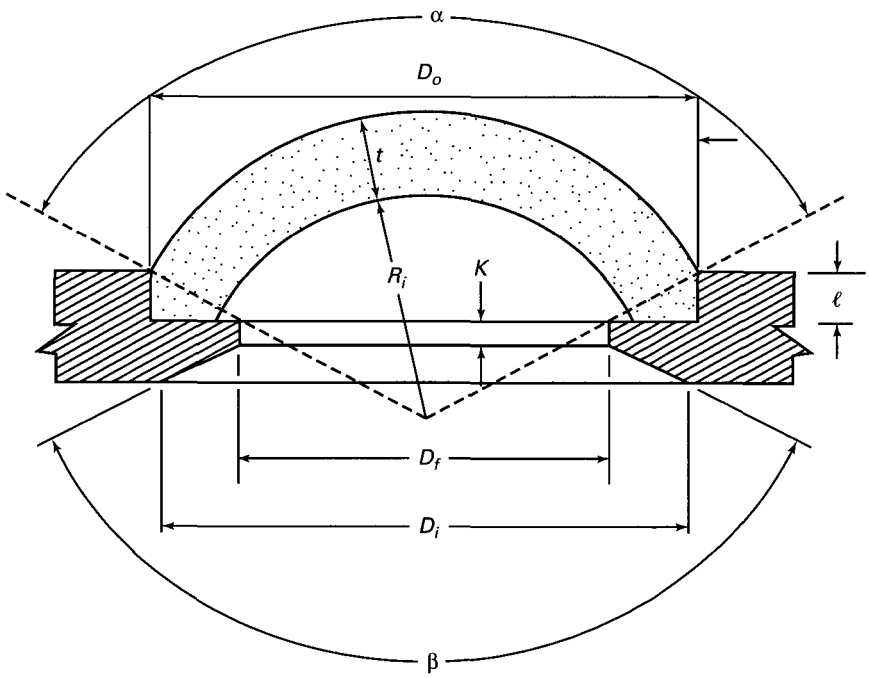
GENERAL NOTES:
(a) For α between values shown, interpolation is required.
(b) K is selected on the basis of structural analysis.
(c) β is selected on the basis of optical requirements.

$$\ell \leq 0.25\ t$$

$$n \leq \ell$$

(d) $\frac{1}{32}$ in. (1.0 mm) $\leq R1 \leq \frac{1}{16}$ in. (2.0 mm).

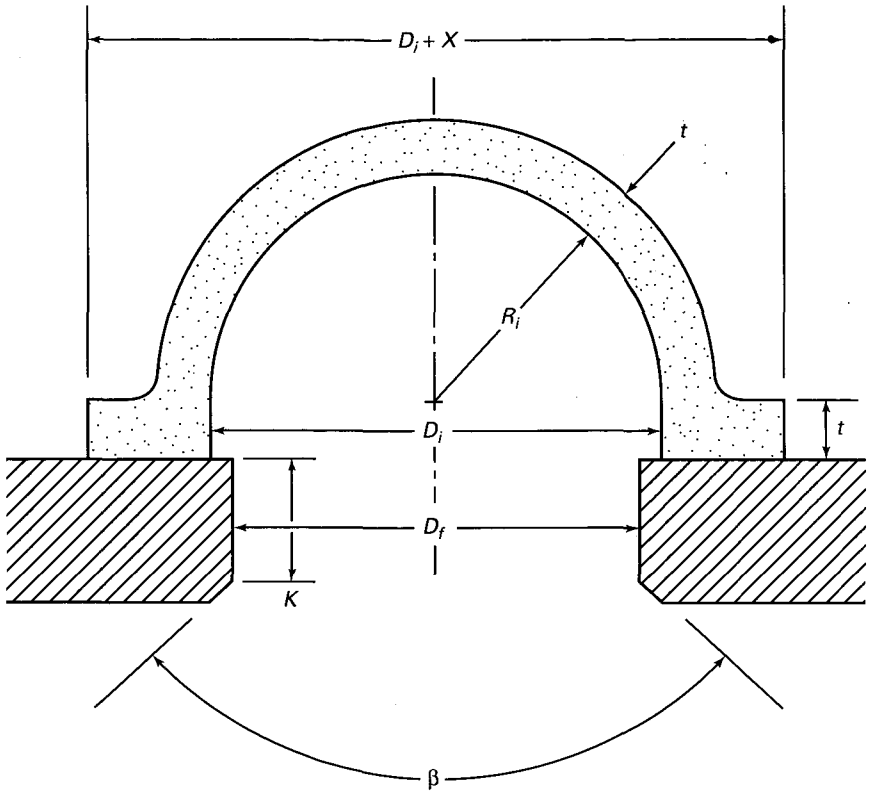
FIG. 2-2.21 SEAT CAVITY REQUIREMENTS — DOUBLE BEVELED DISK WINDOW



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) $D_i - D_f \geq \frac{1}{8}$ in. (3.0 mm).
(f) $\ell \geq t \sin (90 \text{ deg} - \alpha/2)$

FIG. 2-2.22 SEAT CAVITY REQUIREMENTS — SPHERICAL SECTOR WINDOW WITH SQUARE EDGE

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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.

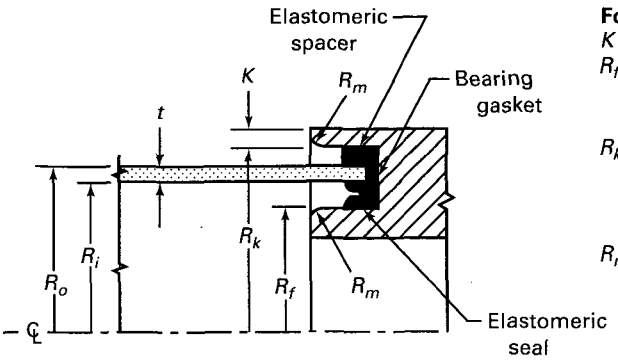
FIG. 2-2.23 SEAT CAVITY REQUIREMENTS — HEMISPHERICAL WINDOW WITH EQUATORIAL FLANGE

2-2.11 Window Seals

2-2.11.1 As *primary seals* for standard window geometries shown in Figs. 2-2.1 through 2-2.4, 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.

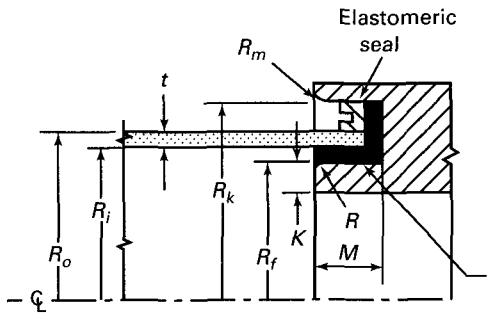
2-2.11.2 Flat disk windows with design pressure less than 15 psig may utilize as the primary seal an elastomeric potting compound that, after injection into the annular space between the edge of the window and the cylindrical surface of the seat (which have been coated beforehand with appropriate primer), shall, after room temperature cure, adhere to both the window and the seat surfaces. The primer and elastomeric potting

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(a) Under Internal Pressure

For Sketch (a):
K is selected on the basis of structural analysis
R_f = internal radius of window seat;
≤ calculated R_i of cylinder at zero internal pressure and −30°C minus gasket compressed 50%
R_k = external radius of window seat;
≥ 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)



(b) Under Internal Pressure

For Sketch (b):
K is selected on the basis of structural analysis
R_f = internal radius of window seat;
≈ calculated R_i of cylinder under zero external pressure at design temperature minus thickness of gasket
R_k = external radius of window seat;
≥ 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)
$M \geq 0.05 R_i$

FIG. 2-2.24 SEAT CAVITY REQUIREMENTS — CYLINDRICAL WINDOW

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 must provide the following minimum initial compression of the gasket in inches (millimeters).

(a) Conical frustum acrylic windows

$$0.010 + \left(\frac{0.025 \sqrt[3]{D_i}}{\tan \alpha / 2} \right) \text{ (in.)}$$

$$0.254 + \left(\frac{0.211 \sqrt[3]{D_i}}{\tan \alpha / 2} \right) \text{ (mm)}$$

(b) Spherical acrylic shell sector with conical edge

$$0.02 + 0.02 \sqrt{R_i \sin \alpha / 2} \text{ (in.)}$$

$$0.50 + 0.10 \sqrt{R_i \sin \alpha / 2} \text{ (mm)}$$

(c) Flat disk windows

$$0.01\,t + 0.01 \text{ in. } (0.25 \text{ mm})$$

(d) Spherical acrylic shell sector windows with square edges

$$0.01\,t + 0.01 \text{ in. } (0.25 \text{ mm})$$

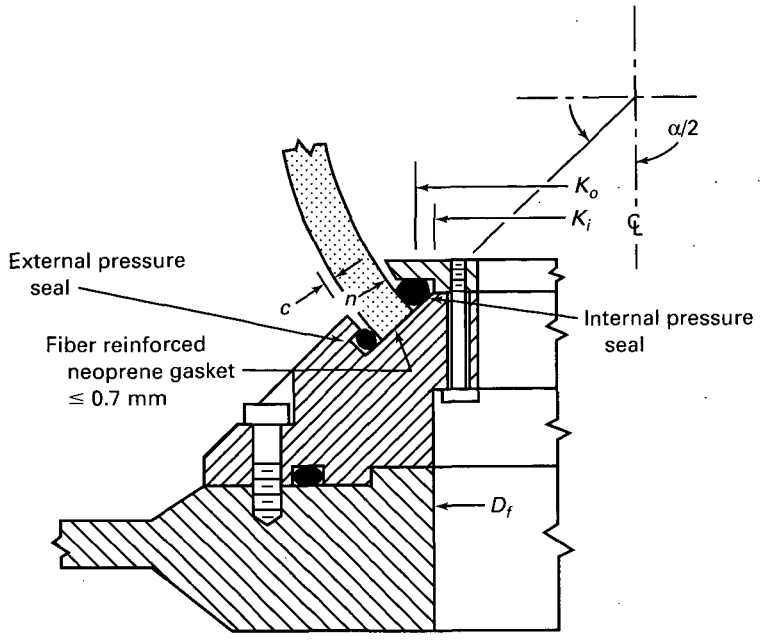
(e) Hemispherical acrylic windows with equatorial flange

$$0.01\,t + 0.01 \text{ in. } (0.25 \text{ mm})$$

where
t = thickness of the window

2-2.11.4 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

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GENERAL NOTES:
(a) α = included spherical angle of the opening
(b) K_i = inner diameter of the conical seat
(c) D_f = diameter of the opening in the pressure hull
(d) K_o = inner diameter of the penetration in the window
(e) $K_o - K_i \geq 1/4$ in. (6.0 mm)
$n \geq 1/32$ in. (1.0 mm)
$c \geq 1/16$ in. (2.0 mm)
$\alpha \leq 100$ deg

FIG. 2-2.25 SEAT CAVITY REQUIREMENTS — HYPERHEMISPHERICAL WINDOW

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

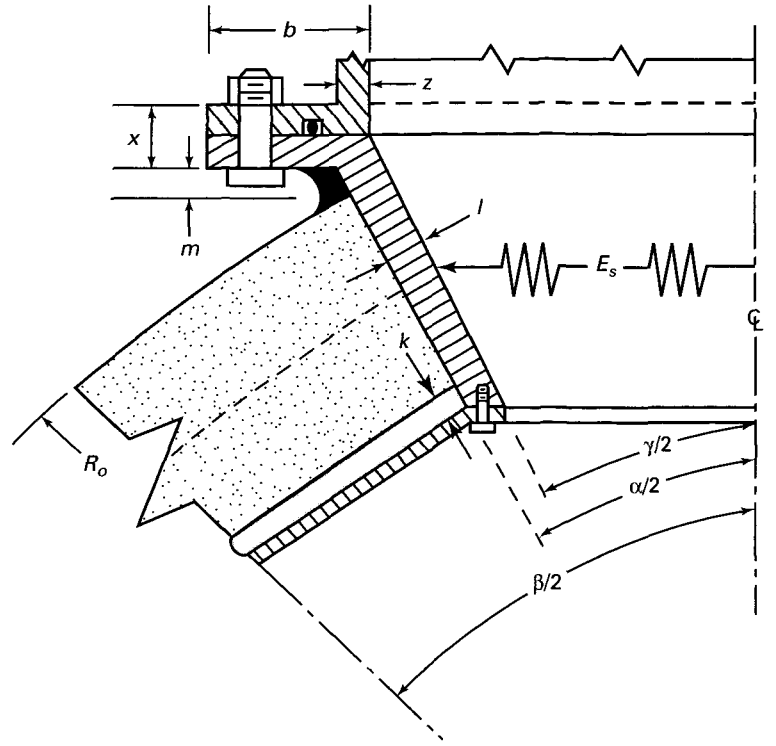
2-2.11.6 The retainer ring and the associated fastening arrangement shall be designed with a safety factor of 4, based on the ultimate strength of materials and the design pressure forcing the window against the retainer ring. For applications where the magnitude of design pressure forcing the window against the retainer ring is zero, a minimum value of 15 psig shall be utilized in calculations.

2-2.11.7 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 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 1/8 in. (3.0 mm). Neoprene impregnated nylon cloth, neoprene of 90 durometer hardness, and cork gaskets are acceptable for such application.

2-2.11.9 Seal ring grooves are not 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

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GENERAL NOTES:
(a) *x, b, z, 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%.
(b) E_s = orientation of effective radial stiffness
(c) γ = spherical angle of hatch seat
(d) α = spherical angle of window penetration
$\alpha \leq 50$ deg
(e) k = thickness of compressed gasket
$k \geq 0.005\ R_0$
(f) m = elevation of hatch ring
$m \geq 0.01\ R_0$
(g) β = spherical angle of split retaining ring
(h) $(\alpha + 8\ \text{deg}) \leq \beta \leq (\alpha + 12\ \text{deg})$

FIG. 2-2.26 SEAT CAVITY REQUIREMENTS — NEMO WINDOW (STANDARD SEAT)

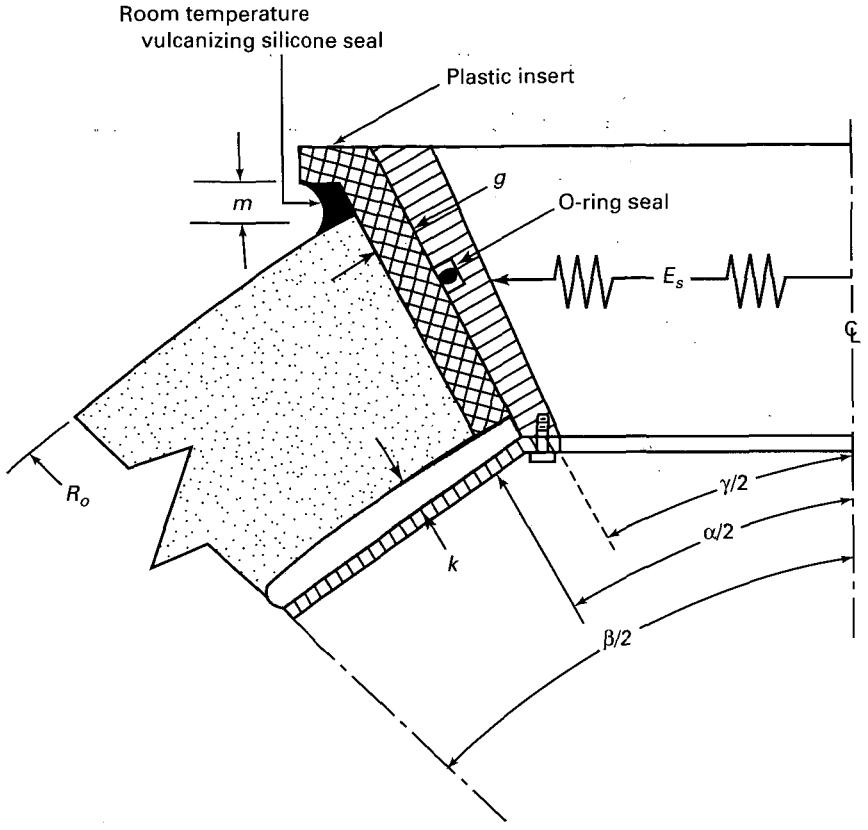
the criteria of para. 2-2.6.6 are included with the window design certification package.

2-2.11.10 Seal ring grooves are permitted in the window seat in the mounting, providing 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 $0.01 < R < 0.02$ in. ($0.25 < R < 0.50$ mm).

2-2.11.11 Edges of bearing surfaces at the high pressure faces of windows may be beveled for containment of O-rings providing that the width of the bevel as shown on Figs. 2-2.28 and 2-2.29 shall not exceed $0.125t$ for spherical sectors, $0.062t$ 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.

2-2.11.12 The configuration of window mountings and seal arrangements shown in Figs. 2-2.5 through 2-2.19 represent designs acceptable under this Standard, and are shown there only for the guidance of designers.

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GENERAL NOTES:
(a) *x, b, z, 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%.
(b) E_s = orientation of effective radial stiffness
(c) γ = spherical angle of hatch seat
(d) α = spherical angle of window penetration
$\alpha \leq 50$ deg
(e) k = *thickness of compressed gasket (neoprene)*
$k \geq 0.005\ R_0$
(f) m = elevation of hatch ring
$m \geq 0.01\ R_0$
(g) β = spherical angle of split retaining ring
(h) g = thickness of plastic insert
$g \geq 0.03\ R_0$
(i) $(\alpha + 8\ \text{deg}) \leq \beta \leq (\alpha + 12\ \text{deg})$

FIG. 2-2.27 SEAT CAVITY REQUIREMENTS — NEMO WINDOW (SEAT WITH EXTENDED CYCLIC FATIGUE LIFE)

2-2.11.13 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 providing that

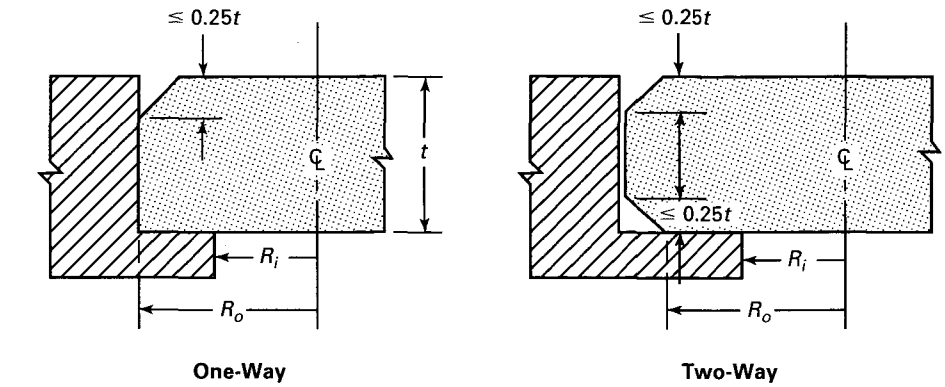
(a) the window meets all the requirements of the 1977 or 1981 edition; and

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

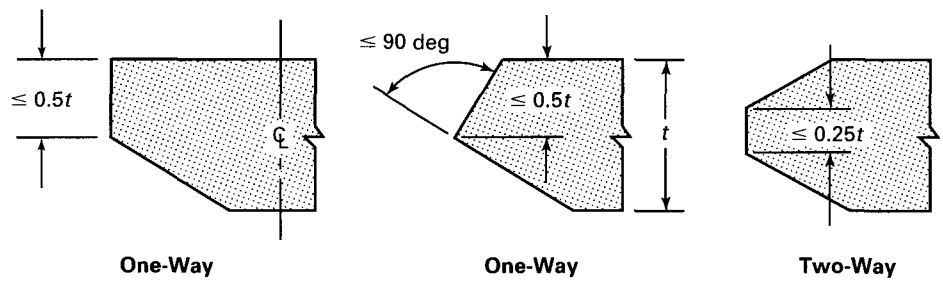
2-2.12 Dimensional Tolerances and Surface Finish

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

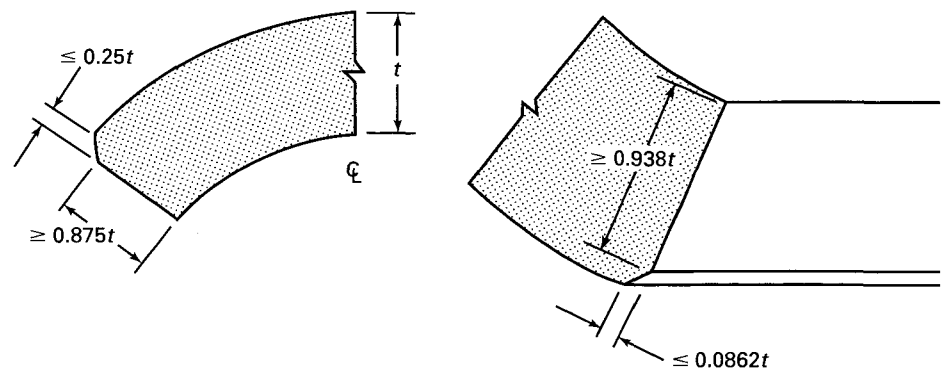
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(a) Flat Disk Windows



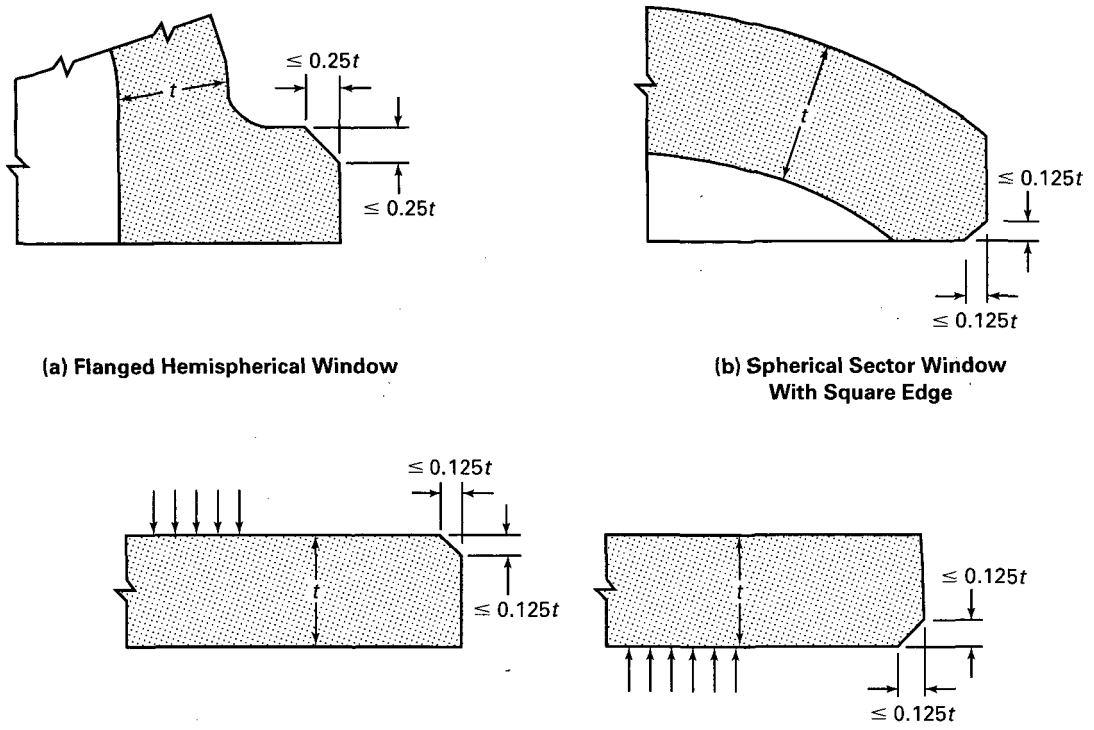
(b) Conical Frustum Windows



(c) Spherical Sector Windows (d) Hyperhemispheres

FIG. 2-2.28 BEVELS ON WINDOW EDGES — FLAT DISK WINDOWS, CONICAL FRUSTUM WINDOWS, SPHERICAL SECTOR WINDOWS, HYPERHEMISPHERES

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(a) Flanged Hemispherical Window

(b) Spherical Sector Window With Square Edge

External Pressure

Internal Pressure

(c) Cylindrical Windows

FIG. 2-2.29 BEVELS ON WINDOW EDGES — FLANGED HEMISPHERICAL WINDOW, SPHERICAL SECTOR WINDOW WITH SQUARE EDGE, EXTERNAL PRESSURE AND INTERNAL PRESSURE OF CYLINDRICAL WINDOWS

2-2.12.2 The major diameter of the conical bearing surface on a window shall be machined within +0.000/ $-0.002D_o$ of the nominal value.

2-2.12.3 The included conical angle of the window must be within +0.25/–0.000 deg of the nominal value.

2-2.12.4 The included conical angle of the window seat in the flange must be within +0.000/–0.25 deg of the nominal value.

2-2.12.5 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.

2-2.12.6 The major diameter of the conical seat cavity in the flange must be within $+0.002D_o$/–0.000 of the nominal value.

2-2.12.7 The concave or convex surface of a 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 and 2-2.4, and Figs. 2-2.10, 2-2.11, and 2-2.18). 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 $\pi/2$, whichever is the lesser value.

2-2.12.8 The dimensional tolerance on 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

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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/–0.125 in. (+0.0/–3.2 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 external diameter of the flat disk window shall be within +0.00/–0.02 D_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.

2-2.12.9 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.

2-2.12.10 The external diameter of the spherical window with square seat shall be within +0.000/ $-0.0005D_o$ of the nominal value.

2-2.12.11 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.

2-2.12.12 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.

2-2.12.13 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 2-2.5).

2-2.12.14 The bearing surface of the window shall have an as-cast or machined finish no rougher than 32 rms.

2-2.12.15 Viewing surfaces shall be polished to satisfy ASTM D 702 optical clarity requirements.

2-2.12.16 All other surfaces shall be machined or sanded to attain at least a 63 rms finish. Saw cut finish is not acceptable on any window surface.

2-2.13 Documentation

2-2.13.1 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 Drawings which 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 The designer shall fill out a *design certification* as described in para. 2-1.7(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 the form in appendix I, enclosure 1, as a representative sample.

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

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2-2.13.5 The design certification and additional referenced documentation plus copies of the fabrication drawings shall become a part of the permanent design package for the chamber.

2-2.14 Windows With Inserts for Penetrators

2-2.14.1 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 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), hemispheres with or without flanges (see Fig. 2-2.3), hyperhemispheres (see Fig. 2-2.4), and NEMO spheres (see Fig. 2-2.4).

2-2.14.3 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 On spherical shell sectors with conical seats, hemispheres without flanges, hyperhemispheres, and NEMO spheres, the penetrations may be located anywhere, provided that

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

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

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

2-2.14.6 The penetrations shall have circular configurations.

2-2.14.7 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 The total area of all penetrations in a single window shall not exceed 30% of the window's concave surface.

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

2-2.14.10 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 The maximum size of the penetration diameter shall be defined by a solid cone angle of 50 deg, provided that the area of the penetration, defined as $\pi(M_o)^2/4$ (see Fig. 2-2.30), does not exceed the limits specified in paras. 2-2.14.7 and 2-2.14.8.

2-2.14.12 The angular and dimensional tolerances for penetrations, as well as for the surface finish on the seat, are shown in Fig. 2-2.1.

2-2.14.13 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 2-3.2 and polycarbonate plastic meeting the criteria of Table 2-2.7 are acceptable materials for the fabrication of inserts, provided that in service they shall only

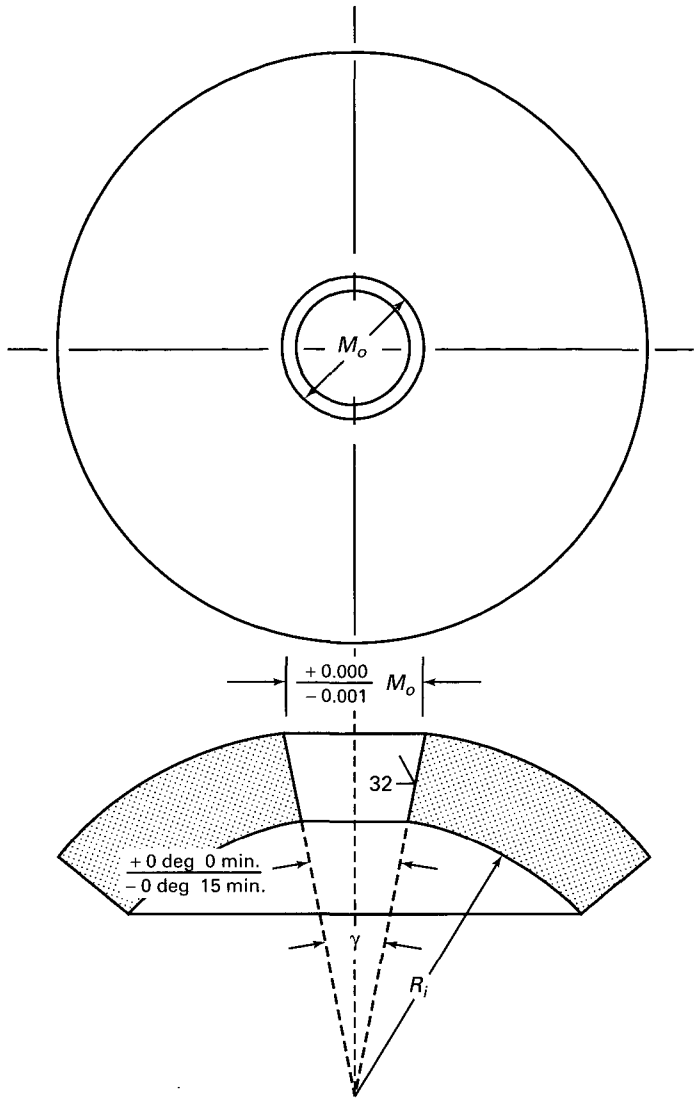
(1) come in contact with fluids and gases defined by para. 2-1.3(c); and

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

Cast unfilled monolithic Type 6 nylon meeting the criteria of Table 2-2.8 may be utilized for the fabrication of bearing gasket inserts for NEMO windows (see Fig. 2-2.27).

2-2.14.14 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.

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GENERAL NOTES:
(a) M_o = outside diameter of penetrations
(b) R_i = radius of convex curvature
(c) γ = conical seat angle

FIG. 2-2.30 DIMENSIONAL TOLERANCES FOR PENETRATIONS IN ACRYLIC WINDOWS

2-2.14.15 The angular and dimensional tolerances for inserts are shown in Fig. 2-2.31. All surfaces on the insert shall have a finish of 32 rms or finer.

2-2.14.16 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; and

(b) the bearing surface of the insert extends past the edges of the seat in the penetration (Fig. 2-2.32).

2-2.14.17 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 Smooth holes may be drilled in the polycarbonate insert to receive hydraulic, electrical, optical, or mechanical bulkhead penetrators, provided that

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TABLE 2-2.7 SPECIFIED VALUES OF PHYSICAL PROPERTIES FOR POLYCARBONATE PLASTIC

Test Procedures	Physical Property	Specified Values	
		U.S. Customary Unit	Metric Unit
ASTM D 638 [Note (1)]	Tensile:		
	(a) ultimate strength	≥ 9,000 psi	≥ 62 MPa
	(b) elongation at break	≥ 20%	≥ 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
ASTM D 621 [Note (1)]	Compressive deformation at 4,000 psi (27.6 MPa) and 122°F (50°C), 24 hr	≤ 2%	≤ 2%
ASTM D 732 [Note (1)]	Shear, ultimate strength	≥ 9,000 psi	≥ 62 MPa
ASTM E 308	Ultraviolet transmittance [for 0.5 in. (13 mm) thickness]	≤ 5%	≤ 5%

GENERAL NOTE: To be verified by testing of specimen from each plate that serves as machining stock for inserts.

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 2-2.8 SPECIFIED VALUES OF PHYSICAL PROPERTIES FOR CAST NYLON PLASTIC

Test Procedures	Physical Property	Specified Values	
		U.S. Customary Unit	Metric Unit
ASTM D 638	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	Compressive:		
	(a) yield strength	6,000 psi	41.4 MPa
	(b) modulus of elasticity	250,000 psi	1 725.0 MPa
ASTM D 621	Compressive deformation at 4,000 psi (27.6 MPa) and 122°F (50°C) for 24 hr	<1.4%	<1.4%
ASTM D 732	Shear, ultimate strength	4,300 psi	29.7 MPa

GENERAL NOTES:

(a) To be verified by testing of specimen from each casting that serves as machining stock for inserts.

(b) The above 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.

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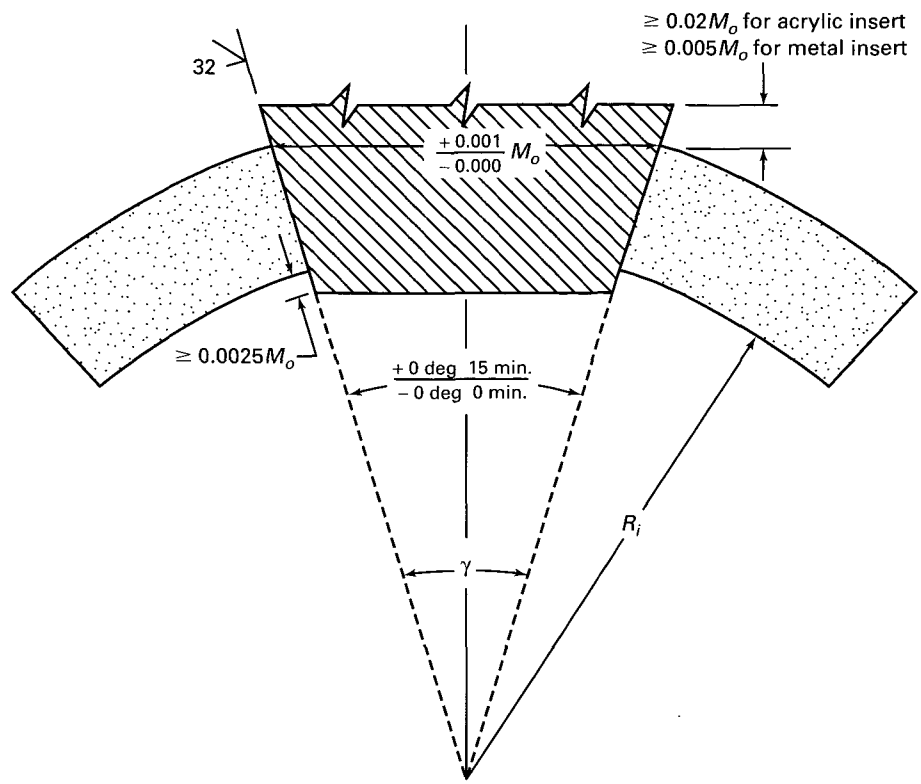


FIG. 2-2.31 DIMENSIONAL TOLERANCES FOR INSERTS IN ACRYLIC WINDOWS

(a) the spacing between edges of adjacent holes in the insert shall exceed 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; and

(c) the surface finish inside the holes shall be 32 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 Smooth holes may be drilled in the acrylic insert to receive hydraulic, electrical, optical, or mechanical bulkhead penetrators provided that

(a) the spacing between edges of adjacent holes in the insert shall exceed 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; and

(c) the surface finish inside the holes shall be 32 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 The thickness of the insert shall depend on the material from which the insert is fabricated.

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

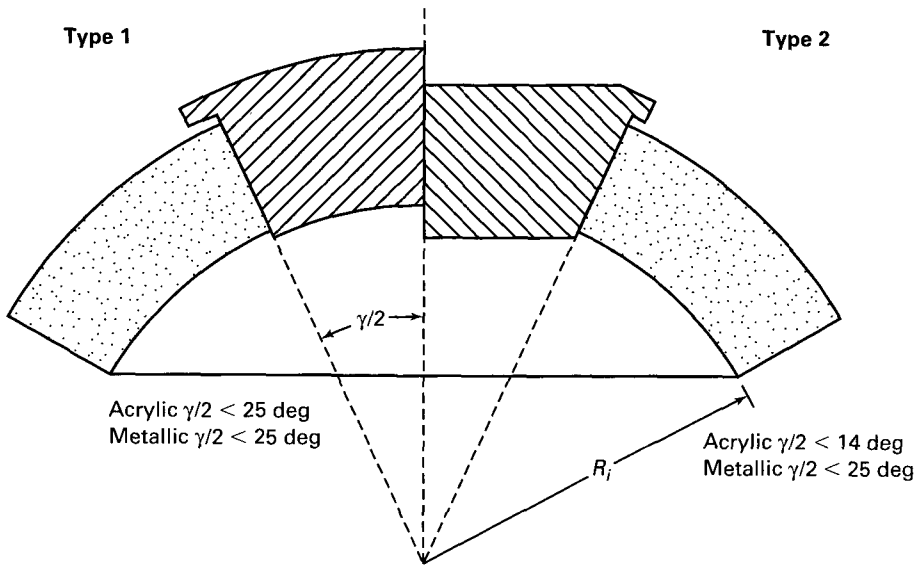
(b) An alternate approach requires hydrostatic testing of the new insert design in an acrylic seat to 3 times the desired design pressure without producing permanent deformation ≥ 0.2%. The pressurization shall be at a 650 psi/min (4.5 MPa/min) rate.

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

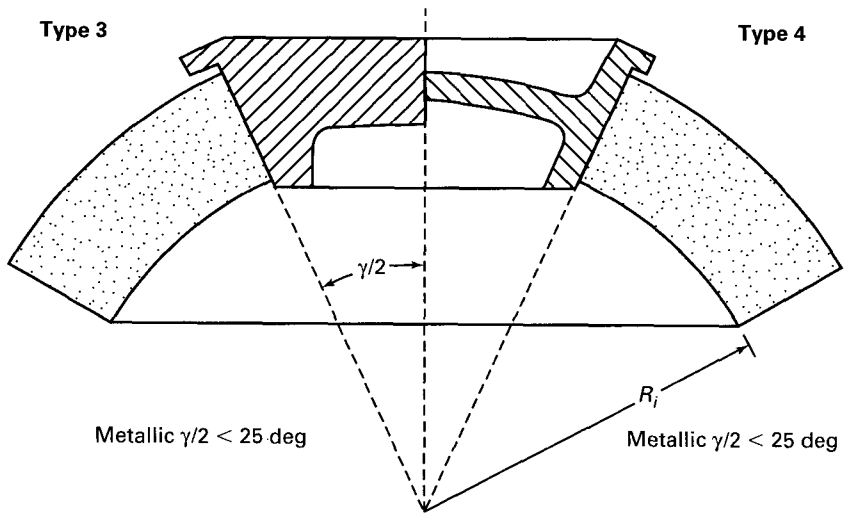
2-2.14.22 All inserts require two separate seals to prevent entry of water through the joint between the bearing surface of the insert and the seat in the window: a *primary seal* and a *secondary seal.*

(a) Sealing between the insert and the window shall be provided by two seals. A primary seal shall serve

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(a) For Metallic and Acrylic Materials



(b) For Metallic Materials

FIG. 2-2.32 TYPICAL SHAPES OF INSERTS

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. 2-2.33 represent designs acceptable under this Standard and are provided for guidance only.

2-2.14.23 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. 2-2.27).

2-2.14.24 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 feed-throughs.

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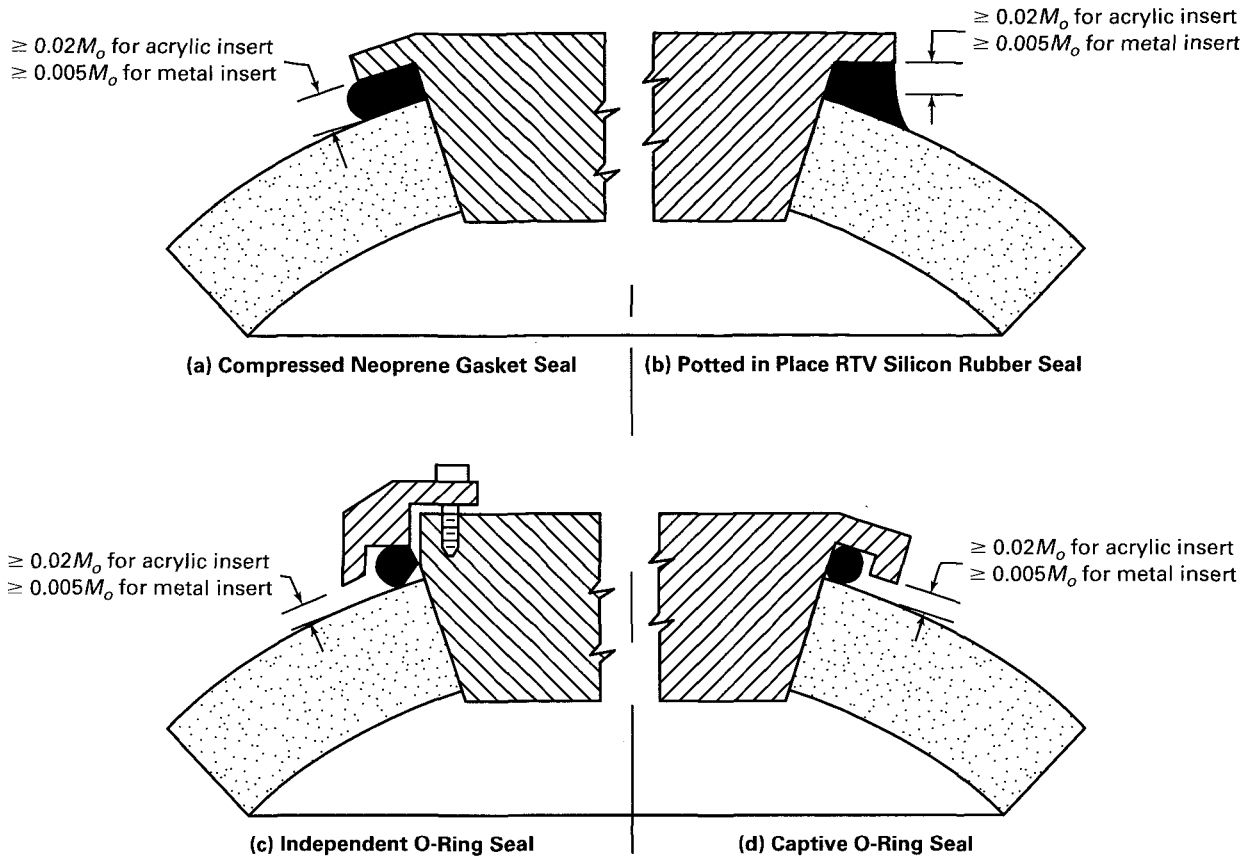


FIG. 2-2.33 SEAL CONFIGURATIONS FOR INSERTS IN ACRYLIC WINDOWS

(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 2500 psi (12.2 MPa).

(b) Experimentally proven restraint designs shown in Fig. 2-2.34 represent designs acceptable under this Standard and are provided for guidance only.

2-2.14.25 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 2-4.1. Polycarbonate shall be stress relieved for a period of 8 hr at 250°F (120°C).

2-2.14.26 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 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, Article 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 Each insert shall be individually certified. The certification shall include the following:

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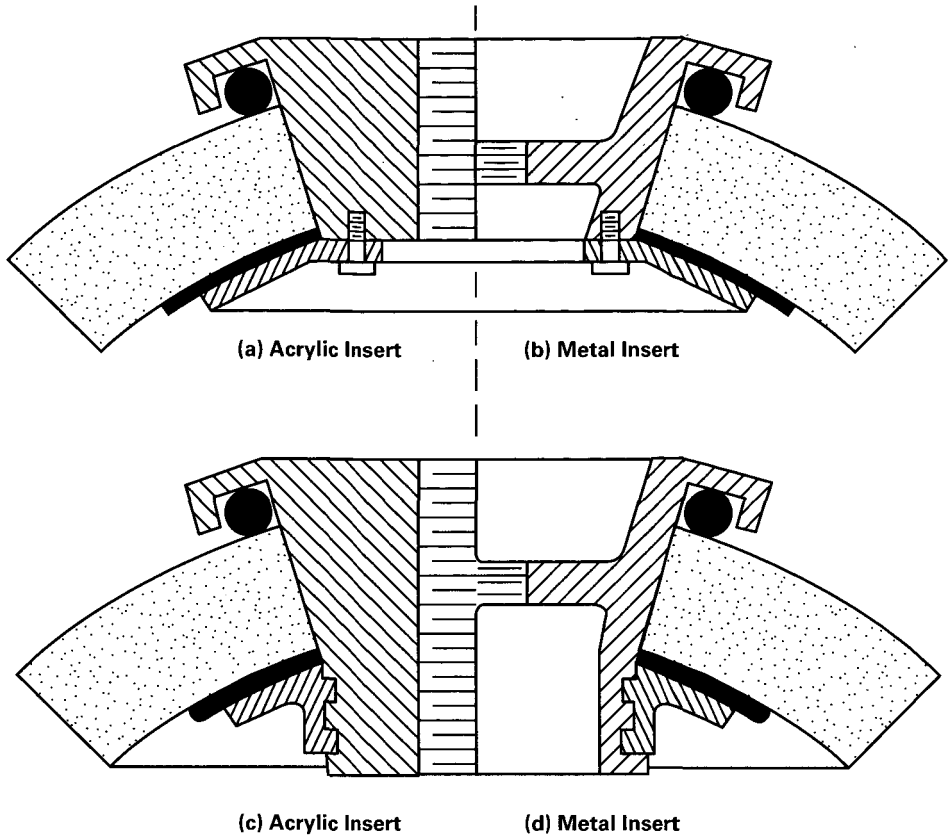


FIG. 2-2.34 RESTRAINTS FOR INSERTS IN ACRYLIC WINDOWS

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

2-2.14.29 Each of the certifications shall follow the procedure described in para. 2-1.7 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 2-2.7 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.

ARTICLE 3 MATERIAL

2-3.1

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

2-3.2

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

2-3.3

Joining of acrylic castings by bonding is permitted provided the following provisions 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.

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(c) The joint shall be pressure tight during hydrostatic testing of the window.

2-3.4

The acrylic used for fabrication of windows must satisfy 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 2-3.1. The manufacturer of material shall provide certification to the window fabricator that the typical physical properties of the material satisfy the criteria of Table 2-3.1. The material manufacturer's certification shall convey the information in a form equivalent to appendix I, enclosure 2. 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 2-3.1, experimental verification of all properties shown in Table 2-3.1 becomes mandatory.

(b) The acrylic castings from which the windows are produced must meet the *minimum physical properties* specified in Table 2-3.2 after the castings have been annealed per para. 2-4.4. 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 2-3.2) for sheet or custom castings shall be certified on a form equivalent to appendix I, enclosure 3. 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 castings shall be supplied in sheet form or as custom castings. All acrylic sheet castings shall have a nominal thickness of $\frac{1}{2}$ in. (12.5 mm) or greater.

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

(a) Type 1 custom castings are defined as being of such thickness and configuration, and produced by such a process as to meet the requirements of Table 2-3.1 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 2-3.1.

(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 2-3.1. All custom castings failing to meet the requirements of Type 1 shall be classified as Type 2 custom castings.

2-3.6

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 providing 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 2-3.1 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 which 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 casting, taken at random from a lot of 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 paras. 2-3.4(a) and (b) on specimens cut from each casting.

(e) Type 2 custom castings shall have tests performed according to paras. 2-3.4(a) and (b) on specimens cut from each casting to experimentally verify that the acrylic possesses the physical properties specified in both Tables 2-3.1 and 2-3.2. Tests for experimental verification of properties in Table 2-3.1 shall serve also to certify the properties in Table 2-3.2.

2-3.7

Testing of acrylic castings for the physical and optical properties specified in Tables 2-3.1 and 2-3.2 shall

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TABLE 2-3.1 SPECIFIED VALUES OF PHYSICAL PROPERTIES FOR EACH LOT

Test Procedures	Physical Property	Specified Values	
		U.S. Customary Unit	Metric Unit
ASTM D 256*	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*	Water absorption, 24 hr	≤ 0.25%	≤ 0.25%
ASTM D 621	Compressive deformation at 4,000 psi (27.6 MPa), 122°F (50°C), 24 hr	≤ 1.0%	≤ 1.0%
ASTM D 638*	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*	Compressive:		
	(a) yield strength	≥ 15,000 psi	≥ 103 MPa
	(b) modulus of elasticity	≥ 400,000 psi	≥ 2 760 MPa
ASTM D 732*	Shear ultimate strength	≥ 8,000 psi	≥ 55 MPa
ASTM D 785*	Rockwell hardness	≥ M scale 90	≥ M scale 90
ASTM D 790*	Flexural ultimate strength	≥ 14,000 psi	≥ 97 MPa
ASTM D 792*	Specific gravity	1.19 ± 0.01	1.19 ± 0.01
ASTM E 308	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	≤ 10^{-5} (in./in. °F)	≤ 10^{-5} (mm/mm °C)
	°F / °C		
	− 40 / −40	2.9	5.22
	− 20 / −29	3.0	5.40
	0 / −18	3.2	5.76
	+ 20 / − 7	3.4	6.12
	+ 40 / 4	3.7	6.66
	+ 60 / 16	4.0	7.20
	+ 80 / 27	4.3	7.74
	+100 / 38	4.7	8.46
	+120 / 49	5.1	9.18
	+140 / 60	5.4	9.72
ASTM 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 (b) ethyl acrylate	≤ 1.6%	≤ 1.6%

GENERAL NOTES:
(a) To be certified by the manufacturer of material.
(b) Tests marked with an asterisk 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.

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 2-3.2 shall be as follows.

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TABLE 2-3.2 SPECIFIED VALUES OF PHYSICAL PROPERTIES FOR EACH CASTING

Test Procedures	Physical Property	Specified Values	
		U.S. Customary Unit	Metric Unit
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
ASTM D 621 [Note (1)]	Compressive deformation at 4,000 psi (27.6 MPa) and 122°F (50°C), 24 hr	≤ 1.0%	≤ 1.0%
ASTM E 308	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 (b) ethyl acrylate	≤ 1.6%	≤ 1.6%

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

NOTE:

(1) These tests require testing 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.

(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 properties shall be per ASTM D 695.

(c) Tests for compressive deformation shall be performed per ASTM D 621 Method A, using specimens loaded to 4000 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. Nominal thicknesses over ½ in. (12.5 mm) yield standard test specimens. These sampling procedures override those specified in ASTM D 621.

(d) Tests for the presence of an ultraviolet absorber (ultraviolet transmittance) shall be made using a monochromator having a bandwidth of 10 nm or less, a photometer having reproducibility of +1% of full scale, and the practices of ASTM E 308 to measure the spectral transmittance in the 290 to 330 nm wavelength band. Report the value of one specimen of nominal ½ in. (12.5 mm) thickness. 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 (02)

A sample of suitable size shall be obtained and analyzed for unpolymerized methyl methacrylate and unpolymerized ethyl acrylate 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

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of Plastics," April 1962, pp. 145–151) is a suitable procedure.

(a) The instrument shall be a Beckman GC-2A gas chromatograph with a hydrogen flame detector, or equivalent, and a 6 ft (1.8 m) column of $\frac{1}{4}$ in. (6.0 mm) stainless tubing operated at 212°F (100°C). Pack the column with 25% diethylene glycol adipate polyester (LAC-2-R-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 microliter aliquot of the plastic-solvent solution into the gas chromatographic apparatus. Compare the areas 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 which 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. 2-3.8(a).

2-3.9

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 2-3.2.

2-3.10

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 $cm^2/10$. The critical density of population shall not exceed 2 inclusions per cm^2 of contiguous joint cross-sectional area.

ARTICLE 4 FABRICATION

2-4.1

Windows shall be fabricated only from acrylic castings satisfying the requirements of Section 2, Article 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 which complies with Section 3, Article 2, of this Standard. The Quality Assurance Program shall be accepted by the PVHO manufacturer and owner/user(s), hereafter referred to as the purchaser(s), prior to fabrication.

(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 appendix I, enclosures 2 and 3, and Form PVHO-2).

(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 Form PVHO-2.

2-4.2

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

2-4.3

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

2-4.4

All window material shall be annealed after all forming, machining, and machine polishing have been completed, hereafter referred to as the *final anneal.* All annealing shall take place in a forced air circulation oven. The final anneal and any other anneals performed prior to the final anneal shall be in accordance with Table 2-4.1. Time and temperature data for all annealing cycles shall be entered into Form PVHO-2. A copy of the final anneal's time/temperature chart shall be attached to Form PVHO-2.

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TABLE 2-4.1 ANNEALING SCHEDULE FOR ACRYLIC WINDOWS (02)

Part A: Minimum Heating Times for Elevated Temperature Annealing of Acrylic

Thickness, in. (mm)	Heat Time [Note (1)], hr, for Acrylic Placed in a Forced-Circulation Air Oven Maintained at the Indicated Temperature Within ± 5°F (2.8°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.)	3.5	4	6	11
0.875 to 1.125, incl. (22 to 28, incl.)	4	4½	6½	11½
1.250 to 1.500, incl. (32 to 38, incl.)	6	5	7	12
1.750 (44)	7	5	7	12
2.000 (50)	8	6	8	13
2.250 (57)	9	7	9	14
2.500 (64)	10	9	11	15
3.000 (75)	12	11	12	17
3.250 (82)	13	13	14	17
3.500 (89)	14	13	14	19
3.750 (92)	15	14	16	20
4.000 (100)	16	17	18	22
>4.000	4	6	6	6 (per in. of additional thickness over 4)

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

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

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

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2-4.5

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

2-4.6

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

ARTICLE 5 INSPECTION

2-5.1

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 Section 2, articles 2, 3, and 4. Windows that meet the requirements of Section 2, articles 2, 3, and 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

All dimensional and angular measurements shall be performed at a material temperature of 70 to 75°F (21 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

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

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 16 cm^2 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 16 cm^2 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

2-5.5

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 surface area divided by 1000

(4) critical density of population: none specified

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(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 $t/D_i < 0.5$, 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 surface area divided by 1000

(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 surface area divided by 1000

(4) critical density of population: none specified

(5) critical spacing between scratches: none specified

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

2-5.6

Repairs to new windows which do not meet acceptance criteria shall be performed in accordance with appendix III.

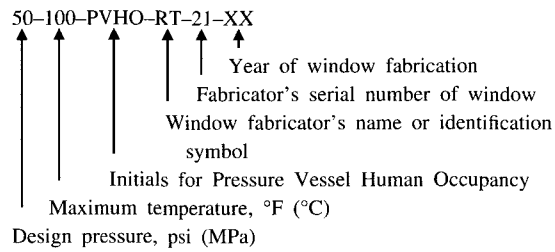
2-5.7

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 Form PVHO-2. This report shall be forwarded to the chamber manufacturer or user as a part of the certification package.

ARTICLE 6 MARKING

2-6.1

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. (13 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 example shown below.



2-6.2

At the time of marking, the window fabricator shall certify the overall fabrication of the window by completing a window certification equivalent to Form PVHO-2. This certification shall indicate revision number of window fabricator's Quality Assurance Program and date accepted by purchaser. Only after completion of Form PVHO-2 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

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 fabrication certifications 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

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.

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2-6.5

The window certification and data reports (Form PVHO-2 and appendix I, enclosures 1–4) shall be retained for each window as follows.

(a) One copy of Form PVHO-2 and enclosures 1–4 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 Form PVHO-2. One copy of Form PVHO-2 and enclosures 1–3 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 article 7, either of which requires the completion of enclosure 4.

(d) It shall be the responsibility of the owner/user and the chamber manufacturer to possess and retain Form PVHO-2 and enclosures 1–4 for a period not less than the design life of the window plus two years.

(e) It shall be the responsibility of the window fabricator to possess and retain a minimum Form PVHO-2 and enclosures 1–3 (and enclosure 4 if he performs the pressure test) for a period not less than the design life of the window plus two years.

ARTICLE 7 PRESSURE TESTING

2-7.1

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

2-7.2

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

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

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/−2.5°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

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

At 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

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 (02

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. 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 window assembly during the test shall be 25°F to 35°F (14°C to 20°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

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mandatory pressure test specified in paras. 2-7.5 through 2-7.7 shall be retained.

2-7.9

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 appendix I, enclosure 4 by the party who performs the pressure test.

2-7.10

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

ARTICLE 8 INSTALLATION OF WINDOWS IN CHAMBERS

2-8.1

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

2-8.2

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

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.

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SECTION 3
WINDOW FABRICATORS

ARTICLE 1 RESPONSIBILITIES AND DUTIES FOR WINDOW FABRICATORS

3-1.1 General

The responsibilities set forth herein relate only to compliance with this Standard.

3-1.2 Responsibilities

3-1.2.1 Definition of a Window Fabricator. As used in this Standard, the term *window fabricator* is defined as that fabricator of PVHO windows who assumes responsibility for certifying that the windows comply with Section 2 of this Standard with respect to material, design, fabrication, testing, inspection, certification, and marking in accordance with Section 2.

3-1.2.2 Examples of the Window Fabricator's Responsibilities. The window fabricator's responsibilities include the following:

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

(b) procurement control of material, parts, and services in accordance with para. 3-2.6;

(c) establishing and maintaining a Quality Assurance Program in accordance with article 2 of this section;

(d) documenting the Quality Assurance Program in accordance with para. 3-1.2.6; and

(e) furnishing the purchaser with appropriate Certification Report(s) in accordance with para. 3-1.2.7.

3-1.2.3 Compliance With This Standard. The PVHO window fabricator has the responsibility for fabrication of windows in compliance with Section 3.

3-1.2.4 Subcontracting. It is the PVHO window fabricator's responsibility to assure 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.

3-1.2.5 Responsibility for Quality Assurance of Subcontracted Activities. The PVHO window fabricator shall be responsible for evaluation and qualification of suppliers of subcontracted services. On-site supplier evaluation is required prior to procurement of all subcontracted activities. All subcontracted activities shall be audited at least annually.

3-1.2.6 Documentation of Quality Assurance Program. The PVHO window fabricator shall be responsible for documenting his Quality Assurance Program with a Quality Assurance Manual in accordance with article 2 of this section.

3-1.2.7 Certification Report. The PVHO window fabricator shall certify compliance with this Standard by furnishing the purchaser with an appropriate Certification Report and by marking the window in accordance with Section 2.

3-1.2.8 Right of Access. The PVHO window fabricator shall afford the purchaser or his designated agent reasonable access to facilities and documents to ascertain that the window being purchased is being fabricated to the requirements of this Standard.

ARTICLE 2 QUALITY ASSURANCE PROGRAM FOR FABRICATION OF THE WINDOW

3-2.1 General

This article sets forth the requirements for establishing and maintaining Quality Assurance Programs to control the quality of work performed by the fabricators of windows that are used in pressure vessels for human occupancy, in accordance with the applicable edition of this Standard.

3-2.2 Organization

(a) The window fabricator required to comply with this Standard shall have a documented organizational structure, with responsibilities, authorities, and lines of communication clearly delineated in writing for activities affecting quality. Persons or organizations responsible for the Quality Assurance Program shall have authority and organizational freedom to

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(1) identify problems affecting quality;

(2) initiate, recommend, or provide solutions to quality problems, through designated channels;

(3) verify implementation of solutions; and

(4) control further processing, delivery, or assembly of a nonconforming item, deficiency, or unsatisfactory condition until proper corrective action has been taken.

(b) The necessary scope and detail of the system shall depend on the complexity of the work performed and on the size and complexity of the fabricator's organization (including factors such as number and experience level of employees and number of viewports produced).

3-2.3 Quality Assurance Program

(a) A documented program for the assurance of quality of activities, items, and services shall be planned, implemented, and maintained in accordance with specified requirements of this Standard.

(b) The program shall apply to activities, materials, parts, assemblies, and services which affect the quality of the windows. It need not apply to other activities, products, and services at the same location.

(c) The program shall identify the PVHO activities to which it applies.

(d) The program shall provide for indoctrination and training of personnel to assure compliance with this Standard.

(e) Management shall, at least annually, assess the program and take corrective action, if necessary.

3-2.4 Quality Assurance Manual

(a) The Quality Assurance Program shall be described in a Quality Assurance Manual.

(b) The Quality Assurance Manual must provide a mechanism to document issuance and revision, and must include a method to identify and/or highlight the revisions.

3-2.5 Drawing, Design, and Specification Control

(a) The window fabricator shall establish measures to assure that window design drawings and all applicable documents and requirements of this Standard relative to the design of windows are received from the designer, and are correctly translated into fabrication specifications, drawings, procedures, and shop instructions for the windows.

(b) Procedures shall be established for the review, approval, release, distribution, and revision of fabrication documents.

3-2.6 Procurement Control

(a) Applicable requirements necessary to assure compliance with this Standard shall be specified or included in documents for procurement of materials, items, or services to be used by the window fabricator.

(b) The procurement of materials, items, and services shall be controlled by the fabricator to assure conformance with specified requirements.

(c) These controls shall include, but not be limited to, any of the following, as appropriate:

(1) source evaluation and selection;

(2) appraisal of objective evidence of quality furnished by the supplier including all necessary material certification documents;

(3) inventory control;

(4) material identification; and

(5) examination of supplied items upon delivery.

(d) Procedures for assuring continued compliance with pertinent requirements, including identification of procedural revisions, shall be described in the Quality Assurance Manual.

3-2.7 Identification and Control of Items

(a) Identification shall be maintained on all items or in documentation traceable to these items.

(b) Controls shall be established to prevent use of incorrect or defective items.

(c) The window fabricator, based on his judgment, shall also maintain additional identification and documentation to assure that significant problems can be identified and proper corrective action taken.

(d) Traceability procedures shall be described in the Quality Assurance Manual.

(e) Traceability of the completed window shall extend to identification of the immediate purchaser.

3-2.8 Control of Processes

(a) Processes affecting quality shall be controlled in accordance with specified requirements using process control documents such as process sheets and travelers.

(b) Special processes affecting quality, such as bonding and nondestructive examination, shall be performed by qualified personnel using qualified procedures referenced in this Standard.

3-2.9 Inspection

(a) Inspection shall be planned and controlled by the fabricator.

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(b) These inspections shall verify conformance to documented instructions, procedures, and drawings describing the activities.

(c) Inspection results shall be documented.

(d) Inspection for acceptance shall be performed by qualified persons other than those who performed or supervised the work.

(e) Inspection documents shall contain appropriate criteria for determining that such activities have been satisfactorily accomplished.

3-2.10 Test Control

(a) Testing required to demonstrate that the windows will perform in accordance with this Standard shall be so defined, controlled, and documented.

(b) Tests shall be performed in accordance with written instructions stipulating acceptance criteria.

(c) Test results shall be recorded on the required forms.

(d) Examination, measurement, and testing equipment used for activities affecting quality shall be controlled, calibrated, and adjusted at specified periods to maintain required accuracy.

(e) Specifications, calibration, and control of measuring and testing equipment used for acceptance shall be described in written instructions or procedures.

(f) Calibrations shall be traceable to National Standards where such exist.

3-2.11 Handling, Storage, and Shipping

Handling, storage, cleaning, packaging, shipping, and preservation of items shall be controlled to prevent damage or loss, and to minimize deterioration, and shall be documented.

3-2.12 Documentation and Status of Test Activities

(a) The status of inspection and testing activities shall be indicated either on the items, or in records traceable to the items, to assure that required inspections and tests are performed.

(b) Items which have satisfactorily passed required inspections and tests shall be identified.

3-2.13 Corrective Action

(a) Items, services, or activities which do not conform to specified requirements shall be controlled to assure proper disposition and prevent inadvertent use.

(b) Controls shall provide for identification, documentation, evaluation, segregation when practical, and disposition of nonconformances and notification to affected organizations.

(c) Conditions adverse to quality shall be promptly investigated, documented, evaluated, and corrected.

(d) In the case of a significant condition adverse to quality, the cause of the condition shall be determined and corrective action taken to preclude recurrence.

(e) The identification, cause, and corrective action planned and taken for significant conditions shall be documented and reported to appropriate levels of management.

(f) Follow-up action shall be taken to verify implementation of corrective action.

3-2.14 Quality Assurance Records

(a) Records shall be specified, compiled, and maintained to furnish documentary evidence that services, materials, items, and completed windows meet this and applicable referenced standards.

(b) Records shall be legible, identifiable, and retrievable.

(c) Records shall be protected against damage, deterioration, or loss.

(d) Requirements and responsibilities for record transmittal, distribution, retention, maintenance, and disposition shall be established and documented.

(e) Records required for traceability shall be retained for the maximum allowable design life plus a minimum of 2 years.

3-2.15 Quality Assurance Audits

(a) The window fabricator shall schedule and perform regular internal audits to verify compliance with all aspects of the Quality Assurance Program.

(b) These audits shall be performed at least annually and stipulated in the Quality Assurance Manual.

(c) These audits shall be performed by qualified personnel who do not have direct responsibility for performing or controlling the activities being audited.

(d) The audits shall be performed in accordance with written instructions.

(e) Audit results shall be reported to and reviewed by management having responsibility and authority to take any necessary corrective action. Follow-up action shall be taken where indicated.

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SECTION 4
PIPING SYSTEMS

ARTICLE 1 GENERAL

4-1.1 Temperature Limitations

Piping systems constructed under the rules contained in this Standard are limited to design temperatures between 0°F and 150°F, inclusive.

Additional precautions may be required if temperatures outside that range are expected.

4-1.2 Certification of Design and Fabrication

The following requirements relate solely to compliance with this Standard.

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 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 Standard. Those requirements shall include, as a minimum, the following:

(a) required pressurization and depressurization rates, ventilation rates, and the conditions under which those rates are to be maintainable (paras. 4-7.1.1 and 4-7.1.2);

(b) requirements affecting the required amounts of stored gas reserves (para. 4-7.1.3); and

(c) required number of breathing gas outlets and their characteristics (para. 4-7.6.1).

4-1.2.2 Design Certification. Conformance of the piping system design to the requirements of this Standard and the User's Design Specification shall be established by one of the two following procedures.

(a) A Professional Engineer, registered in one or more of the states of the United States of America, or the provinces of Canada, and experienced in piping systems designs, shall certify that the piping system was designed either by him or under his direct supervision, or that he has thoroughly reviewed a design prepared by others, and that to the best of his knowledge, within the User's Design Specification, the piping system design complies with this Standard.

(b) 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 Standard.

4-1.2.3 *Fabricator's Certification.* The fabricator of the piping system shall be responsible for complying with the requirements of this Standard. The fabricator shall provide written certification as to compliance with this Standard and with the User's Design Specification.

4-1.2.4 Data Retention. A copy of the Fabricator's Certification and supporting data (test data, material test reports, as applicable, etc.) shall be retained by the fabricator for at least 5 years. A copy of the piping system User's Design Specification and the Fabricator's Certification shall be provided to the user with the system.

ARTICLE 2 MATERIAL REQUIREMENTS

4-2.1 Acceptable Materials

4-2.1.1 Pipe and Tube. Pipe and tube for use in chamber piping systems, except as otherwise restricted or permitted, shall be seamless and shall be of a material for which allowable stress values are listed in Appendix A of ASME B31.1 or are listed in Table 4-2.1. Cast pipe shall not be used.

4-2.1.2 Fittings. Unless otherwise restricted or permitted

(a) fittings which 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;

(b) fittings which 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.

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TABLE 4-2.1 MAXIMUM ALLOWABLE STRESS VALUES FOR SEAMLESS PIPE AND TUBE MATERIALS NOT LISTED IN APPENDIX A OF ASME B31.1

Material	Specification	Temper or Grade	Strength, ksi	Max. 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.

4-2.2 Limitations on Materials

4-2.2.1 Service Requirements. All metallic materials used for oxygen service, breathing gas service, and all components subject to the requirements of para. 4-7.3, Pressure Boundary Valve Requirements, shall be one of the following:

(a) copper,
(b) brass,
(c) bronze,
(d) austenitic stainless steel,
(e) copper–nickel alloy, or
(f) nickel–copper alloy.

Aluminum materials may be used as permitted in para. 4-2.2.3.

4-2.2.2 Carbon Steel. The use of carbon steel pipe, tube, valves, and fittings in chamber piping 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 following guidelines apply to the usage of carbon steel components.

(a) Hot trisodium phosphate cleaning solutions can remove cadmium plating.

(b) Unprotected plain carbon steel, especially when cleaned in accordance with the requirements for breathing gas service, is subject to accelerated corrosive attack and its use should be avoided.

(c) Plated carbon steel components such as chrome plated carbon steel balls for ball valves have poor service histories in applications involving exposures to humid gases containing oxygen and their use in such applications shall be avoided.

(d) 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 can, under some conditions, react violently with the fluorocarbon lubricants frequently used in oxygen and breathing gas systems. It may also react with the CO_2 absorbent chemicals used in life-support systems. Aluminum may be used only when adequate precautions are taken to prevent contact with fluorocarbon lubricants and hydroxide-based absorbents. Further, the corrosive effect of 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, unless there is a prior record of satisfactory service. Cast, ductile, and malleable iron pipe, tube, pipe fittings, and tube fittings shall not be used. Cast components of other materials may be used if not otherwise prohibited by other paragraphs of this Standard.

4-2.2.5 Seawater Service. Materials which will be repeatedly or continuously exposed to seawater shall be compatible with seawater service. In particular, brasses and bronzes should be selected for resistance to dezincification and dealuminification. Materials which comply with the requirements of MIL-B-24480 (SHIPS), *Military Specifications: Bronze, Nickel–Aluminum Castings for Seawater Service*, may be considered acceptable without further investigations. Materials with a zinc content in excess of 15% may also be considered acceptable if they give satisfactory results in a mercurous nitrate test performed in accordance with the requirements of ASTM B 154.

4-2.2.6 Pressure Ratings. When possible, all pipe and tubing of the same material and diameter used in a single chamber piping system shall have the same pressure rating. When this is not possible, special precautions shall be taken to prevent inadvertent mixing of materials.

4-2.2.7 Dissimilar Metals. The designer shall consider galvanic effects of corrosion when combinations of dissimilar metals are used in the presence of an electrolyte, e.g., seawater.

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4-2.3 Nonmetallic Materials

4-2.3.1 Lubricants and Sealants. Lubricants and sealants shall meet the requirements of para. 4-7.12.

4-2.3.2 Hose Materials. Nonmetallic hose materials shall meet the requirements of para. 4-4.5.1.

4-2.3.3 Nonmetallic Pipe and Tube. This Standard recognizes the existence of a wide variety of nonmetallic piping materials which may be used in corrosive (either internal or external) or other specialized applications such as pneumatic control circuits. Extreme care must be taken in their selection as their design properties vary greatly and depend upon the materials, type, and grade. Particular consideration shall be given to the possibility of

(a) destruction where fire hazard is involved;

(b) decrease in tensile strength at slight increase in temperature; and

(c) effects of toxicity.

Another consideration is that of providing adequate support for flexible pipe.

4-2.4 Deterioration of Materials in Service

The selection of materials to resist deterioration in service is generally outside the scope of this Standard. It is the responsibility of the designer to select materials suitable for the conditions of operation.

4-2.5 Prohibited Materials

Components of beryllium or those containing mercury shall not be used. Components containing asbestos shall not be used for breathing gas service applications.

ARTICLE 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

$$t_m = \frac{PD_o}{2\,SE + 0.8\,P} + A \qquad (1)$$

$$t_m = \frac{Pd + 2\,SEA + 0.8\,PA}{2(SE - 0.6\,P)} \qquad (1a)$$

Design pressure shall not exceed

$$P = \frac{2\,SE\,(t_m - A)}{D_o - 0.8\,(t_m - A)} \qquad (2)$$

$$P = \frac{2\,SE\,(t_m - A)}{d - 0.8\,(t_m - A) + 2\,t_m} \qquad (2a)$$

where

t_m = minimum required wall thickness, in. (mm)

(a) If piping is specified by its nominal wall thickness, the manufacturing tolerance on wall thickness must be taken into account. After the minimum wall thickness t_m is determined, this minimum thickness shall be increased by an amount sufficient to provide the manufacturing tolerance allowed in the applicable specification.

(b) If piping is specified by its nominal diameter and schedule weight, the next heavier commercial wall thickness shall then be selected from thickness schedules as contained in ASME B36.10M, or from manufacturers' schedules for other than standard thickness.

P = internal design pressure, psi gage

D_o = outside diameter of pipe or tube, in. For design calculations, the outside diameter of piping as given in tables of standards and specifications shall be used in obtaining the value of t_m. When calculating the allowable working pressure of piping on hand or in stock, the actual measured outside diameter and actual measured minimum wall thickness at the thinner end of the pipe or tube may be used to calculate this pressure.

d = inside diameter of piping, in. For design calculations, the inside diameter of piping is the maximum possible value allowable under the purchase specification. When calculating the allowable working pressure of piping on hand or in stock, the actual measured inside diameter and actual measured minimum wall thickness at the thinner end of the pipe or tube may be used to calculate this pressure.

SE = maximum allowable stress in material due to internal pressure and joint efficiency at the design temperature, psi. The value of SE shall not exceed the value given in Appendix A of ASME B31.1, or the value given in Table 4-2.1.

A = an additional thickness

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(a) To provide for corrosion and/or erosion, refer to para. 4-3.3.1.

(b) To compensate for material removed in threading, grooving, etc., required to make a mechanical joint, refer to para. 4-3.3.2.

(c) To provide for additional mechanical strength of the piping, refer to para. 4-3.3.3 (not intended to provide for extreme conditions of misapplied external loads or for mechanical abuse).

(d) To compensate for thinning in bends, refer to paras. 4-3.3.4 and 4-3.4.1.

4-3.2.2 Additional Thickness Requirements. While the thicknesses determined from the formulas in para. 4-3.2.1 are theoretically ample for both bursting pressure and material removed in threading, the following minimum requirements are mandatory to furnish added 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) When threaded brass or copper pipe is used for the services described above, it shall have a wall thickness at least equal to that specified above for steel pipe.

(c) For chambers subject to external pressure due to immersion in seawater, the piping between penetrations and the corresponding first stop valves on the chamber interior shall be adequate for the design pressure in accordance with para. 4-3.2, but shall not be less than the equivalent of Schedule 160 of ASME B36.10M for nominal diameters of $^{3}/_{4}$ in. and greater, and Schedule 80 for smaller sizes.

(d) Pipe or tubing subject to bending shall comply with the wall thickness requirements of para. 4-3.3.4.

4-3.3 Additional Thickness Allowances

4-3.3.1 Corrosion or Erosion. When corrosion or erosion is expected, an increase in wall thickness of the piping shall be provided over that required by other design requirements. This allowance, in the judgment of the designer, shall be consistent with the expected life of the piping.

4-3.3.2 Threading and Grooving. The calculated minimum thickness of pipe or tubing which is to be threaded shall be increased by an allowance equal to thread depth; dimension h of ASME B1.20.1 or equivalent shall apply. For machined surfaces or grooves, where the tolerance is not specified, the tolerance shall be assumed to be $^{1}/_{64}$ in. (0.40 mm) in addition to the specified depth of cut.

TABLE 4-3.1 BEND THINNING ALLOWANCE

Radius of Bends [Notes (1)–(3)]	Min. Thickness Recommended Prior to Bending [Note (4)]
6 pipe dia. or greater	1.06 t_m
5 pipe dia.	1.08 t_m
4 pipe dia.	1.14 t_m
3 pipe dia.	1.25 t_m

NOTES:
(1) Radius of bend is measured at the centerline of the pipe or tube.
(2) Interpolation is permissible for bending to intermediate radii.
(3) Pipe diameter is the nominal diameter as tabulated in ASME B36.10M, Table 2, and ASME B36.19M, Table 2. For pipe with diameter not listed in these tables and also for tubing, the nominal diameter corresponds with the outside diameter.
(4) t_m is determined by the formulas in para. 4-3.2.1.

4-3.3.3 Mechanical Strength. Where necessary for mechanical strength to prevent damage, collapse, excessive sag, or buckling of pipe or tube due to superimposed loads from supports or other causes, the wall thickness of the pipe shall be increased; or, if this is impractical or would cause excessive local stresses, the superimposed loads or other causes shall be reduced or eliminated by other design methods (see Article 5). The requirements of para. 4-3.5 shall also apply.

4-3.3.4 Bending. Except as permitted in para. 4-3.4.1, the minimum wall thickness at any point in a completed bend shall not be less than that required by the formulas of para. 4-3.2.1.

(a) Table 4-3.1 is a guide to the designer who must specify wall thickness for ordering pipe or tube. In general, it has been the experience that when good shop practices are employed, the minimum thicknesses of straight pipe and tubing shown in Table 4-3.1 should be sufficient for bending, and still meet the minimum thickness requirements of para. 4-3.2.1.

(b) The bend thinning allowance in Table 4-3.1 may be provided in all parts of the cross section of the pipe or tube circumference without any detrimental effects being produced.

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4-3.4 Bending of Pipe and Tube

4-3.4.1 Wall Thickness Allowance

(a) The allowances for pipe and tube wall thinning as a result of bending contained in para. 4-3.3.4 are mandatory except as permitted by para. 4-3.4.1(b).

(b) When fully annealed tube is bent as permitted under para. 4-3.4.2, the increase in tensile strength due to work hardening normally offsets the loss in wall thickness due to thinning. For fully annealed tube only, the bending allowances of para. 4-3.3.4 may be reduced or eliminated if the fabricator can demonstrate by actual test that the bending procedures used do not reduce the tube burst pressure below a level of 4.0 times the design pressure for the tube.

(c) Tube bent under the provisions of (b) shall not be annealed following bending or subjected to welding or brazing operations within 12 in. of the nearest bend.

4-3.4.2 Bending Requirements

(a) 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, as determined by a method of inspection specified in the design, and substantially free of buckles. Additionally, the radii of pipe and tube bends shall be controlled so that they fall in the region below the $D_o/(R_b)_f$ and $D_o/(R_b)_b$ curves in Fig. 4-3.1, where

D_o = outside diameter, in.
t_w = wall thickness, in.
e = nominal percent elongation limit typical of the pipe or tube material
$(R_b)_f$ = bend radius causing fracture of the pipe or tube along the outside of the bend
$(R_b)_b$ = bend radius causing buckling of the pipe or tube along the inside of the bend

Table 4-3.2 lists the percent elongation limits for some typical types of pipe and tube materials. Bending coordinates should be maintained below the outer wall fracturing curve for e = 10% and the inner wall buckling curve, as those two curves define a coordinate region where failure due to either fracture or buckling is unlikely.

(b) Bends in pipe or tube with a wall thickness equivalent to that of Schedule 40 pipe or thicker, and all bends where heating of the material is required, shall also conform to the requirements of ASME B31.1, paras. 104.2.1 and 129.3.

4-3.5 Stress Analysis of Piping Components

It shall be the responsibility of the designer to determine if the completed piping system must be subjected to a detailed stress analysis. Factors to be considered shall include, but not necessarily be limited to, the following:

(a) stresses due to thermal expansion;

(b) effects of vibration, where appropriate;

(c) dynamic effects of shipboard motion, where appropriate;

(d) handling loads, especially in transportable systems;

(e) vessel expansion and contraction due to pressure changes;

(f) effects of differential movement in the supporting structures; and

(g) other factors, such as earthquake loads, where appropriate.

Should a stress analysis be required, it shall be performed in accordance with the requirements of paras. 102.3 and 104.8 of ASME B31.1.

4-3.6 Pressure Design of Fabricated Joints and Intersections

Except as permitted in (c), where joints and intersections are not made with fittings but must be fabricated, the design rules of para. 104.3 of ASME B31.1 shall be followed, with the following additional restrictions.

(a) Fabricated tees and elbows and miter joints consisting only of pieces of pipe or tube jointed together shall not be used except in vent lines (or other locations) that are subject to internal or external pressures of less than 5 psig.

(b) Fabricated branch connections with angles of other than 90 deg shall not be used except in vent lines (or other locations) that are subject to internal or external pressures of less than 5 psig. Fabricated branch connections with angles of 90 deg shall be of a type that either does not require reinforcement or uses integrally reinforced outlets.

(c) Fabricated branch joints made by brazing a branch line into an extruded opening in the run line may be used provided

(1) line MAWP is 175 psig or less; and

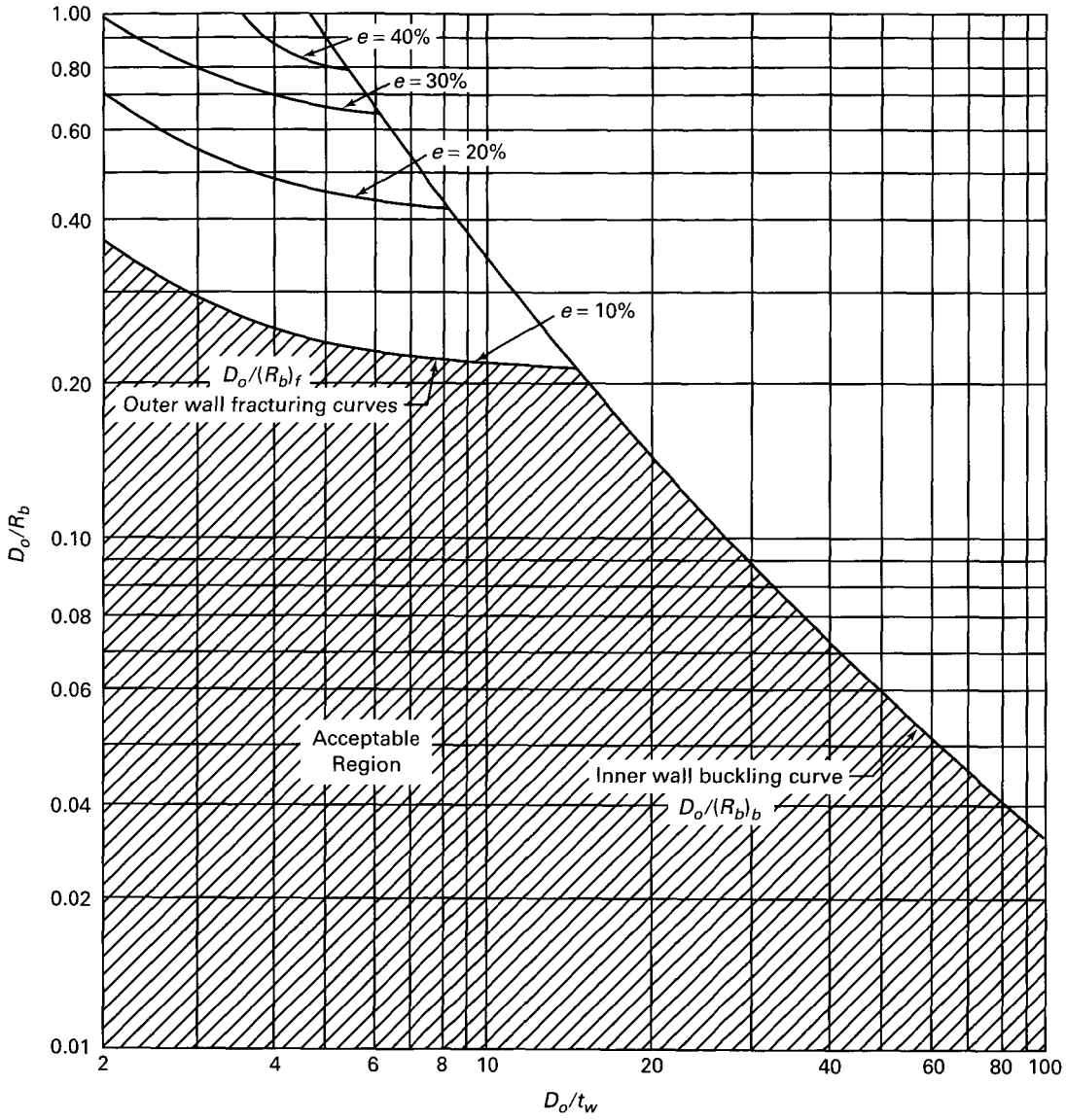
(2) the joint meets the reinforcement requirements of para. 104.3.1(g) of ASME B31.1.

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 with the following additional restrictions.

(a) Flanges shall be joined to the pipe by butt

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FIG. 4-3.1 CURVES FOR DETERMINING THE MINIMUM BEND RADIUS NOT PRODUCING OUTER WALL FRACTURING OR INNER WALL BUCKLING

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TABLE 4-3.2 ELONGATION LIMITS FOR TUBING MATERIALS (METAL)

Material	% Elongation	Material	% Elongation	Material	% Elongation
Stainless steel 303	45	Duranickel 301	35	Aluminum 7078	10
Stainless steel 304	45	Monel 400	32	Aluminum 7079	10
Stainless steel 305	45	Monel 404	32	Oxygen-free copper	35
Stainless steel 309	40	Monel R–405	30	Everdur 1010	43
Stainless steel 310	40	Monel K–500	28	Chromium copper	23
Stainless steel 316	40	Nickel 200	30	Cupronickel 10	31
Stainless steel 321	40	Nickel 201	32	A	40
Stainless steel 347	38	Nickel 211	30	Aluminum brass	37
Stainless steel 348	38	Nickel 270	32	Leaded-tube brass, 0.25%	41
Stainless steel 403	25	NI–O–HEL 825	35	Leaded-tube brass, 0.50%	39
Stainless steel 410	25	NI–span "C"	30	Leaded-tube brass, 1.00%	37
Stainless steel 430	25	Waspaloy	35	Naval brass	30
Stainless steel 446	20	Aluminum 1060	15	Red brass, 85%	33
Stainless steel 502	27	Aluminum 1100	15	Yellow brass	37
Nickel alloy A–286	25	Aluminum 2014	12	Aluminum bronze, 5%	37
30% Cupronickel	30	Aluminum 2024	12	Commercial bronze, 90%	32
Hastelloy "C"	25	Aluminum 2219	12	Nickel-silver, 18%	23
Hastelloy "X"	25	Aluminum 3003	20	Phosphor bronze, 10%	39
Haynes 25	40	Aluminum 5050	16	Molybdenum	30
Inconel 600	35	Aluminum 5086	14	Titanium	22
Inconel 702	25	Aluminum 5154	12	Tungsten–26% rhenium	11
Inconel 718	30	Aluminum 5454	12	Tantalum	30
Inconel X–750	40	Aluminum 5456	12		
Inconel 800 (Incoloy)	35	Aluminum 6061	14		
Invar	30	Aluminum 7075	10		

GENERAL NOTES:

(a) Normal room temperature % elongation limit values (2 in. sample) for tubes whose wall thickness equals or exceeds 0.015 in., whose outside diameter equals or exceeds 0.125 in., and whose outside diameter to wall thickness ratio (D_o/t_w) does not exceed 16.

(b) This table has been reprinted from Aerojet Nuclear Systems Co. Report RN-TM-0599, *Minimum Bend Radius Recommendations for Pneumatic Instrumentation Lines*, R.D. Samuelson, July 1970, supported by U.S. government funds.

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welding, socket welding, threading, or other proven mechanical joining techniques.

(b) Gasket materials and design shall be suitable for the intended service. For breathing gas service, O-ring flanges are recommended over conventional gasket or ring-joint flanges.

(c) Gasket materials containing asbestos shall not be used for breathing gas service.

4-3.8 Design of Penetrations Through the Pressure Boundaries of Chambers

The design of penetrations through the pressure boundaries of chambers should consider ease of maintenance and repair as well as structural adequacy. Nonmandatory Appendix III contains guidelines for the design of piping penetrations through the pressure boundaries of chambers.

ARTICLE 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 design 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 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

(a) Components subject to alternating (i.e., both internal and external) pressure shall be designed for the maximum differential pressure that may exist in both directions. Note that the pressure, internal or external, which controls the required design thickness may vary depending upon circumstances and both conditions must be considered.

(b) O-rings subject to reversing pressures occurring as a result of submergence have been known to permit small amounts of seawater to penetrate the system by working past the O-ring as it moved from one side of the groove to the other. System designs shall take this into consideration.

4-4.2 Valves

4-4.2.1 Valves Subject to Internal and External Pressures. Valves subject to both internal and external pressures shall employ seals and stem packings suitable for bidirectional pressures.

4-4.2.2 Stop Valves. Stop valves shall be selected and installed so that all stop valves 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 Valve Seats. Except as permitted in para. 4-7.7.2, all valves used for breathing gas service shall be of a "soft seat" design; valves employing metal-to-metal seats shall not be used.

4-4.2.5 Service Access. Stop, regulating, and ball valves in breathing gas and other life-sensitive systems shall be selected and installed so that service access to the working parts of the valves is readily available. In situations when the valve body, as a whole, cannot be removed from the line for service, three-piece, top-entry body, or other designs permitting service access to the valve internals with the end pieces or valve body in place shall be used.

4-4.2.6 Quick Opening Valves. Quick opening valves shall not be used in oxygen systems operating 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 smaller than the capacity of upstream components enough 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.

4-4.2.7 Remotely Operated Valves. Remotely operated valves, when used, shall be selected and installed so that, where possible, they fail in the safe position.

4-4.2.8 Relief Valves. Relief valves used for protection against overpressures in excess of system design 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 used in filters in breathing gas and other life-sensitive systems shall have a collapse pressure rating

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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. Except as otherwise permitted, all particulate filters in breathing gas and other life-sensitive systems shall use elements of the woven wire, screen, or sintered metal types. Particulate filters requiring very low flow resistance, such as on compressor intakes and atmospheric conditioning systems, may employ any suitable noncombustible elements. 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, or installed in a chamber or the piping communicating with a chamber (including vent lines downstream from exhaust control valves) shall be fabricated of materials which are noncombustible.

4-4.5 Hoses

4-4.5.1 Hose Materials

(a) Liner. The principal limitation on the selection of liner materials is that the liner shall not give off noxious or toxic gases or vapors. 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 appendix I. PTFE, nylon, and flexible metal liners meeting the requirements of para. 4-2.2 and which 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 which are suitable for use with gaseous oxygen at the design pressure of the hose.

(b) Reinforcement Layer. For marine systems, reinforcement layer materials shall be compatible with seawater service. Hoses employing carbon steel reinforcing wire shall not be used in marine systems unless the wire has been plated or otherwise protected from corrosion if seawater penetrates the outer jacket.

(c) Outer Jacket. For marine systems, outer jacket materials shall be compatible with seawater service and extensive exposure to the elements. The outer jacket on hoses intended for helium service shall be perforated or sufficiently permeable to allow escape of gas which may seep through the inner liner. For other gas service applications, the designer should consider the possible needs for outer jacket perforation.

(d) Fittings. Fitting materials shall comply with para. 4-2.2. Fittings used on divers' umbilicals shall be types which are resistant to inadvertent disengagement.

4-4.5.2 Pressure Ratings

(a) MAWP. All hoses used in chamber 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.

4-4.5.3 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 in piping systems 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 loadings.

4-4.5.4 Marking. Hoses shall be marked with the manufacturer's name or trademark, type or catalog number, and MAWP. 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 abraid the hose or prevent the hose from normal bending or expansion due to pressure.

4-4.5.5 Testing

(a) Hoses which are received made-up from the hose manufacturer and which were tested by the manufacturer

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in a manner substantially equivalent to the procedure described in Article 9 need not be retested.

(b) Locally assembled hose assemblies shall be tested as prescribed in Article 9 before being placed in service. Hose assemblies may be tested individually or as a portion of the system of which they form a part.

4-4.5.6 Hoses Subject to External Pressure

(a) Hoses subject to external pressure are very sensitive to any form of structural damage to the reinforcing layer. The following guidelines are recommended for hoses subject to external pressure.

(1) The reinforcement layer should be of a type which is resistant to collapse. Spiral-wound metal wire constructions usually give good service. Wire braid and synthetic reinforcement layers should be avoided unless there is adequate test data to support their use.

(2) The liner should be securely bonded to the reinforcing layer. Hoses with separable liners, e.g., nylon tubes, are subject to liner collapse if depth pressure penetrates the outer jacket.

(3) Fittings should be of a type that forms a good seal at the end of the hose. Many field-attachable-type fittings leave the cut end of the hose open to external pressure. This can result in depth pressure penetrating the hose outer jacket via the cut end and collapsing the liner.

(4) The hoses should be installed in a manner that minimizes the chances of structural damage to the hose. Minor kinks, crushes, etc., that may not harm the internal working pressure capability of the hose may cause it to collapse when subject to external pressure.

(5) Tight radius bends and torsional loads should be avoided.

(b) Hoses intended for external pressure service shall be tested as follows.

A 10 ft section of hose shall be fitted 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 around a mandrel 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 rated external pressure for 1 hr. Air is an acceptable pressurizing medium. The hose shall show 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 flowing a fluid, usually air, through the hose at a specific rate and observing the resulting pressure drop. 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 oil-free water and measuring the amount of water displaced as the hose is pressurized.

ARTICLE 5 SELECTION AND LIMITATIONS OF PIPING JOINTS

4-5.1 Welded Joints

Welding procedures, welders, and welding operators shall be qualified in accordance with Section IX of the ASME Code. Welded joints in chamber piping systems shall be constructed in accordance with the requirements of paras. 127, 131, and 132 of ASME B31.1, subject to the following additional restrictions.

(a) Welded joints of $2\frac{1}{2}$ in. pipe size or smaller may be socket welded or buttwelded. Welded joints over $2\frac{1}{2}$ in. pipe size shall be buttwelded.

(b) The finished interior surface of pipe joints shall be as smooth as practically possible to reduce the amount of noise generated. Backing rings, when used, shall either be removed or be of a consumable type.

4-5.2 Brazed Joints

4-5.2.1 Fabrication Requirements and Pressure Limitations. Except as required in paras. 4-5.2.2 and 4-5.2.3, brazing shall be in accordance with the requirements of Section IX, Part QB, of the ASME Code.

4-5.2.2 Brazing Materials

(a) Corrosion Resistance. All brazed materials, components, and fittings shall be of corrosion-resistant metals (stainless steel, copper, brass, bronze). The effect of the filler metal and flux are also of concern when brazing austenitic stainless steel, due to the possibility of intergranular attack of the base metal by the filler metal or flux. Material combinations from Section IX, Part QB, of the ASME Code are recommended.

(b) Filler Metal. The filler metal used in brazing shall be a nonferrous metal or alloy having a melting point above 1000°F and below that of the metals being joined. The filler metal shall melt and flow freely within the desired temperature range and, in conjunction with a suitable flux or controlled atmosphere, shall wet and adhere to the surfaces to be joined.

(c) Flux. Fluxes that are fluid and chemically active at the brazing temperature shall be used when necessary to prevent oxidation of the filler metal and the surfaces to be joined, and to promote free flowing of the filler

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metal. Fluxes shall be soluble in hot water to facilitate flushing from the piping system.

4-5.2.3 Preparation and Procedure

(a) Surface Preparation. The surfaces to be brazed shall be clean and free from grease, oxides, paint, scale, and dirt of any kind. A suitable chemical or mechanical cleaning method shall be used to provide a clean wettable surface for brazing.

(b) Joint Clearance. The clearance between surfaces to be joined shall be no larger than is necessary to ensure complete capillary distribution of the filler metal.

(c) Heating. The joint shall be brought to brazing temperature in as short a time as possible to minimize oxidation. Also the brazing heat shall be concentrated towards the center of the sleeve to minimize thermal degradation of the strength properties of the pipe or tubing material where it enters the sleeve.

(d) Brazing Qualification. The qualification of the brazing procedure and of brazers and brazing operators shall be in accordance with the requirements of Section IX, Part QB, of the ASME Code.

4-5.3 Mechanical Unions

4-5.3.1 Seal Selection. Flat-face O-ring unions and other mechanical joint designs employing self-energizing seals where effective sealing is not dependent on bolt preloading are recommended over bolted flanges. Where bolted flanges are used, consideration should be given to using O-ring flanges in place of gasket or ring-joint flanges.

4-5.3.2 Special Requirements for Bolted Flanges

(a) All bolted flanged joints shall be aligned so that the gasket contact faces bear uniformly on the gasket, and then shall be made up with relatively uniform bolt stress. The gasket shall be properly compressed in accordance with the design principles applicable to the type of gasket used.

(b) All bolts shall be of sufficient length so that when the joint is completed there are at least $1\frac{1}{2}$ full threads visible beyond the nut or threaded attachment.

(c) Where bolted flange joints are used in breathing gas systems, the fabricator shall provide making and unmaking instructions with the system. The instructions shall include as a minimum: required bolt and nut materials, required gasket material compatible with breathing gas service, maximum and minimum allowable nut torques, and torquing sequence.

4-5.4 Threaded Joints

4-5.4.1 Pressure Limitations

(a) Except as permitted in para. 4-3.6, all threaded branch connections shall be made with fittings.

(b) Fittings shall have a pressure rating equal to or greater than the design pressure of the system in which they are used.

(c) Size–pressure limits for pipe threaded joints shall be as follows:

Size	Pressure
Over 3 in.	Not permitted
$2\frac{1}{2}$ to 3 in.	400 psig
2 in.	600 psig
$1\frac{1}{4}$ to $1\frac{1}{2}$ in.	800 psig
1 in.	1500 psig
$\frac{3}{4}$ in. or smaller	MAWP of the fittings or pipe, whichever is less

(d) Straight thread O-ring sealed fittings may be used up to the manufacturer's rated MAWP with no limitation on size.

4-5.4.2 Helium Service. For helium service, pipe threads should be avoided, especially in the larger sizes, at higher pressures or where stainless-on-stainless joints are required. 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 which 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. 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 Rockwell B, or some other method of galling prevention shall be used.

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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 pipe to prevent seizing. Aluminum pipe in the annealed temper should not be threaded.

4-5.5 Joints and Fittings in Tubes

Piping systems used with marine chambers are often subjected to vibration loads. Portions of chamber piping systems are also subject to frequent disassembly and reassembly. These factors shall be considered in the types of tube fittings to be used.

4-5.5.1 Limitations. Flared and compression-type fittings may be used for tube sizes not exceeding 2 in. (50 mm) O.D. Compression-type fittings of aluminum shall not be reused. Bite-type fittings shall not be used in chamber 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.

4-5.5.2 Restrictions. Fittings and their joints shall be compatible with the tubes with which they are to be used and shall conform to the range of wall thicknesses 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 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 preswaged using a swaging tool or a suitable temporary fitting.

(c) System design pressure shall not exceed the maximum value recommended by the fitting manufacturer for the fittings when used with copper tube.

4-5.5.3 Flare Fitting Gaskets. The use of crushable metal gaskets between the sealing surfaces of flare fittings should be used for helium service, particularly for stainless steel fittings and locations subject to disassembly/reassembly.

4-5.5.4 Cutting of Tube. Tubing cutters can cause work hardening of the tube end, especially if the cutter wheel has lost its edge. This work hardening, plus the additional work hardening resulting from flaring operations, can embrittle the tube and render the tube more susceptible to brittle fracture. All tube which is to be used with flare tube fittings should be saw cut. Stainless steel tube which is to be flared shall be saw cut.

4-5.5.5 Fittings Subject to Frequent Disassembly. The designer shall pay special attention to the selection of fittings in locations where frequent disassembly and reassembly is likely. For these locations, the following fitting types should be used:

(a) flare fittings with crushable metal gaskets; and

(b) welded or brazed fittings employing a flat-face seal mechanical union integral to the fitting.

4-5.5.6 Other Types of Joints

(a) Expanded or Rolled Joints. Expanded or rolled joints may be used where experience or test has demonstrated that the joint is suitable for the design conditions and where adequate provisions are made to prevent separation of the joint.

(b) Shrink Joints. Fittings that shrink upon heating to a previous dimension from which they were mechanically expanded may be used where experience or test has demonstrated that the joint is suitable for the design conditions.

ARTICLE 6 SUPPORTS

It shall be the responsibility of the designer to determine the support requirements of the piping system. The following guidelines, however, are considered good practice regarding support spacing:

Size	Maximum Support Spacing
1 in. nominal and larger	In accordance with Table 121.1.9 of ASME B31.1
$\frac{1}{8}$ to $\frac{3}{4}$ in.	75 times the square root of the nominal diameter, in.

Where detailed support designs and calculations are required, they shall be performed in accordance with para. 127 of ASME B31.1.

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ARTICLE 7 SYSTEM DESIGN REQUIREMENTS

4-7.1 Pressurization and Depressurization Systems

4-7.1.1 Pressurization and Depressurization Rates. The 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 chamber pressure at all storage pressures over 50% of maximum.

4-7.1.2 Ventilation Rates. On all medical chambers and on all other chambers 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 chamber.

4-7.1.3 Stored Gas Reserves. The requirements for stored gas reserves vary with the application for which a chamber system is to be used. The designer shall consider all pertinent operational and jurisdictional requirements.

4-7.1.4 Exhaust Inlet Protection. The inlets to all chamber exhaust lines shall be fitted with a device that prevents a chamber 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 chamber floor. Chamber 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 chamber being injected into the exhaust line.

4-7.1.5 Exhaust Locations. The exhausts from the depressurization system of chambers located inside enclosures shall be piped to a location outside the enclosure and at least 10 ft away from any air intake.

4-7.2 Noise

Noise in a chamber may interfere with voice communication as well as present a risk of hearing damage if severe. The designer shall consider all sources of noise in the chamber and shall take appropriate actions to minimize the amounts of noise generated by routine chamber operations.

4-7.3 Pressure Boundary Valve Requirements

4-7.3.1 Internal Pressure Chambers. All lines penetrating the pressure boundary of a chamber subject to internal pressure only shall have a stop valve or a check valve, as appropriate, on the outside of the chamber as close as practically possible to the penetration. Where check valves are used, consideration shall be given to preventing chattering of the valve. Where stop valves are placed in locations which prevent ready access in an emergency, they shall be provided with operators which are controllable from suitable accessible locations. Depressurization lines, drain lines, and other lines that normally communicate between chamber pressure and outside atmospheric pressure shall also have a second valve. This second stop valve may be located either inside or outside of the chamber.

4-7.3.2 External Pressure Chambers. All lines penetrating the pressure boundary of a chamber 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 chamber. A second stop valve shall be provided on lines which are normally open to external pressure.

4-7.3.3 Internal and External Pressure Chambers. Chambers which may be subject to both internal and external pressure shall meet the requirements of paras. 4-7.3.1 and 4-7.3.2.

4-7.3.4 External Override. When valves are provided inside a chamber for the purpose of permitting the chamber occupants to control the pressure in the chamber, an external means of overriding the effect of those valves shall be provided. Note that 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 chamber in the event the personnel inside become incapacitated.

4-7.3.5 Special Requirements for Chambers Used for Saturation Service. For chambers designed to be used for saturation applications, all lines which are open to chamber pressure except pressure relief lines and pressure reference lines (e.g., all lines used for pressurization, depressurization, external gas, or water conditioning systems) shall be double valved with one stop, or check, valve inside the chamber and the other valve outside.

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4-7.3.6 Flow Rate Sensitive Valves. When check valves cannot be used or are not desired, a flow rate sensitive valve which closes automatically in the event of excess flow (out of an internal pressure chamber or into an external pressure chamber) shall be used in each line of 2 in. nominal size or larger, and should be used in any line with a ratio of cross-sectional flow area (in square inches) to chamber volume (in cubic feet) of over 0.0015. Flow rate sensitive valves, when used, may be used to satisfy the second stop valve requirement of paras. 4-7.3.1, 4-7.3.2, and 4-7.3.5, provided that the valves are designed to be closed manually should the primary stop valve develop a leak, as well as automatically upon the development of excess flow.

4-7.3.7 Remotely Operated Stop Valves. Remotely operated stop valves, whose operation is triggered either automatically or manually upon uncontrolled loss of pressure, are an acceptable alternative to the flow rate sensitive valves described in para. 4-7.3.6. Such valves may be used to satisfy the second stop valve requirements of paras. 4-7.3.1, 4-7.3.2, and 4-7.3.5 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/depressurizing the chamber shall be provided for use in the event the valve becomes inoperable.

4-7.4 Depth Gages

4-7.4.1 Quantity and Location

(a) Each internal pressure chamber in a chamber system shall have at least one dedicated depth gage (chamber pressure indicator) indicating chamber internal pressure to the chamber operator or chamber system operator. Each chamber in chamber systems other than monoplace medical chambers shall also have a second depth gage which may be located either inside or outside the chamber.

(b) External pressure chambers and chambers subject to both internal and external pressure shall have dedicated gages indicating both internal and external pressures to the chamber operator or chamber system operator, and separate gages indicating these pressures to the chamber occupants, unless the occupants are also the operators, as in the case of a submersible.

4-7.4.2 Calibration. A means shall be provided to permit depth gages to be checked, while in use, against other system depth gages normally accessible to the chamber or system operator or an external master gage for accuracy.

4-7.4.3 Piping. The lines connecting depth gages to their associated chambers shall not be used for any other purpose. The inside diameter of depth gage lines shall not be smaller than 0.12 in. (3 mm).

4-7.4.4 Valving Arrangements. Valving arrangements used with depth gages shall be designed so that the pressure source to which each gage is connected is clearly indicated to the system operator.

4-7.5 Pressure Gages Other Than Depth Gages

All breathing gas and life-sensitive systems shall be fitted with at least one pressure gage equipped with a gage isolation valve. Measures to protect gages from excessive vibration or sudden pressure changes shall be taken where appropriate.

4-7.6 Breathing Gas Systems

4-7.6.1 Breathing Gas Outlets. The number of breathing gas outlets provided in chambers 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.

4-7.6.2 Redundancy of Breathing Gas Supply. The piping system shall be designed so that breathing gas can be delivered to the breathing gas outlets in chambers and to the divers' breathing gas manifold in diving bells from at least two different supply sources.

4-7.6.3 Stored Gas Reserves. The requirements for stored breathing gas vary with the application for which a chamber system is to be used. The designer shall consider all pertinent operational and jurisdictional requirements.

4-7.6.4 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.

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4-7.6.5 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."

4-7.6.6 Separation of Breathing Gases. This Standard recognizes that complete separation of breathing gases of different types is generally not possible in PVHO applications. However, the designer should 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.

4-7.6.7 Pressure Control Valves in Demand Breathing Systems. Where pressure control valves are used in demand breathing systems, they shall meet the requirements of para. 4-7.7.6.

4-7.7 Pressure Control Valves

4-7.7.1 Performance Characteristics. The performance of a pressure control valve is characterized primarily by two factors, both of which must be taken into account by the designer. These factors are

(a) the rate at which the outlet pressure falls (drops) as flow demand increases. In many designs there is a significant difference between outlet pressure at lockup (no flow) and the outlet pressure at useful flow rates. Outlet pressure may also be influenced by changes in inlet pressure, especially in unbalanced single stage designs. However, the flow effect usually dominates.

(b) limit flow capacity. This factor is a function of upstream pressure, orifice size, downstream pressure, and outlet porting size. Developing the full rated capacity on many large capacity pressure control valves is frequently possible only at relatively high outlet pressures due to the development, at lower outlet pressures, of choked flow conditions in the outlet ports.

4-7.7.2 Seats. Pressure control valves used in applications requiring complete shutoff shall employ soft seats. Where complete shutoff is not required, pressure control valve seats meeting the requirements for Class IV leakage rates under ANSI/FCI 70-2 may be used.

4-7.7.3 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 which meets the requirements of para. 4-4.3.

4-7.7.4 Gages. Gages 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.

4-7.7.5 Bypass Requirements. Except as otherwise required in para. 4-7.7.6(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.

4-7.7.6 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:

$$Q = 3.14(N)(D)(RMV)(F)$$

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 cu ft per min

RMV = maximum anticipated user respiratory minute volume, in cu ft per min at usage pressure. The minimum RMV that may be used is 1.41 cu ft per min (40 L per min)

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for a working diver and 0.7 cu ft per min (20 L per min) for a resting diver or chamber occupant

(b) Bypass Requirements. The unsteady nature of the flow in demand breathing circuits makes use of hand-operated valves for bypass purposes around pressure control valves inappropriate in many situations.

(1) The pressure control valves in circuits supplying breathing gas to divers using demand breathing apparatus in the water or in a diving bell shall either be

(a) provided with a bypass loop containing a second pressure regulator of equal capacity and appropriate related components; or

(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 chamber mask breathing gas outlets provided that adequate overpressure relief is provided.

(3) Bypass capability is not required for pressure control valves supporting single consumers where a service interruption is tolerable, such as for pressure control valves dedicated one to each of several mask breathing gas outlets in a chamber.

(4) Bypass capability is not required for pressure control valves supporting overboard dump manifolds in chambers.

4-7.8 Pressure Relief Requirements

4-7.8.1 Overpressure Relief

(a) All systems potentially subject to internal pressures in excess of their design pressure shall be provided with overpressure relief devices capable of maintaining system pressure at not more than 110% of design pressure.

(b) Systems located inside of chambers which are normally pressurized at less than chamber pressure shall be equipped with relief devices (check valves are acceptable) if any of the components in the system (such as vacuum gages) are subject to damage if chamber pressure is released without a concurrent release of system pressure.

4-7.8.2 Underpressure Relief

(a) Systems located inside of chambers which are normally pressurized in excess of chamber pressure shall be equipped with vacuum breakers if any of the components on the system (such as pressure gages) are subject to damage if the chamber is pressurized without pressure in the system.

(b) Systems located inside of chambers which are normally pressurized to a level less than chamber pressure (mask overboard dump lines, medical suction lines) shall be provided with vacuum relief valves capable of relieving underpressures in excess of the maximum limits established by the system designer.

4-7.8.3 Rupture Disks. Rupture disks shall not be used except on gas containers with less than 2.0 cu ft water volume.

4-7.8.4 Division Valves. Where piping systems operating at different pressures are connected, a division valve shall be provided which shall be designed for the higher pressure.

4-7.8.5 Pressure Reducing Valves. Where pressure reducing valves are used, one or more relief devices shall be provided on the low pressure side of the system, or the piping and equipment on the low pressure side shall meet the requirements for the full initial pressure. The relief devices shall be located adjoining or as close as possible to the reducing valve. The total relieving capacity provided shall be such that the design pressure of the low pressure system will not be exceeded by more than 10% if the reducing valve fails open.

4-7.8.6 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 valves or meets the design requirements of the higher system pressure.

4-7.8.7 Stop Valves. There shall be no intervening stop valves between piping being protected and its protective device or devices, except that stop valves may be installed between a relief valve and the piping being protected under the following conditions:

(a) when, in the judgment of the designer, the hazard from a relief valve failing open exceeds the hazard presented by the possible concurrent occurrence of system overpressure plus a closed stop valve;

(b) when a stop valve is provided between a relief valve and the associated protected piping, the valve shall be of a quarter turn design and it shall be wired open with frangible wire.

4-7.8.8 Exhausts From Relief Devices

(a) Exhausts from relief devices which are located

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inside enclosed spaces shall be piped outside of the space if operation of the relief device could result in overpressurizing the space.

(b) Exhausts from relief devices which are located inside enclosed spaces on lines containing gases other than air shall be ducted out of the space except that this requirement does not apply to relief devices on individual gas storage bottles when the individual bottle capacity is less than 400 standard cu ft and the requirements of (a) are satisfied.

4-7.9 Color Coding

4-7.9.1 Consistent Color Codes. Chamber piping systems shall employ a consistent color coding system. Suggested guidelines are listed in nonmandatory appendix D.

4-7.9.2 Owner's Responsibility. Color code requirements vary substantially between the various jurisdictions in which chamber systems may be used. It shall be the responsibility of the owner to specify the required color coding system.

4-7.10 Labeling

4-7.10.1 Piping and Gas Storage Vessels. All piping and gas storage bottles shall be labeled to show contents, direction of flow (when appropriate), and MAWP.

4-7.10.2 Critical Components. All critical components whose function is not obvious from their location and appearance shall be labeled as to function. Except as required in para. 4-7.9.2, it is the responsibility of the designer to establish labeling requirements unless such requirements are specified by the owner.

4-7.10.3 Panel-Mounted Components. All components which are mounted in panels shall be labeled as to function. The panel face shall contain a schematic representation of the internal connections between all panel-mounted components and of the external connections between the panel-mounted components and the associated elements of the piping system.

4-7.11 Soft Goods

4-7.11.1 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.

(a) PTFE O-rings shall be avoided. PTFE O-rings may cold flow, "take a set," and fail.

(b) Soft goods for use in breathing gas and oxygen systems shall carry manufacturers' recommendations as listed below:

Service	Manufacturer's Service Recommendation
Air	Air
Mixed gas with oxygen concentrations of less than 25% by volume	Air
Mixed gas with oxygen concentrations equal to or greater than 25% by volume	Oxygen
Oxygen	Oxygen

4-7.11.2 Other Systems. Soft goods used in other systems shall be compatible with the fluids contained, at the maximum anticipated pressures.

4-7.12 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) Where there is a possibility that lubricants selected for use on piping system components may also be used for O-rings contacting acrylic windows, the lubricants shall be compatible with acrylic.

(c) Fluorocarbon-based lubricants shall not be used on aluminum.

(d) Some chemicals used to remove rust from carbon steel can react with fluorocarbon compounds to form very strong acids. If fluorocarbon lubricants have been used on carbon steel components, they shall be removed prior to the initiation of any chemical rust removal operations.

4-7.13 Cleaning Requirements

4-7.13.1 Oxygen and Breathing Gas Systems. The internal cleaning of oxygen and breathing gas systems is an essential part of chamber piping system design and fabrication. The following guidelines are recommended.

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(a) A written cleaning procedure with well-defined procedures, personnel responsibilities, and acceptance/recleaning criteria should be developed and implemented.

(b) Component handling procedures should be developed and implemented so that components and systems, once cleaned, are not recontaminated.

(c) The intended cleaning procedures should be considered by the designer during the selection of all materials, especially soft goods, and during the layout of the piping runs.

4-7.13.2 Components Located Inside Chambers. Components which are to be located inside chambers 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 medical chambers should show no fluorescence typical of oil or grease when examined under ultraviolet light.

4-7.13.3 Prohibited Cleaning Materials. Trichloroethylene shall not be used to clean breathing gas systems or any components to be located inside a chamber. When passed through a moderately heated alkali bed (such as those used in most CO_2 scrubbers), trichloroethylene can decompose into highly toxic dichloroacetylene.

ARTICLE 8 INSPECTION

4-8.1 Inspection of Welded Joints

All welds in chamber piping systems which are subject to stresses due to pressure shall be inspected in accordance with the requirements of Table 4-8.1. The inspection procedures and acceptance standards shall be in accordance with para. 136.4 of ASME B31.1. It shall be the responsibility of the fabricator (or his agent) to ensure that all inspection personnel are qualified to perform the required inspections.

4-8.2 Inspection of Brazed Joints

Brazed joints performed in accordance with Section IX, Part QB, of the ASME Code 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 $^3/_4$ 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.

ARTICLE 9 TESTING

4-9.1 Hydrostatic Tests

4-9.1.1 Air Vents. 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. If required, additional venting during the filling of the system may be provided by the loosening of flanges, tube fittings, or union joints in pipelines, or by the use of equipment vents.

4-9.1.2 Test Fluid. Water shall normally be used for a hydrostatic test fluid unless otherwise specified by the owner. Test water shall be clean, and oil free, and shall be of such purity as to minimize corrosion of the material in the piping system.

4-9.1.3 Test Pressure. Piping systems shall be subjected to a hydrostatic test pressure so that every point in the system is not less than 1.5 times the design pressure, but shall not exceed the maximum allowable test pressure of any nonisolated component in the system.

4-9.1.4 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.

4-9.1.5 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.

4-9.2 Pneumatic Tests

4-9.2.1 Limitations

(a) Pneumatic testing shall not be used in lieu of other means of leak testing except as limited in para. 4-9.2.3, or when one or more of the following conditions exist:

(1) when owner's specification requires or permits the use of this test as an alternative;

(2) when piping systems are so designed that they cannot be filled with water;

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TABLE 4-8.1 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.
(f) Nondestructive examinations specified above do not apply to components made to standards listed in Table 126.1 of ASME B31.1.

(3) when piping systems are to be used in service where traces of the testing medium cannot be tolerated, e.g., lines to gas analyzers.

4-9.2.2 Test Medium. The gas used as the test medium shall be oil free, nonflammable, and nontoxic. 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.

4-9.2.3 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. 4-9.2.2 and 4-9.2.7.

4-9.2.4 Test Pressure. The pneumatic test pressure shall be not less than 1.2 nor more than 1.5 times the design pressure of the piping system. The test pressure shall not exceed the maximum allowable test pressure of any nonisolated component in the system.

4-9.2.5 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.

4-9.2.6 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.

4-9.2.7 Examination. Examinations for leakage detected by a soap bubble or equivalent method shall be made of all joints and connections. The piping system, exclusive of possible localized instances at valve packings, shall show no evidence of leaking, except that for oxygen systems detectable leaks shall not be permitted at any location.

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MANDATORY APPENDIX I
CERTIFICATION FORMS FOR ACRYLIC WINDOWS

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Appendix I

ENCLOSURE 1
ACRYLIC WINDOW DESIGN CERTIFICATION

Window Description **Window Drawing No.**_____

Maximum allowable working pressure _____psi_____MPa

Maximum design temperature _____°F_____°C

Minimum design temperature _____°F_____°C

Window shape _____

Conversion factor table number _____

Pressure range, N _____

Conversion factor, CF _____

Short-term critical pressure and fig. no. _____

Experimental verification[Note (1)] No. 1_____No. 2_____

Thickness t (actual) _____

D_o (actual) _____ No. 3_____No. 4_____

D_i (actual) _____

Water temperature____°F____°C 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) _____

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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, Article 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.

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Appendix I

ENCLOSURE 2
MATERIAL MANUFACTURER'S CERTIFICATION FOR ACRYLIC

The _____ centimeters × _____ centimeters acrylic sheet/custom castings of _____ centimeters 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 2-3.1, 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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Appendix I

ENCLOSURE 3
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 _____ (material manufacturer) under the trademark of _____ possess the following physical and chemical properties:

Test Method	Property	Results
ASTM D 621	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	_____
ASTM E 308	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 2-3.2 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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Appendix I

ENCLOSURE 4
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 Section 2, Article 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, Article 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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MANDATORY APPENDIX II
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 are to be used.

ASME Boiler and Pressure Vessel Code
ASME B31.1, Power Piping
ASME B1.20.1, Pipe Threads, General Purpose (Inch)
ASME B36.10M, Welded and Seamless Wrought Steel Pipe
ASME B36.19M, Stainless Steel Pipe

Publisher: The American Society of Mechanical Engineers (ASME International), 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 621, Test Methods for Deformation of Plastics Under Load
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

Publisher: American Society for Testing and Materials (ASTM), 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959

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

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

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

Naval Ships' Technical Manual NAVSEA 0901-LP-450-0002 (change 1), Chapter 9450, "Lubricating Oils, Greases and Hydraulic Fluids, and Lubricating System," September 1, 1967 (changed October 15, 1976)

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MANDATORY APPENDIX III
REPAIR OF DAMAGED WINDOWS PRIOR TO BEING PLACED IN SERVICE

III-1

New fabricated windows that do not meet acceptance criteria of Section 2, Article 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 Appendix are met.

III-2

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

III-3

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

III-4

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.

III-5

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

III-6

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.

III-7

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 (appendix I, enclosure 1) and the Fabrication Certification (Form PVHO-2).

(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, Article 4.

(e) Upon completion of repair, the window is to be annealed according to the schedule of Table 2-4.1.

(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.

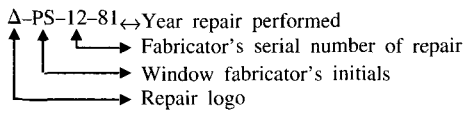
(g) Repair windows shall be marked with the identification of the window fabricator performing the repair.

(h) The repair identification shall consist of 0.5 in. letters and numbers made with indelible black marker,

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or 0.125 in. 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 example below:



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 which 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.

III-8

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; and

(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, and

(2) only two repaired spots are permitted.

(e) After completion of machining and polishing operations, the window is to be annealed per para. 2-4.4.

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

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Appendix III

ENCLOSURE 1
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 Attached Appendix I, Enclosure 1)

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 Form PVHO-2)

Original fabrication certification prepared by _____
(Name of preparer)

_____
(Name of fabricator)

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Fabricated according to drawing _____

Identification marking _____

Actual minimum thickness t _____

Actual inside diameter D_i _____

Actual outside diameter D_o _____

4 Repair Instructions

Refinish the following surfaces

High pressure face _____

Low pressure face _____

Bearing surfaces _____

Beveled edges _____

Sealing surfaces _____

Spot casting meeting requirements of paras. 2-3.10 and III8 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 _____

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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 to Appendix III, Enclosure 1 _____ (Yes) _____ (No)

Minimum thickness of repaired window _____

The minimum thickness t 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 (Appendix I, Enclosure 1).

_____

Authorized representative of window fabricator

_____

Name and address of window fabricator

_____

GENERAL NOTES:

(a) The data for Parts 1 through 4 of this enclosure 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.

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MANDATORY APPENDIX IV
DEFINITIONS

acrylic: methyl methacrylate plastic possessing physical and mechanical properties shown in Tables 2-3.1 and 2-3.2.

actual values: dimensions and angles of fabricated chamber components as measured during quality control inspection at 70°F–75°F material temperature range.

breathing gas service: any line which 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 which 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. The chamber may be pressurized internally, externally, or both. Diving bells, decompression chambers, altitude chambers, medical chambers whether fixed or transportable, submersible pilot spheres, and submersible lock-out compartments are all considered chambers under this Standard.

chamber system: two or more chambers intended to function as an operational unit. For purposes of this Standard, each compartment in a multicompartment vessel that is capable of occupancy by humans at a pressure different from the pressure in other compartments is considered a chamber.

component: component as used in this Standard is defined as consisting of, but not limited to, items such as pipe, piping subassemblies, parts, valves, strainers, relief devices, fittings, etc.

conversion factor (CF): an empirical ratio of short-term critical pressure to design pressure specified on the basis of long experience as the safe relationship between the two variables for a given temperature.

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: the dimension of inclusion or scratch that cannot be exceeded. For inclusions it is diameter or length, whichever is largest. For scratches it is the maximum depth measured from the smooth surface to the bottom of the scratch.

critical location: the location where inclusions or scratches whose size exceeds the significant dimension cannot be tolerated.

critical pressure: hydrostatic pressure that, acting on one side of the window, causes it to lose structural integrity and ability to remain impermeable to water.

critical size of population: total number of inclusions or total length of scratches with significant dimensions that cannot be exceeded in a finished window.

critical spacing: the minimum allowable spacing between peripheries of inclusion or scratches with significant dimensions in a finished window.

custom casting: a casting of any shape that is not carried as a standard production item in a manufacturer's sales catalog.

cyclic fatigue life: the number of pressure cycles that a window must withstand prior to catastrophic failure when pressure cycled to design pressure in design temperature environment. This Standard defines the cyclic fatigue life as 10^4 standard pressure cycles.

cyclic proof pressure (CPP): the pressure that a window must withstand without cracking under intermittent pressurization in the form of 1000 standard pressure cycles (4 hr long pressure phase followed by 4 hr long relaxation phase) in design temperature environment. This Standard defines cyclic proof pressure as equal to design pressure.

cylindrical window: a window consisting of a tube with circular cross section.

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design qualification: an experimental procedure for verifying the conformance of a nonstandard window design to mandatory structural requirements of this Standard.

elastomer: a natural or synthetic material which 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.

fpm: a rate of pressure change equivalent to 1 ft seawater/min (0.445 psi/min).

fsw: pressure equivalent to 1 ft seawater (0.445 psig/fsw).

full-scale window: a window, all of whose dimensions are identical to the window in actual service.

helium service: any portion of a piping system which may contain gases containing helium shall be considered to be in helium service.

inclusion: a foreign substance in the body of acrylic. An inclusion may take the form of a void, a grain of sand, a pebble, or chunk of plaster, or a piece of silicone rubber that flaked off from the mold.

inventory control identification: 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. All breathing gas systems are considered life-sensitive systems.

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: identification affixed by the manufacturer of plastic to all castings constituting a lot of material.

lot of material: 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.

manufacturer of plastic: the party who converts methyl methacrylate resin into acrylic castings, and who provides Material Manufacturer's Certification for Acrylic (appendix I, enclosure 2), and may also provide Material Testing Certification for Acrylic (appendix I, enclosure 3).

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.

material testing laboratory: the party who tests material specimens cut from plastic casting and provides Material Testing Certification for Acrylic (appendix I, enclosure 3).

MAWP: maximum allowable working pressure.

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.

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.

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 which may contain a gas containing over 25% by volume oxygen shall be considered to be in oxygen service.

personal breathing equipment: breathing apparatus carried on the wearer's person such as SCUBA gear, umbilical supplied helmets, etc. For purposes of this Standard, the boundary between *PVHO piping systems* as defined in this Standard and excluded *personal breathing equipment* occurs at the normal disconnection point closest to the apparatus. For underwater breathing apparatus, that point will normally be the point where the umbilical connects to the breathing apparatus. For

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devices where the umbilical or *supply hose* is an integral part of the device (such as is often the case with medical masks), or is disposable, that point will normally be the point where the hose or hoses connect to the permanently installed parts of the PVHO piping system.

pipe and tube: The fundamental difference between pipe and tube is the dimensional standard to which each is manufactured. A pipe is a tube with a circular cross section conforming to the dimensional requirements for nominal pipe size as tabulated in ASME B36.10M, Table 2 and ASME B36.19M, Table 2. For special pipe having a diameter not listed in these tables, and also for round tube, the nominal diameter corresponds with the outside diameter. A tube is 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.

piping: refers to all circular cross section conduit 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.

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 laboratory: the party who pressure tests windows installed in viewport flanges and provides pressure testing certification.

pressure vessel for human occupancy: a chamber that encloses a human being within its pressure boundary while it is under internal or external pressure, regardless of the pressure magnitude. Examples are submersibles, diving bells, personnel transfer capsules, decompression chambers, recompression chambers, hyperbaric chambers, high altitude chambers, and medical hyperbaric oxygenation facilities. This does not include nuclear reactor containments, pressurized airplane and aerospace vehicle cabins, and caissons.

saturation: any manned exposure to pressure in a chamber where the normally resultant decompression obligation exceeds 12 hr, any exposure which exceeds 12 hr and has a resultant decompression obligation, or any exposure to pressure in excess of 24 hr regardless of cause or pressure.

scratch: a mark on the smooth surface of a window. Its origin may be a deep cut by machining tool, or contact with a sharp object during handling.

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): the pressure required to catastrophically fail a window at a 650 psi/min (4.5 MPa/min) pressurization rate in 70°F–77°F (21°C–25°C) ambient temperature 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: 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 elastomer components used in a piping system.

standard temperature: the range of material temperatures from 70°F–75°F (21°C–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.

supplier of 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

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from performing the functions of plastic manufacturer, material testing laboratory, window designer, window fabricator, and pressure testing laboratory, providing that these functions generate the required certifications.

tube: see *pipe and tube.*

tube fitting, brazed: any tube or pipe fitting which is attached to the pipe or tube by means of a brazing process.

tube fitting, compression: any tube fitting which grips the tube by means of one or more ferrules which compress or swage the end of the tube without creating a definite notch in the tube wall.

tube fitting, flare: any tube fitting which grips the tube by means of a flare which is applied to the end of the tube by mechanical means.

tube or pipe fitting, bite type: any tube fitting which grips the tube by means of one or more teeth which bite or dig into the outside diameter of the tube creating a definite notch.

tube or pipe fitting, welded: any tube or pipe fitting which is attached to the tube or pipe by means of a welding process.

viewport: a penetration in the pressure vessel including the window, flange, retaining rings, and seals.

window: a transparent, impermeable, and pressure resistant insert in the viewport.

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MANDATORY APPENDIX V
OFF-GASSING TESTS FOR HOSES USED FOR BREATHING GAS SERVICE

V-1 BACKGROUND

Some compounds 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.

V-2 DEFINITIONS

hydrocarbons: for the purposes of this Appendix, all organic compounds detectable by a total hydrocarbon analyzer.

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, at standard conditions.

mg/m^3: milligrams per cubic meter, at standard conditions.

standard conditions: 73.4°F (23°C) and 14.7 psia (760 mm mercury).

total hydrocarbon analyzer: any suitable process analyzer employing a hydrogen flame ionization detector (FID) having a range of from 0 to at least 1000 mg/m^3 methane equivalents.

V-3 PROCEDURE

V-3.1

Off-gassing measurements shall be made only on hoses which have not been flushed with air, gas, or water, or which have been stored at a temperature not lower than 73°F (22.8°C) for a period of at least 7 days since the hoses were last flushed or opened to the atmosphere. During the 7 day storage period, the ends of the hoses shall either be sealed shut or fastened together so that the confined gas cannot escape. 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.

V-3.2

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 L per min (1 cu ft per min). The temperatures of the test hose, air supply, and analyzer shall not be less than 73°F (22.8°C). A diagram of the flow arrangement is shown in Fig. V1. Before the air passes through the test hose, the air shall be clean and shall contain not 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 airstream passed through it. For the ensuing 15 min, readings of the hydrocarbon concentration shall be recorded frequently, if not continuously. The test hose shall be rated on the reading at the end of the 15 min test period. Hoses which contaminate the air by greater amounts than specified in Table V1 shall not be acceptable.

V-4 REFERENCES

MIL-H-2815 (SHIPS), "Hose Assemblies, Rubber, Diver's Breathing Air and Gas Supply," June 2, 1978.

Publisher: Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402-9325

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TABLE V1
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

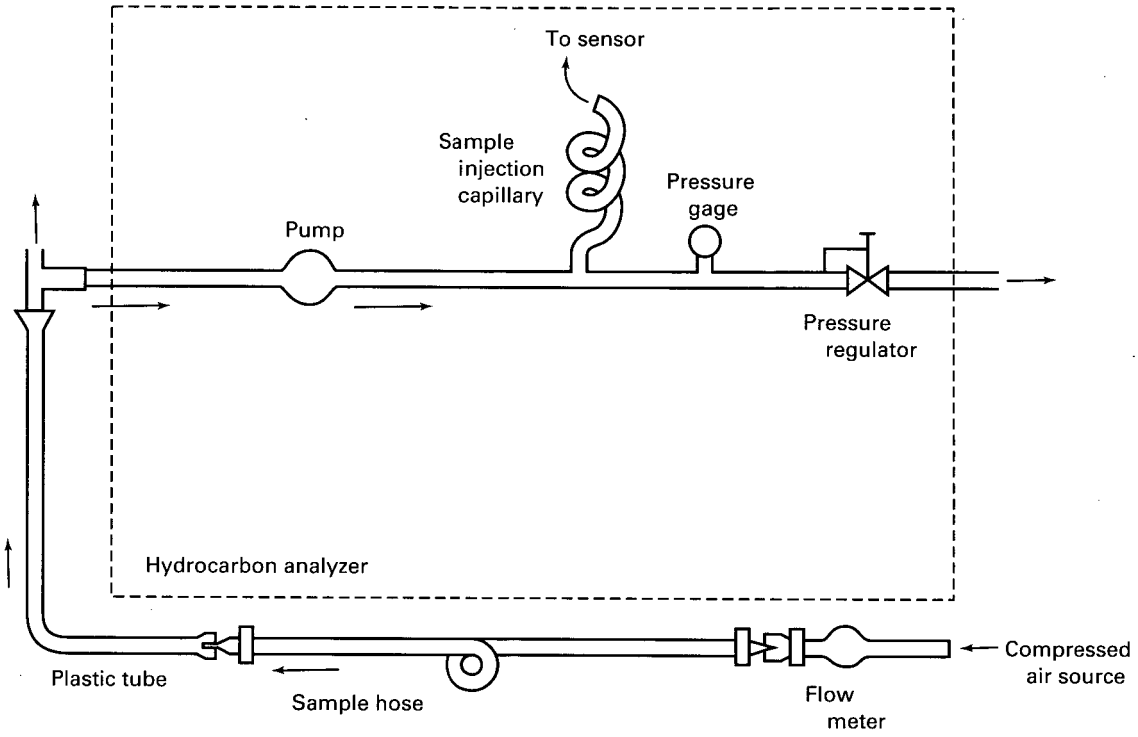


FIG. V1 FLOW DIAGRAM OF APPARATUS FOR MEASURING THE CONCENTRATION OF HYDROCARBONS IN A STREAM OF AIR OR OTHER GAS AFTER IT HAS PASSED THROUGH A TEST HOSE

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NONMANDATORY APPENDIX A
DESIGN OF SUPPORTS AND LIFTING ATTACHMENTS

The designer should consider using the provisions of the following studies, which appear in *Pressure Vessels and Piping: Design and Analysis, Volume Two — Components and Structural Dynamics*, The American Society of Mechanical Engineers, New York, 1972.

(a) "Local Stresses in Spherical and Cylindrical Shells Due to External Loadings," K. R. Whichman, A. G. Hooper, and J. L. Mershon, reprinted from Welding Research Council Bulletin 107, 1968.

(b) "Stresses in Large Horizontal Cylindrical Pressure Vessels on Two Saddle Supports," L. P. Zick, reprinted from Welding Journal Research Supplement, 1971.

The use of these provisions shall not negate Code requirements.

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NONMANDATORY APPENDIX B
GUIDELINES FOR APPLICATION OF THE REQUIREMENTS OF SECTION 2 TO ACRYLIC WINDOWS

B-1 INTRODUCTION

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

(b) Severe 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 (see para. 2-1.4). 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 (see para. 2-1.7).

(c) Only high quality cast acrylic (polymethyl methacrylate) is acceptable as the material for fabrication of windows under this Standard. To preclude unintentional substitution during fabrication process of lesser quality acrylic, the conformance of the material to the specifications of this Standard must be proven by testing of material coupons (see Section 2, Article 3) and certified (Appendix A, Enclosures 2 and 3).

B-2 SAMPLE DESIGN PROCEDURE

(a) The design of windows according to this Standard follows a simplified procedure developed for the engineer with little knowledge of acrylic window technology. The design procedure consists of a series of steps which rapidly allow the engineer to design a window meeting the requirements of this Standard (see Section 2, Article 2).

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

Step 2. Select the desired window shape from available standard window geometries (Figs. 2-2.1 through 2-2.4). 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 (a), (b), and (c) 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 2-2.1 through 2-2.4). 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 which relates the short-term critical pressure to the window's dimensionless ratio (Figs. 2-2.5 through 2-2.16). Draw a horizontal line from the appropriate STCP on the ordinate to the graph and 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 2-2.6 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

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the nominal dimensions and specify surface finishes on the window (see para. 2-2.12). Enter all applicable data on drawing and appendix I, enclosure 1.

(b) The windows can achieve the predicted short-term critical pressures 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 the seat cavity dimensions on the basis of Figs. 2-2.20 through 2-2.27. 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 0–2500, 2500–5000, 5000–7500, and 7500–10,000 psi. For operational pressures above 10,000 psi (69 MPa), utilize Table 2-2.6.

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 through 2-2.10, 2-2.16, 2-2.21, and 2-2.24 through 2-2.27. Select the most appropriate sealing arrangement for your operational conditions. The bevels on the edges of windows cannot exceed the limits shown on Figs. 2-2.28 and 2-2.29.

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

B-3 SAMPLE PURCHASE SPECIFICATION AND PRODUCT REVIEW

The designed window, in order to achieve the short-term critical pressure, must be fabricated by an accredited window fabricator utilizing materials and a production process that meet the requirements of Section 2, Articles 3 and 4, respectively.

Step 1. Request for quotation and all drawings should 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, enclosure 1 (appendix I), filled out by the window designer. Enclosure 1, 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, Article 4). Review all of the paperwork which must accompany the window (Form PVHO-2 and appendix I, enclosures 1, 2, and 3). Check for completeness and signatures. Compare the marking on the window bearing surface with: (a) the identification number on the Fabrication Data Report Form PVHO-2; and (b) the design temperature and pressure on the Acrylic Window Design Certification, Enclosure 1. Only when the window complies with the requirements imposed by this Standard, and the accompanying Window Certification, Form PVHO-2, and Enclosures 1, 2, and 3 are complete, can the fabricator be considered to have met all of the contractual obligations imposed by the above note on the window drawing.

B-4 SAMPLE PRESSURE TEST INSTRUCTION

The window can now be installed into the 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, Article 7, for details of pressure testing), the test must be conducted without human occupants.

Step 1. Immediately after the pressure test, inspect

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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, Enclosure 4.

Step 3. Review certifications, Enclosures 1 through 4, and Form PVHO-2 for completeness.

B-5 SAMPLE CALCULATIONS

Sample calculations of hypothetical window and window seat dimensions are presented here to illustrate the design procedure.

Step 1.1 Determine design conditions:
Design pressure = 1000 psi
Design temperature = 125°F
Window diameter = 10 in.

Step 1.2 Select window shape:
Conical frustum with 90 deg included angle (Fig. 2-2.1)

Step 1.3 Select conversion factor:
CF = 10 N = 1
(Table 2-2.2)

Step 1.4 Calculate short-term critical pressure:
STCP = CF × P = 10 × 1000
= 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. 2-2.8)

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 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. 2-2.20)

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 J. 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
D_o = 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. 2-2.8). The magnitude of the bevel cannot exceed the limits shown in Fig. 2-2.28. The size of the bevel chosen will provide adequate compression to a nominal 0.25 in. diameter O-ring.

Step 3.2 Enter following dimensions on drawing.
Final Viewport Dimensions
Window:
D_o = 18.400 +0.00/−0.020 in. (to sharp edge)
D_o = 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 = 1/4 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

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NONMANDATORY APPENDIX C
RECOMMENDATIONS FOR THE DESIGN OF THROUGH-PRESSURE BOUNDARY PENETRATIONS

C-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.

C-2 PENETRATOR DESIGNS

Figure C-2.1 shows four basic penetrator designs intended principally for services as follows:

(a) full coupling intended for standard threaded pipe couplings or a special coupling dictated by the Design Specification. For most applications, a standard 6000 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 6000 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.

C-3 COUPLING DETAILS

Figure C-3.1 shows four acceptable coupling details.

C-3.1 Threaded Couplings

(a) NPT (National Pipe Thread) 6000 psi Coupling. For marine systems the coupling material should be a stainless steel per para. C-4. The heavy wall of the 6000 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.

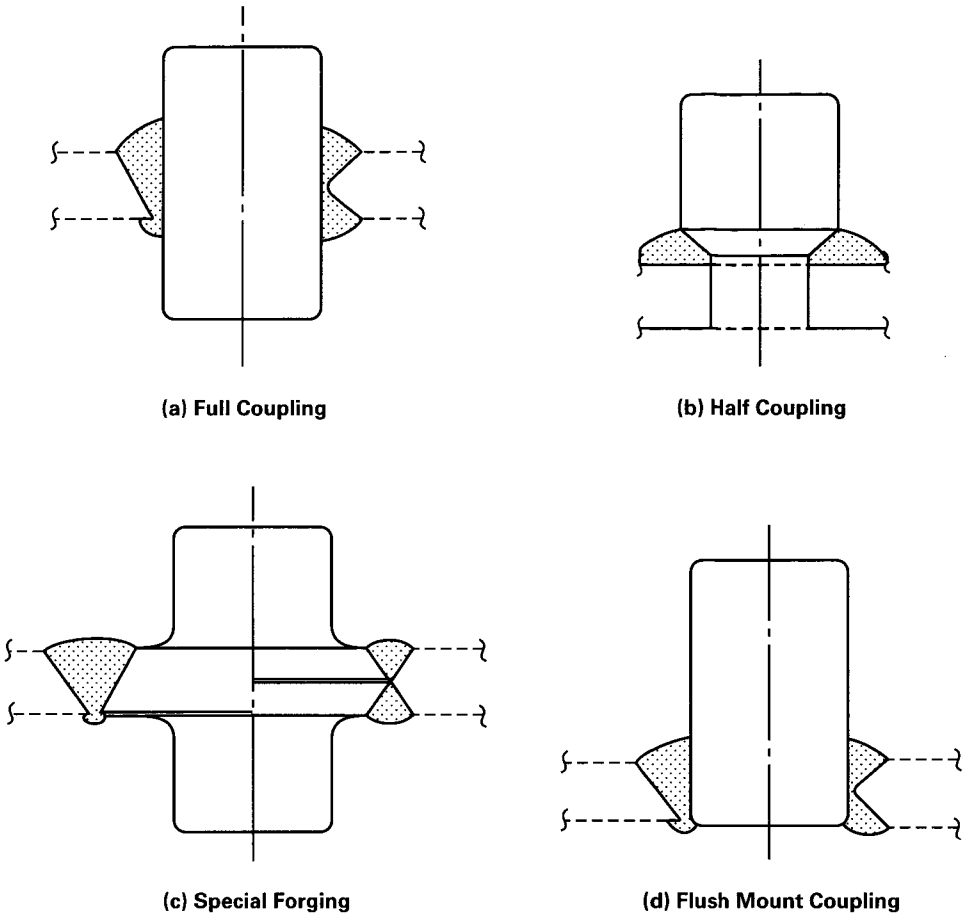
C-3.2 Threaded Insert Couplings

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.

C-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.

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(a) Full Coupling

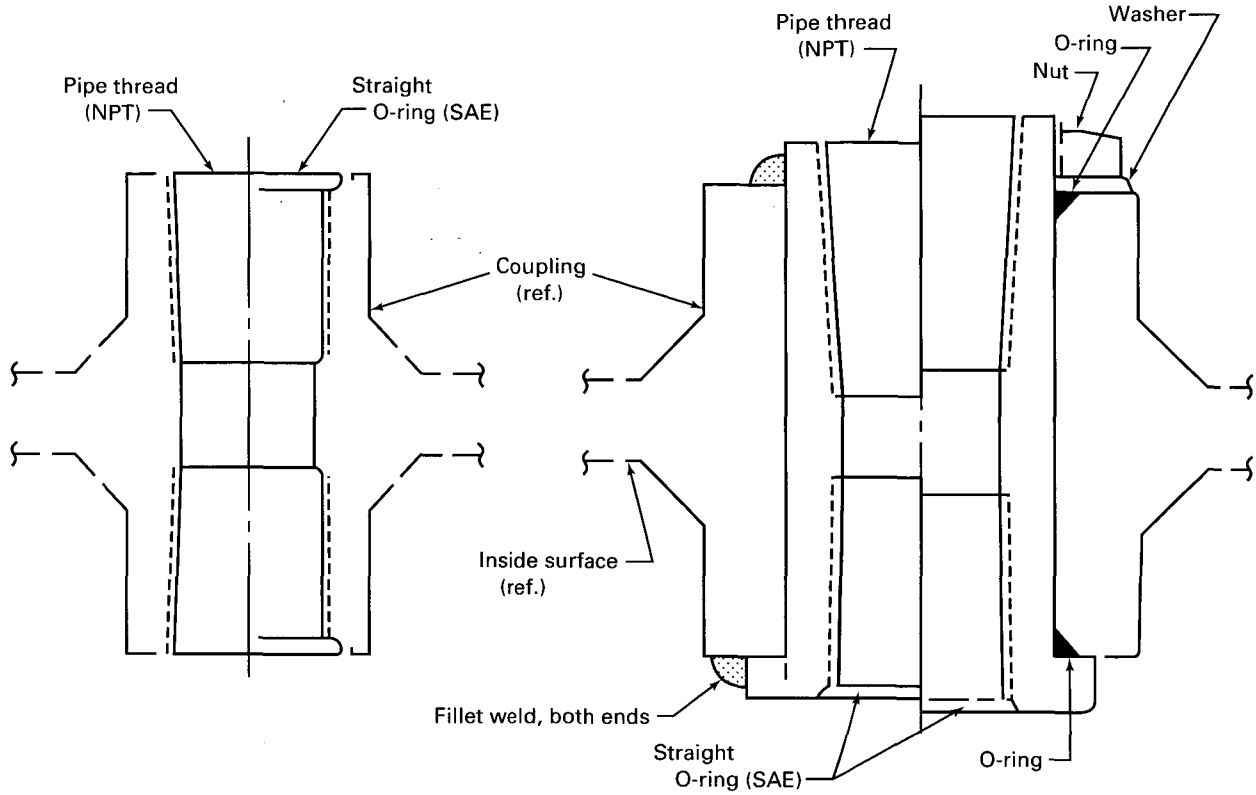
(b) Half Coupling

(c) Special Forging

(d) Flush Mount Coupling

FIG. C-2.1 ACCEPTABLE WELD NOZZLE PENETRATORS (2 in. Pipe and Under)

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(a) Threaded Couplings **(b) Threaded Insert Couplings**

FIG. C-3.1 ACCEPTABLE THREADS AND INSERTS

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NONMANDTORY APPENDIX D
RECOMMENDED PRACTICES FOR COLOR CODING AND LABELING

All piping and gas storage bottles should be colored and labeled to indicate content, maximum allowable working pressure, and direction of flow. Except for certain pipe materials such as stainless steel, the color should be a continuous coat of paint. For stainless steel and similar corrosion-resistant materials, color coding may be a 1 in. band of paint or tape. Bands should be applied at every bend and intersection, and at each side of obstructions. To aid in tracing the pipe, a minimum of three bands should be visible at any location. In addition to color coding, piping should be labeled with the name and/or symbol of its contents, direction of flow, and maximum allowable working pressure. This labeling should be applied at every intersection and at each side of obstructions. For labeling, a color which contrasts with that of the pipe should be used. Tables D-1 and D-2 give the color codes required by the U.S. Navy and International Maritime Organization (IMO). Other color codes may also be used.

TABLE D-1
U.S. NAVY

Name	Designation	Color
Oxygen	O_2	Green
Nitrogen	N	Light Gray
Air (Low Pressure)	ALP	Black
Air (High Pressure)	AHP	Black
Helium	He	Buff
Helium–Oxygen Mix	He–O_2	Buff and Green

GENERAL NOTE: Taken from *U.S. Navy Diving Manual NAVSHIPS 0994-001-9010.*

TABLE D-2
IMO

Name	Symbol	Color
Oxygen	O_2	White
Nitrogen	N_2	Black
Air	Air	White and Black
Carbon Dioxide	CO_2	Gray
Helium	He	Brown
Oxygen–Helium Mix	O_2–He	White and Brown

GENERAL NOTE: Taken from *IMO Resolution A536,* "Code of Safety for Diving Systems."

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ASME PVHO-1 CASES

(These Cases are not part of ASME PVHO-1 and are included for information only.)

The Pressure Vessels for Human Occupancy Committee meets regularly to consider proposed additions and revisions to the Standard and to formulate Cases to clarify the intent of existing requirements or provide, when the need is urgent, rules for materials or constructions not covered by existing rules in the Standard. Those Cases which have been adopted will appear in the next edition.

A Case is the prescribed form of reply to an inquiry when study indicates that wording in the Standard needs clarification or when the reply modifies existing requirements of the Standard or grants permission to use new materials or alternative constructions. Proposed Cases are published in *Mechanical Engineering* for public review. In addition, the Case will be published as part of the subscription service to PVHO-1.

A Case is normally issued for a limited period, after which it may be reaffirmed, incorporated into the Standard, revised, or allowed to expire if there is no indication of further need for the requirements covered by the Case. However, the provisions of a Case may be used after its expiration or withdrawal, provided the Case was effective on the original contract date or was adopted before completion of the work, and the contracting parties agree to its use.

Requests for interpretation and suggestions for revision should be addressed to the Secretary, ASME PVHO Committee, The American Society of Mechanical Engineers, Mail Stop 20S2, Three Park Avenue, New York, NY 10016-5990.

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PVHO Case 2-1
Annealing Requirements for PVHO Acrylic Windows Under 1 in. Nominal Thickness

Approval Date: May 15, 1992
Expiration Date: May 15, 1995

This Case has been allowed to expire.

PVHO Case 3
Annealing of Windows After Initial Machining

Approval Date: July 3, 1991
Expiration Date: July 3, 1994

This Case has been allowed to expire.

PVHO Case 4
Increased Cyclic Life for Windows

Approval Date: July 30, 1992
Expiration Date: July 30, 2004

Inquiry: As an alternative to the provisions of para. 2-1.3(d) of PVHO-1, is it possible to increase the number of design pressure cycles for windows in excess of that stated in PVHO-1?

Reply: It is the opinion of the Committee that for standard geometry PVHO viewports having a design pressure of less than 2000 psi, 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 (0) to design pressure to determine whether its cyclic 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 which 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

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tolerances are allowed, provided that the deviations do not exceed ±10°F (5.5°C) and last less than 10 min within each 24 hours 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) Presence of 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 life of 10,000 cycles, an extension of one (1) cycle may be granted by the Standard for each two (2) test cycles after completion of the first 10,000 cycles, up to failure of the test window.

(i) This Case number (PVHO Case 4), along with the maximum number of design pressure cycles, shall be shown on the Window Certifications.

PVHO Case 5
Alternative Rules to the Provisions of Paras. 1.2.3, 2-6.2, 2-6.3, 3-3.1, and 3-3.9, Requirements for the Purchase of Acrylic Windows

Approval Date: June 14, 1993
Expiration Date: November 20, 1996

This Case has been allowed to expire.

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PVHO Case 6
Use of Nonmetallic Vessels Under PVHO

Approval Date: September 11, 1999
Expiration Date: September 11, 2005

Inquiry: Under what conditions may nonmetallic flexible chambers be used in construction under the rules of PVHO-1?

Reply: It is the opinion of the Committee that portable nonmetallic flexible chambers may be constructed under the requirements of PVHO-1, and be marked only as a PVHO vessel for emergency use when the requirements of PVHO-1, with the following exceptions, have been met.

1 GENERAL

(a) The rated pressure is not greater than 31 psig.

(b) The maximum inside diameter is 24 in.

(c) The maximum length is 96 in.

(d) The vessel is a cylindrical vessel with removable end closures (windows).

(e) The rated life of filament-wound vessels shall be 10 years from the date of manufacture.

(f) The design temperature is between 0°F and 100°F.

(g) The maximum number of occupants is one.

2 MATERIALS

Materials shall meet PVHO-1, para. 1.3, PVHO Materials, with the exception of the cylindrical shell which shall conform to Table 1.

All materials used in the manufacture of the cylindrical shell shall be supplied with documentation certifying that each lot used in the manufacture of the PVHO meets those properties listed in Table 1. Shelf life of materials shall be identified.

3 DESIGN AND MANUFACTURE

3.1 Design

The PVHO shall be designed in accordance with para. 1.2, General, of PVHO-1 with the exception of paras. 1.2.1 and 1.2.2.

3.2 Requirements

In para. 1.4 of PVHO-1, Design and Fabrication of PVHOs, the design and manufacture of the PVHO shall only be in accordance with paras. 1.4.2, 1.4.5(a), 1.4.7, and 1.4.8 of PVHO-1, and the following requirements.

(a) A detailed stress analysis shall be performed by a Professional Engineer registered in one or more of the states of the United States of America, or the provinces of Canada, or licensed by any other country that has equivalent licensing procedures, and who is experienced in composite pressure vessel design and construction.

(b) The stress analysis shall include full geometric modeling and a detailed finite element analysis of the PVHO and the cylindrical shell-to-window interface during assembly, disassembly, and under varying pressures up to a minimum of five times the rated pressure.

(c) The design analysis shall consider the effects of aging of the shell materials plus the effects of folding, unfolding, and long-term storage of the cylindrical shell. The design shall ensure that no damage will occur to the fibers within the cylindrical shell by acute bending or by bending at less than the minimum bend radius of the fiber. *Acute bending* is defined as a bend in the cylindrical shell at an inside angle of less than 5 deg. The minimum bend radius for the fiber shall be no less than 0.05 in.

(d) The cylindrical shell of the PVHO shall be manufactured using a filament winding method. The cylindrical shell shall be wound as an integral unit without seams. The end closures shall have internal reinforced flanges as an integral part of the shell. The reinforced flange shall act as the closure-retaining ring and sealing surface for the closure (window). There shall be no penetrations in the cylindrical shell of the PVHO.

(e) The cylindrical shell shall be manufactured in three stages, each of which shall require curing after completion.

(1) The inner layer shall comprise an airtight skin of 100% room temperature vulcanizing (RTV) silicone

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TABLE 1

Room Temperature Vulcanizing (RTV) Silicone Rubber (Cured)
Inner and Outer Gel Coat
Chemical Name: Vinylpolydimethylsiloxane

Test Procedure	Physical Properties	Min.	Max.
ASTM D 2240	Hardness Shore A durometer	55	65
ASTM D 412	Extension at break, %	200	...
ASTM D 412	Tensile strength, psi	700	...
ASTM D 624	Tear strength, lb/in.	85	...

Silicone Liquid Elastomer (Cured)
Main Wind
Chemical Name: Vinylpolydimethylsiloxane and Calcium Carbonate

Test Procedure	Physical Properties	Min.	Max.
ASTM D 2240	Hardness Shore A durometer	32	45
ASTM D 412	Extension at break, %	130	...
ASTM D 412	Tensile strength, psi	100	...

Main Wind
Continuous Polyparaphenylene Terephthalamide Fiber

Test Procedure	Physical Properties	Min.	Max.
ASTM D 2343	Tensile strength, ksi	450	580
ASTM D 2343	Strength (breaking), lb	380	490
ASTM D 2343	Tensile modulus, psi x 10^6	17.5	20.5
ASTM D 1907 [Note (1), (3)]	Denier (ASTM Option 5)	6675	7605
ASTM D 2257 [Note (2)]	Finish on yarn (DI-7), %	0.0	1.2
ASTM D 1505	Density, g/cc	1.4	1.5

NOTES:
(1) Zero twist, zero moisture, finish free.
(2) Using IR spectrophotometer, substitute ASTM method is Sozhlet extraction.
(3) One tex equals 9 denier or 10 decitex.

rubber applied directly onto a suitably prepared collapsible mandrel.

(2) The middle layer shall comprise several windings of continuous uncut polyparaphenylene terephthalamide (para-aramid) fiber that has been treated with a 100% silicone liquid elastomer. The winding process shall ensure that the fiber is completely coated with the elastomer and that there are no areas of unbonded fiber within the cylindrical shell.

(3) The outer layer shall comprise 100% RTV silicone rubber.

(f) The design and manufacturing process shall produce a cylindrical shell such that the inner layer, outer layer, and the para-aramid fibers will not be damaged by the assembly, pressurization, disassembly, or storage of the PVHO.

(g) The rated pressure shall be based on a minimum ratio of burst pressure to rated pressure of 5:1.

(h) The windows shall meet the requirements of PVHO-1, Section 2, Viewports, with the exception of para. 2-2.9, Viewport Flanges. The design of the viewport flange shall be conducted as a part of the stress analysis requirement of para. 3.2(b) of this Case.

(i) The windows shall be fitted with an endless nylon bead ring secured to the windows with a retainer rigidly attached to the bead ring and sealed with an "O" ring. The bead ring shall seal against the reinforced integral flange of the cylindrical shell.

(j) In lieu of the requirements of para. 4-7.6.1, Breathing Gas Outlets, the number of breathing gas outlets shall be one.

(k) Any changes to the design or manufacturing

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procedures of the cylindrical shell shall be cause for full prototype retesting.

3.3 Design Certification

Conformance of the design of the PVHO to the requirements of PVHO-1 shall be established by one of the two following procedures.

(a) A professional engineer registered in one or more of the states of the United States of America, or the provinces of Canada, or licensed by any other country that has equivalent licensing procedures, and who is experienced in composite pressure vessel design shall certify that the PVHO was designed either by him or under his direct supervision, or that he has thoroughly reviewed a design prepared by others, and that to the best of his knowledge, the PVHO complies with PVHO-1 and this Case.

(b) The design of the PVHO shall be reviewed by an independent third party agency competent in PVHO systems, and such organization shall provide a certificate that the PVHO complies with PVHO-1 and this Case.

4 TESTING

All tests shall be witnessed by the purchaser/owner/user and/or by an independent third party agency designated by them. In lieu of the requirements of PVHO-1, para. 1.5, Inspection and Tests of PVHOs, the following requirements shall apply.

4.1 Prototype Testing

(a) A hydrostatic test to failure shall be performed on at least one completely assembled PVHO of the same design, shape, and form. Failure of the vessel under hydrostatic test shall occur at a pressure equal to or greater than five times the rated pressure. Failure shall only be by leakage caused by a breakdown of the RTV liquid elastomer in the cylindrical shell. Failure of the acrylic window, the nylon bead ring, the window insert, or the release of a window through the reinforced flange of the cylindrical shell shall be cause for failure of the prototype design.

(b) A drop test of at least one PVHO on concrete shall be conducted without failure. The PVHO shall be fitted with windows and loaded with 165 pounds of bagged sand and then pressurized to the rated pressure. The PVHO shall be inclined at 45 deg and elevated to a height such that the minimum distance to the concrete impact surface is 3 ft, and then dropped. No leakage, damage, or permanent distortion of the PVHO is permissible.

(c) A cyclic hydrostatic pressure test of at least one completely assembled PVHO shall be conducted for a minimum of 4,000 cycles. The test shall comprise pressurization from zero to rated pressure and back to zero. The cycling time shall be between 10 and 100 sec per cycle. A 1 psi residual pressure is permissible to retain the windows in position. In order to establish the maximum number of cycles satisfactorily completed on the chamber under test, the pressure retention properties of the vessel shall be checked at agreed cyclic levels for leakage. At these levels, the PVHO shall be subjected to satisfactory completion of testing as in para. 4.2 of this Case, Production Testing. Should leakage occur during cyclic testing or at a cyclic level, then the maximum number of cycles achieved at the previous cyclic level shall be the cyclic limit for the chamber.

(d) A cold storage test demonstrating that the chamber can be assembled and inflated at minimum operating temperature shall be conducted.

(e) Cylindrical shells and windows used for prototype testing in (a), (b), and (c) above shall not be used in a production PVHO.

(f) Production chambers of this design, shape, and form may then be used for up to 25% of the number of cycles completed on the prototype PVHO.

4.2 Production Testing

(a) Every completely assembled PVHO shall be subjected to a hydrostatic test at a pressure of 1.5 times the rated pressure and held for a period of 1 hr without leakage.

(b) Every completely assembled PVHO shall be subjected to an air test at the *rated* pressure and held for a period of 1 hr with an allowable pressure loss not to exceed 1% of the rated pressure. Internal and external air temperatures shall be measured and recorded at the end of each air test so that compensation may be made for any temperature differences.

(c) As an alternative to (a) and (b), a completely assembled PVHO shall be subjected to a pneumatic test at a pressure of 1.5 times the rated pressure and held for a period of 1 hr. The pressure loss shall not exceed 1% of the test pressure of the PVHO. Temperature compensation shall be accomplished as in (b).

Following (a) and (b) or (c), the PVHO will be inspected for damage to the sealing areas and be subjected to a dimensional check. Any permanent change will be grounds for rejection of the PVHO components.

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5 QUALITY ASSURANCE PROGRAM

5.1 General

In lieu of the requirements of PVHO-1, para. 1.2.2, a Quality Assurance Program shall be developed for the design and manufacture of the PVHO. The Quality Assurance Program shall be reviewed and accepted by the purchaser/owner/user and/or an independent third party inspection agency designated by them. This section sets forth the requirements for establishing and maintaining a Quality Assurance Program to control the quality of work performed by the manufacturer of the PVHO.

5.2 Organization

(a) The manufacturer shall have a documented organizational structure, with responsibilities, authorities, and lines of communication clearly delineated in writing for activities affecting quality. Persons or organizations responsible for the Quality Assurance Program shall have authority and organizational freedom to

(1) identify problems affecting quality;

(2) initiate, recommend, or provide solutions to quality problems, through designated channels;

(3) verify implementation of solutions; and

(4) control further processing, delivery, or assembly of a nonconforming item, deficiency, or unsatisfactory condition until proper corrective action has been taken.

(b) The necessary scope and detail of the system shall depend on the complexity of the work performed and on the size and complexity of the manufacturer's organization (including factors such as number and experience level of employees and number of PVHOs produced).

5.3 Quality Assurance Program

(a) A documented program for the assurance of quality of activities, items, and services shall be planned, implemented, and maintained in accordance with specified requirements of PVHO-1.

(b) The program shall apply to activities, materials, parts, assemblies, and services which affect the quality of the PVHO. It need not apply to other activities, products, and services at the same location.

(c) The program shall identify the PVHO activities to which it applies.

(d) The program shall provide for indoctrination and training of personnel to assure compliance with PVHO-1.

(e) Management shall, at least annually, assess the program and take corrective action, if necessary.

5.4 Quality Control Manual

(a) The Quality Assurance Program shall be described in a Quality Assurance Manual.

(b) The Quality Assurance Manual must provide a mechanism to document issuance and revision, and must include a method to identify and/or highlight the revisions.

5.5 Drawing, Design, and Specification Control

(a) The manufacturer shall establish measures to assure that PVHO design drawings and all applicable documents and requirements of PVHO-1 relative to the design of PVHOs are received from the designer, and are correctly translated into manufacturing specifications, drawings, procedures, and shop instructions for the PVHO.

(b) Procedures shall be established for the review, approval, release, distribution, and revision of manufacturing documents.

5.6 Production Control

(a) Applicable requirements necessary to assure compliance with this Case shall be specified or included in documents for procurement of materials, items, or services to be used by the manufacturer.

(b) The procurement of materials, items, and services shall be controlled by the manufacturer to assure conformance with specified requirements.

(c) These controls shall include, but are not limited to, any of the following, as appropriate:

(1) source evaluation and selection;

(2) appraisal of objective evidence of quality furnished by the supplier including all necessary material certification documents;

(3) inventory control;

(4) examination of supplied items upon delivery.

(d) Procedures for assuring continued compliance with pertinent requirements, including identification of procedural revisions, shall be described in the Quality Assurance Manual.

5.7 Identification and Control of Items

(a) Identification shall be maintained on all items or in documentation traceable to these items.

(b) Controls shall be established to prevent use of incorrect or defective items.

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(c) The manufacturer, based on his judgment, shall also maintain additional identification and documentation to assure that significant problems can be identified and proper corrective action taken.

(d) Traceability of the completed PVHO shall extend to identification of the immediate purchaser.

5.8 Control of Processes

(a) Processes affecting quality shall be controlled in accordance with specified requirements using process control documents such as process sheets and travelers.

(b) Special processes affecting quality, such as laying back, curing, and nondestructive examination, shall be performed by qualified personnel using qualified procedures referenced in this Case.

(c) All personnel performing critical manufacturing procedures shall be documented as meeting a specific criteria qualifying them to perform those procedures.

5.9 Inspection

(a) Inspection shall be planned and controlled by the manufacturer.

(b) These inspections shall verify conformance to documented instructions, procedures, and drawings describing the activities.

(c) Inspection results shall be documented.

(d) Inspection for acceptance shall be performed by qualified persons other than those who performed or supervised the work.

(e) Inspection documents shall contain appropriate criteria for determining that such activities have been satisfactorily accomplished.

5.10 Test Control

(a) Testing required to demonstrate that the PVHO will perform in accordance with this Case shall be so defined, controlled, and documented.

(b) Tests shall be performed in accordance with written instructions stipulating acceptance criteria.

(c) Test results shall be recorded on the required forms.

(d) Examination, measurement, and testing equipment used for activities affecting quality shall be controlled, calibrated, and adjusted at specified periods to maintain required accuracy.

(e) Specifications, calibration, and control of measuring and testing equipment used for acceptance shall be described in written instructions or procedures.

(f) Calibrations shall be traceable to national standards where such exist.

5.11 Handling, Storage, and Shipping

Handling, storage, cleaning, packaging, shipping, and preservation of items shall be controlled to prevent damage or loss, and to minimize deterioration, and shall be documented.

5.12 Documentation and Status of Test Activities

(a) The status of inspection and testing activities shall be indicated either on the items, or in records traceable to the items, to assure that required inspections and tests are performed.

(b) Items which have satisfactorily passed inspections and tests shall be identified.

5.13 Corrective Action

(a) Items, services, or activities which do not conform to specified requirements shall be controlled to assure proper disposition and prevent inadvertent use.

(b) Controls shall provide for identification, documentation, evaluation, segregation when practical, and disposition of nonconformances and notification to affected organizations.

(c) Conditions adverse to quality shall be promptly investigated, documented, evaluated, and corrected.

(d) In the case of a significant condition adverse to quality, the cause of the condition shall be determined and corrective action taken to preclude recurrence.

(e) The identification, cause, and corrective action planned and taken for significant conditions shall be documented and reported to appropriate levels of management.

(f) Follow-up action shall be taken to verify implementation of corrective action.

5.14 Quality Assurance Records

(a) Records shall be specified, compiled, and maintained to furnish documentary evidence that services, materials, items, and completed PVHOs meet this and applicable referenced standards.

(b) Records shall be legible, identifiable, and retrievable.

(c) Records shall be protected against damage, deterioration, or loss.

(d) Requirements and responsibilities for record transmittal, distribution, retention, maintenance, and disposition shall be established and documented.

(e) Records required for traceability shall be retained for a minimum of 12 years.

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5.15 Quality Assurance Audits

(a) The PVHO manufacturer shall schedule and perform regular internal audits to verify compliance with all aspects of the Quality Assurance Program.

(b) These audits shall be performed at least annually and be stipulated in the Quality Assurance Manual.

(c) These audits shall be performed by qualified personnel who do not have direct responsibility for performing or controlling the activities being audited.

(d) The audits shall be performed in accordance with written instructions.

(e) Audit results shall be reported to and reviewed by management having responsibility and authority to take any necessary corrective action. Follow-up action shall be taken where indicated.

5.16 Quality Assurance Overview by an Independent Third-Party Agency

An independent third-party agency shall be employed to ensure that all PVHOs intended to be classified under this Case are designed and manufactured to the requirements of PVHO-1 and this Case. This shall include but is not restricted to the following:

(a) The PVHO is designed in accordance with PVHO-1 and this Case.

(b) The manufacturer is working to the requirements of the quality control systems.

(c) The materials used in construction of the PVHO comply with approved procedures by qualified operators as required by PVHO-1 and this Case.

(d) All manufacturing operations are conducted in accordance with approved procedures by qualified operators as required in PVHO-1 and this Case.

(e) All defects are acceptably repaired.

(f) All prototype and production testing has been performed and witnessed as required by PVHO-1 and this Case.

(g) The PVHO is marked in accordance with PVHO-1 and this Case.

(h) A visual inspection of the PVHO is conducted to confirm that there are no material or dimensional defects.

The manufacturer shall arrange and give the third party inspection agency free access to all facilities associated with the manufacture of the PVHO. The manufacturer shall keep the third party inspection agency informed of the progress of the work and shall notify them reasonably in advance when PVHOs will be ready for any required tests or inspections.

6 MARKING

(a) In lieu of PVHO-1, paras. 1.2.1 and 1.6, Stamping and Reports of PVHOs, the internal surface of the cylindrical shell shall be permanently marked, close to one end, with the data required in PVHO-1, para. 1.6.1, and the following (sample) designation:

31–24–96–PVHO (CCxx)–CSC–0001–1993

where

31 = rated pressure, psig
24 = inside diameter, in.
96 = length of the vessel, in.
PVHO (CCxx) = PVHO designator and Case number
CSC = manufacturer's initials
0001 = manufacturer's unique identification for the PVHO
1993 = year of manufacture

The internal surface of the cylindrical shell shall also display the following information:

Restricted to Emergency Use Only

Maximum Working Pressure:	69 FSW/21 MSW
Operating Temperature (min./max.):	0°F/100°F
Allowable Cyclic Life:	_____ Cycles
Cylindrical Shell Expiration Date:	(DD/MM/YY)

(b) Form PVHO Case 6, Manufacturer's Data Report for Pressure Vessels for Human Occupancy, shall be completed to certify that each PVHO meets the requirements of PVHO-1 and this Case.

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FORM PVHO CASE 6 MANUFACTURER'S DATA REPORT FOR PRESSURE VESSELS FOR HUMAN OCCUPANCY

1. Manufactured and certified by _____

2. Manufactured for _____

3. Vessel identification _____ _____ _____
(mfr. serial no.) (year built)

4. The design, construction, workmanship, and chemical and physical properties of all parts meet the applicable material specifications of PVHO-1– _____ (year) and Addenda _____ (date) and Case Nos. _____ .

5. Manufactured for a maximum allowable working pressure of _____ psi, a maximum working temperature of _____ °F, and a hydrostatic test pressure of _____ psi (internal).

6. Design analysis conducted by _____

7. Windows: Certification Reports, properly identified and signed by the viewport fabricator, are attached for the following items.

No.	Location	Type	Diameter or Size	Nominal Thickness	How Attached

CERTIFICATION OF DESIGN

User's Design Specification on file at _____

Manufacturer's Design Report on file at _____

Prototype test program attested by _____

Quality Assurance Program reviewed by _____

Fabrication documentation reviewed by _____
(name and date)

Production testing witnessed by _____
(name and date)

CERTIFICATION OF COMPLIANCE

We certify that the statements made in this report are correct and that all details of the design, material, construction, and workmanship of this vessel conform to the ASME Safety Standard for Pressure Vessels for Human Occupancy (PVHO-1) and PVHO Case 6.

Date _____ Company name _____ Signed _____

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PVHO Case 7
Provisions for the Allowance of Inclusions in Acrylic Castings

Approval Date: January 4, 1999
Expiration Date: January 4, 2005

Inquiry: Under what conditions is it permissible to utilize acrylic casting with inclusions that exceed the 0.03 in. critical size mandated by PVHO standard for window shapes defined by para. 2-5.4(b)?

Reply: It is the opinion of the Committee that windows may be fabricated from acrylic castings with inclusions that exceed the 0.03 in. critical size specified by para. 2-5.4(b), 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.

(a) 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:

(1) significant dimension of the inclusion is 0.03 in. (0.8 mm);

(2) critical dimensions of the inclusions are:

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

(b) hair or cloth fibers 2 in. (50.8 mm) long;

(c) plastic foil fragments 0.15 in. long × 0.06 in. wide × 0.03 in. thick (3.8 mm × 1.5 mm × 0.76 mm);

(3) critical size of population is total volume of the casting in in.^{3} divided by 1000;

(4) critical density of inclusion population is one inclusion per in.^{3};

(5) critical spacing between adjacent inclusions is 0.25 in. (6.35 mm);

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

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

(1) the minimum tensile strength of inclusion-free tensile test specimens from the lot or 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;

(2) 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%;

(3) the minimum tensile strength must be ≥ 9,000 psi, and the window's short-term design critical pressure must exceed the requirements of this Standard by ≥ 20%.

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PVHO Case 8
Alternative Testing Requirements for Large Subatmospheric Pressure PVHO Chambers

Approval Date: January 5, 1999
Expiration Date: January 5, 2005

Inquiry: Altitude physiology training chambers are large, low differential, external pressure vessels (vessel pressure is subatmospheric) that fall under the scope of PVHO-1. Paragraph 1.5.4 of PVHO-1 requires 1.25 times external pressure test. This is not practically possible for such vessels when the design differential pressure is between 10 psia and 0 psia given the size of these chambers. Under what circumstances may large, low differential, external pressure vessels (subatmospheric) be constructed under the rules of PVHO-1?

Reply: It is the opinion of the Committee that in lieu of the requirements for all vacuum chambers to be subject to an external pressure of 1.25 times the MAWP, a chamber too large to fit in a currently operating test chamber or be practically tested in another manner (i.e., water submergence) may use the following alternate rules:

(a) The external pressure test required by para. 1.5.4 may be replaced by an internal pressure test in accordance with Section VIII, Division 1, UG-99(f).

(b) Applicability is restricted to subatmospheric pressure vessels with a maximum operating pressure differential between 10 psia and full vacuum (0 psia).

(c) Upon completion of the internal pressure test, a vacuum test to MAWP shall be conducted.

PVHO Case 9
Use of Nonmetallic Strap Reinforced Flexible Membrane Materials in PVHO Chambers

Approval Date: January 31, 2000
Expiration Date: January 31, 2003

Inquiry: Under what conditions may nonmetallic strap reinforced flexible membrane materials be used in chamber construction under the rules of PVHO-1?

Reply: It is the opinion of the Committee that chambers constructed from nonmetallic strap reinforced flexible membrane materials may be constructed under the requirements of PVHO-1 and be marked as a PVHO chamber when the requirements of PVHO-1, with the following additional requirements, have been met.

1 GENERAL

(a) The chamber shall be cylindrical with metal ends. The cylindrical portion shall consist of an inner fabric bag and an outer strap reinforcement mesh. The inner bag shall be made of a polyester cloth impregnated with urethane for gas sealing. The outer mesh is made of polyester straps. The longitudinal straps are attached and terminated at the metal ends by sewing (additional adhesive bonding may be employed). The circumferential straps are terminated by sewing end to end. The longitudinal and circumferential straps are sewn or bonded together at the crossover points.

(b) The maximum inside diameter is not greater than 60 in. Each chamber of different diameter shall be qualified using the procedures below.

(c) The maximum cylindrical length is not greater than 96 in.

(d) The MAWP is not greater than 5.4 bars gage (80 psig).

(e) The rated life of the gas-tight fabric body shall be 10 years from the date of manufacture, or manufacturer's documented shelf life, whichever is less.

(f) The design temperature is no lower than 0°F and no greater than +150°F.

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(g) There shall be no penetrations in the nonmetallic portions of the chamber.

2 MATERIALS

(a) Materials shall meet PVHO-1, para. 1.3, with the exception of the coated fabric pressure bag and straps, which shall conform to the table below. ASTM test methods shall be followed for coated fabric and straps. Material test reports shall include batch and lot information where appropriate. Viewport(s) shall meet the requirements of PVHO-1, Section 2.

Component	Physical Properties
Pressure bag	Material: 2200 denier polyester Weave: 12 × 12 per cm^2 Coating: Estane 58311 polyether-based thermoplastic polyurethane with: *(a)* tensile strength 4.9 MPa *(b)* elongation 655% *(c)* tear resistance 54 kN/m *(d)* abrasion loss 34 mm^2 Thickness: 1.2 to 1.3 mm Weft tensile strength: 193 kg/cm (min.) Warp tensile strength: 193 kg/cm (min.) Elongation: equal to or less than 20% Permeability: 1 psi loss/hr
Stress resistant strap	Type: polyester sling Working load: 2,500 kg (min.) Breaking load: 12,500 kg (min.) Elongation: 10% (max.) Thread type: polyester
Adhesive	Tensile strength: 22.8 MPa Elongation: 700% (max.) Hardness: 45 Shore D after polymerization Elastic modulus: 37.2 MPa after polymerization

(b) All materials used in the manufacture of the cylindrical chamber shell shall be supplied with documentation certifying that each lot used in the manufacture of the PVHO meets the properties listed in the table in subpara. (a). Shelf life of materials shall be identified.

(1) Tensile and elongation tests shall be conducted at 0°F and 150°F to assure the suitability of the materials at low and high temperatures.

(2) Manufacturer's data shall indicate tensile properties of bag and strap materials, and adhesive variation over time.

3 DESIGN AND MANUFACTURE

3.1 Design

The PVHO shall be designed in accordance with para. 1.2 of PVHO-1 with the exception of paras. 1.2.1 and 1.2.2.

3.2 Requirements

In para. 1.4 of PVHO-1, the design and manufacture of the PVHO shall only be in accordance with paras. 1.4.2, 1.4.5(a), 1.4.7, and 1.4.8, and the following requirements.

(a) A detailed stress analysis shall be performed by a registered Professional Engineer in the United States or Canada or the equivalent in other countries, experienced in composite pressure vessel design and construction.

(b) The design analysis shall consider the effects of aging of the polyester cloth shell, longitudinal straps, and adhesive materials, plus the effects of folding, unfolding, and long-term storage of the collapsed chamber. The design shall ensure that no damage will occur to the cloth within the composite shell by acute bending or by bending at less than the minimum bend radius of the material. *Acute bending* is defined as a bend in the cloth shell at an inside angle of less than 5 deg. The minimum bend radius for the cloth shall be no less than 0.05 in. Strength reduction due to sewn or glued connections shall be based on test data and included in the analysis. Procedures are to be written as to the type of stitch, length of stitch, stitch pattern size, type of thread, and results from the break test.

(c) The cylindrical chamber shell fabric pressure bag and straps allowable stress shall be based on a minimum ratio of failure pressure to design pressure of 6:1. *Failure pressure* shall be defined as burst or a pressure loss greater than 10 psi/min as determined during the prototype test of para. 4. The design pressure of the metallic ends shall conform to ASME Section VIII, Division 1 or 2.

(d) All penetrators and viewport(s) shall be located in the metallic end(s) and shall meet the requirements of PVHO-1.

(e) Any changes to the design or manufacturing procedures of the gas-tight membrane or load containment cage shall be cause for full prototype retesting.

(f) If materials supplier data is not available, the manufacturer shall conduct tests to verify there is no toxic off-gassing of the chamber materials under pressure and that the materials are compatible with the pressurizing medium. MSDS sheets and/or other test

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documentation shall be part of the manufacturer's data report.

3.3 Design Certification

Conformance of the PVHO design to the requirements of PVHO-1 shall be established by one of the following procedures. A Professional Engineer from the United States or Canada or the equivalent in other countries, experienced in pressure vessel design, shall certify that either:

(a) the PVHO was designed either by him/her or under his/her direct supervision; or

(b) that he/she has thoroughly reviewed a design prepared by others, and that the PVHO complies with PVHO-1 and this Case.

4 TESTING

In lieu of the requirements of PVHO-1, para. 1.5, the testing program, as listed in paras. 4.1 and 4.2, shall be implemented.

All tests of paras. 4.1 and 4.2 shall be witnessed and documented by an independent third-party agency. The inspector shall certify the test results and that they comply with the testing requirements of the Case.

All testing must be conducted at the most critical temperature for which the PVHO is designed.

Alternate testing procedures may be proposed that meet the intent of PVHO-1 and the intended use of the PVHO. These procedures should be based on statistically significant sampling, recognized engineering practices, or a recognized standard acceptable to the Committee.

Any design changes or fabrication process changes will require full prototype retesting.

4.1 Prototype Testing

Units used for prototype testing cannot be used other than for testing.

4.1.1 Short-Term Proof Pressure Test (STPP). Pressure tests shall be conducted on a minimum of three full-scale prototype chambers. These prototype vessels do not have to be completely outfitted. They must, however, be full size and of identical construction to the end item, with all fabrication completed that in any manner may affect the integrity of the pressure boundary. If desired, prototype chambers that have already been cyclic pressure tested (see para. 4.1.3) may be used.

For materials whose strength is temperature sensitive, the tests shall be performed at the most critical service temperature.

The pressurization rate used for proof pressure (and cyclic testing) shall be in accordance with that stated in the user's design specifications.

Except as permitted by para. 4.1.5, failure of a vessel shall not occur at a pressure of less than six times the rated pressure (MAWP) of the PVHO.

4.1.2 Long-Term Proof Pressure Test (LTPP). For materials that exhibit time-dependent deformation (creep), the LTPP of the PVHO shall be experimentally verified with a minimum of five model-scale or full-scale PVHOs.

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

(b) Each PVHO 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 the individual PVHO shall be subjected are 0.90, 0.85, 0.80, 0.75, and 0.70 times the average short-term critical pressure established experimentally in para. 4.1.1.

(d) The experimental data points of (c) 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. 4.1.1 with zero sustained loading duration shall also be plotted on the same graph. The testing of any PVHO 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.

4.1.3 Cyclic Proof Pressure Testing. The crack-free cyclic proof pressure (CPP) of the PVHO shall be experimentally verified on a minimum of two completely assembled PVHOs of the same design, shape, and form.

The pressure test cycles shall be from ambient to the specified design pressure (MAWP) and back to ambient in a design temperature environment.

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 the intended use of the PVHO.

The number of approved operational cycles CA shall be $CA = CT/2 - 1000$, where CT is the number of test cycles.

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At the completion of the cyclic testing, the PVHO shall be visually inspected with the unaided eye (except for correction necessary to achieve 20/20 vision) for the presence of cracks. Absence of visible cracks shall be considered proof that the PVHO design meets the crack-free CPP requirement of the Standard.

4.1.4 Drop Test. A drop test of at least one PVHO on concrete shall be conducted without failure. The PVHO shall be fitted with windows and loaded with an evenly distributed load of 165 lb of bagged sand per design occupant, and then pressurized to the rated pressure. The PVHO shall be inclined at 45 deg and elevated to a height such that the minimum distance to the concrete impact surface is 3 ft, and then dropped. No leakage, damage, or permanent distortion of the PVHO is permissible.

4.1.5 Cold Storage Test. A cold storage test demonstrating that the chamber can be assembled and inflated at minimum operating temperature shall be conducted. The chamber shall be folded and stored for a minimum of 8 hr at 0°F, and then inflated to operating pressure in a period not exceeding 15 min. Pressure loss after 15 min shall not exceed 1% of the inflation pressure. Repeat test a minimum of five times.

4.2 Production Proof Pressure Testing

All production units shall be subjected to a hydrostatic or pneumatic test of 1.5 times the MAWP, and isolated from the pressure source, to be held for a minimum of 1 hr. The maximum allowable pressure loss is not to exceed 1% of the rated pressure. Internal and external temperatures shall be measured and recorded at the beginning and end of each test so that compensation can be made for any temperature differences.

Every PVHO is to be examined visually and dimensionally for damage following each test. Any signs of cracks, permanent deformation, or other damage will be cause for rejection of the PVHO.

5 QUALITY ASSURANCE PROGRAM

5.1 General

In lieu of the requirements of PVHO-1, para. 1.2.2, a Quality Assurance Program shall be developed for the design and manufacture of the PVHO. The Quality Assurance Program shall be audited and accepted by the purchaser/owner/user or an independent third-party inspection agency designated by them. This section sets forth the requirements for establishing and maintaining a Quality Assurance Program to control the quality of work performed by the manufacturer of the PVHO.

5.2 Organization

The manufacturer shall have a documented organizational structure, with responsibilities, authorities, and lines of communication clearly delineated in writing for activities affecting quality. Persons or organizations responsible for the Quality Assurance Program shall have authority and organizational freedom to

(a) identify problems affecting quality;

(b) initiate, recommend, or provide solutions to quality problems, through designated channels;

(c) verify implementation of solutions; and

(d) control further processing, delivery, or assembly of a nonconforming item, deficiency, or unsatisfactory condition until proper corrective action has been taken.

5.3 Quality Assurance Program

(a) A documented program for the assurance of quality of activities, items, and service shall be planned, implemented, and maintained in accordance with specified requirements of PVHO-1.

(b) The program shall apply to activities, materials, parts, assemblies, and services that affect the quality of the PVHO. It need not apply to other activities, products, and services at the same location.

(c) The program shall identify the PVHO activities to which it applies.

(d) The program shall provide for indoctrination, training, and testing of personnel to assure compliance with PVHO-1 and this Case.

(e) Management shall, at least annually, assess the program and take corrective action if necessary.

5.4 Quality Assurance Manual

(a) The Quality Assurance Program shall be described in a Quality Assurance Manual.

(b) The Quality Assurance Manual must provide a mechanism to document issuance and revision of drawings and specifications, and must include a method to identify or highlight the revisions.

(c) The Quality Assurance Manual shall be a controlled document.

5.5 Drawing, Design, and Specification Control

(a) The manufacturer shall establish measures to assure that PVHO design drawings and all applicable documents and requirements of PVHO-1 relative to the

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design of PVHOs are received from the designer, and are correctly translated into manufacturing specifications, drawings, procedures, and shop instructions for the PVHO.

(b) Procedures shall be established for the review, approval, release, distribution, control, and revision of manufacturing documents.

5.6 Production Control

(a) Applicable requirements necessary to assure compliance with this Case shall be specified or included in documents for procurement of materials, items, or services to be used by the manufacturer.

(b) The procurement of materials, items, and services shall be controlled by the manufacturer to assure conformance with specified requirements.

(c) These controls shall include, but are not limited to, any of the following, as appropriate:

(1) source evaluation and selection;

(2) appraisal of objective evidence of quality furnished by the supplier, including all necessary material certification documents;

(3) inventory control;

(4) examination of supplied items upon delivery.

(d) Procedures for assuring continued compliance with pertinent requirements, including identification of procedural revisions, shall be described in the Quality Assurance Manual.

(e) During production, materials samples shall be tested daily to verify materials properties.

5.7 Identification and Control of Items

(a) Identification shall be maintained on all items or in documentation traceable to these items.

(b) Controls shall be established to prevent use of incorrect or defective items.

(c) Complete documentation and traceability shall be maintained on all materials and fabrication and test procedures used in the manufacture of the chamber as specified in the quality assurance procedures.

(d) Traceability of the completed PVHO shall extend to identification of the immediate purchaser and to a specific chamber by serial number.

5.8 Control of Manufacturing Processes

(a) Processes affecting quality shall be controlled in accordance with manufacturer's specified quality assurance procedures.

(b) Special processes affecting quality, such as laying back, curing, and nondestructive examination, shall be performed by qualified personnel using qualified procedures.

(c) All personnel performing manufacturing procedures shall be documented as meeting specific criteria qualifying them to perform those procedures. Documentation shall consist of training procedures and testing results where appropriate.

5.9 Inspection of Manufacturing Processes

(a) Inspections shall be planned and controlled by the manufacturer in accordance with manufacturer's written procedures.

(b) These inspections shall verify conformance to documented instructions, procedures, and drawings describing the activities.

(c) Inspection results shall be documented.

(d) Inspection for acceptance shall be performed by qualified persons, experienced in composite pressure vessel construction and inspection, other than those who performed or supervised the work.

(e) Inspection documents shall contain appropriate criteria for determining that such activities have been satisfactorily accomplished.

5.10 Test Control

(a) Testing required to demonstrate that the PVHO will perform in accordance with this Case shall be so defined, controlled, and documented.

(b) Tests shall be performed in accordance with written instructions stipulating acceptance criteria.

(c) Test results shall be recorded on the required forms.

(d) Examination, measurement, and testing equipment used for activities affecting quality shall be controlled, calibrated, and adjusted at specified periods to maintain required accuracy.

(e) Specifications, calibration, and control of measuring and testing equipment used for acceptance shall be described in written instructions or procedures.

(f) Calibrations shall be traceable to national standards where such exist.

5.11 Handling, Storage, and Shipping

Handling, storage, cleaning, packaging, shipping, and preservation of items shall be controlled to prevent damage or loss, and to minimize deterioration. In addition, these methods shall be documented.

5.12 Documentation and Status of Test Activities

(a) The status of inspection and testing activities

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shall be indicated either on the items or in records traceable to the items, to assure that required inspections and tests are performed.

(b) Items that have satisfactorily passed inspections and tests shall be identified.

5.13 Corrective Action

(a) Items, services, or activities that do not conform to specified requirements shall be controlled to assure proper disposition and prevent inadvertent use. Nonconforming materials or workmanship shall be documented on a written Nonconformance Report and shall be part of the records of 5.13(e).

(b) Controls shall provide for identification, documentation, evaluation, segregation when practical, disposition of nonconformances, and notification of affected organizations.

(c) Conditions adverse to quality shall be promptly investigated, documented, evaluated, and corrected.

(d) In the case of a significant condition adverse to quality, the cause of the condition shall be determined and corrective action taken to preclude recurrence.

(e) The identification, cause, and corrective action planned and taken for significant conditions shall be documented and reported to appropriate levels of management.

(f) Follow-up action shall be taken to verify implementation of corrective action.

5.14 Quality Assurance Records

(a) Records shall be specified, compiled, and maintained to furnish documentary evidence that services, materials, items, and completed PVHOs meet this and applicable referenced standards.

(b) Records shall be legible, identifiable, and retrievable.

(c) Records shall be protected against damage, deterioration, or loss.

(d) Requirements and responsibilities for record transmittal, distribution, retention, maintenance, and disposition shall be established and documented.

(e) Records required for traceability shall be retained for a minimum of 12 years.

5.15 Quality Assurance Audits

(a) The PVHO manufacturer shall schedule and perform regular internal audits to verify compliance with all aspects of the Quality Assurance Program.

(b) These audits shall be performed at least annually and be stipulated in the Quality Assurance Manual.

(c) These audits shall be performed by qualified personnel who do not have direct responsibility for performing or controlling the activities being audited.

(d) The audits shall be performed in accordance with written instructions.

(e) Audit results shall be reported to and reviewed by management having responsibility and authority to take any necessary corrective action. Follow-up action shall be taken where indicated.

5.16 Quality Assurance Overview by an Independent Third-Party Agency

An independent third-party agency shall be employed to ensure that all PVHOs intended to be classified under this Case are designed and manufactured to the requirements of PVHO-1 and this Case. This shall include but is not restricted to the following.

(a) The PVHO is designed in accordance with PVHO-1 and this Case.

(b) The manufacturer is working to the requirements of the quality control systems.

(c) The materials used in construction of the PVHO comply with approved procedures by qualified operators as required by PVHO-1 and this Case.

(d) All manufacturing operations are conducted in accordance with approved procedures as required by PVHO-1 and this Case.

(e) An NCR is generated and all defects are acceptably repaired.

(f) All prototype and production testing has been performed and witnessed as required by PVHO-1 and this Case.

(g) The PVHO is marked in accordance with PVHO-1 and this Case.

(h) A visual inspection of the PVHO is conducted to confirm that there are no material or dimensional defects.

The manufacturer shall arrange and give the third-party inspection agency free access to all facilities associated with the manufacture of the PVHO. The manufacturer shall keep the third-party inspection agency informed of the progress of the work and shall notify them reasonably in advance when PVHOs will be ready for any required tests or inspections.

6 MARKING

(a) The collar end closure will be marked in accordance with PVHO-1, paras. 1.2.1 and 1.6, with the data required in PVHO-1, para. 1.6.1, and the following (sample) designation:

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80-30-96-PVHO(CCxx)-GSE-0001-1996

where

80 = rated pressure, psig
30 = inside diameter, in.
96 = length of the vessel, in.
PVHO(CCxx) = PVHO designator and Case number
GSE = manufacturer's initials
0001 = manufacturer's unique identification for the PVHO
1996 = year of manufacture

The collar end closure shall also display the following information:

(1) maximum working pressure: 80 psig (180 ft of seawater);

(2) operating temperature (min./max.): 0°F/140°F;

(3) allowable cyclic life: ____ expansion and collapse cycles;

(4) gas-tight main body expiration date: _____ (10 yr from date of manufacture).

(b) Form PVHO Case 9, Manufacturer's Data Report for Pressure Vessels for Human Occupancy, shall be completed to certify that each PVHO meets the requirements of PVHO-1 and this Case.

(c) The coated fabric pressure bag and straps shall be marked with the rated pressure and expiration date. An indelible marking compatible with the materials shall be used.

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ASME PHVO-1 INTERPRETATIONS NO. 5

Replies to Technical Inquiries
September 9, 1999, through September 27, 2001

It has been agreed to publish interpretations issued by the PVHO Committee concerning PVHO-1 as part of the update service. This publication includes interpretations concerning PVHO-1 issued between September 9, 1999 and September 27, 2001. They have been assigned interpretation numbers in chronological order. Each interpretation applies to the latest Edition at the time of issuance of the interpretation or the Edition stated in the reply. Subsequent revisions to PVHO-1 may have superseded the reply. **These interpretations are not a part of the Edition.**

These replies are taken verbatim from the original letters, except for a few typographical and editorial corrections made for the purpose of improved clarity.

ASME procedures provide for reconsideration of these interpretations when or if additional information is available which the inquirer believes might affect the interpretation. 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.

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Interpretation: 5-1

Subject: Use of Latest Edition

Date Issued: March 20, 2000

Question: Is there a requirement to use the most current standard edition of PVHO-1 when fabricating a vessel as P.V.H.O.?

Reply: No. Use of the latest edition may be required by the authority having jurisdiction or by contract.

Interpretation: 5-2

Subject: Pressure Test of Window in Excess of Design Pressure

Date Issued: March 23, 2000

Question: Does a pressure test in excess of the design pressure with pressuring medium 25°F–35°F lower than the design temperature meet the requirements of ASME PVHO-1-1997, para. 2-7.8?

Reply: Yes.

Interpretation: 5-3

Subject: Clarification of PVHO requirements

Date Issued: May 24, 2000

Question (1): Are PVHO rules open to interpretation?

Reply (1): Yes, upon request the PVHO committee renders interpretations of the requirements. An interpretation applies to either the edition and addenda in effect on the date of issuance to the interpretation by the PVHO Committee Secretary or the edition and addenda stated in the interpretation. Subsequent revisions to the standard may supersede the interpretation. Note, only the PVHO Committee has the authority to provide official interpretation of the standard.

Question (2): Is a successful pressure test enough to validate a deviation from PVHO rules?

Reply (2): No. The Committee does not rule on whether or not a specific component meets all the provisions of the standard. Laws or regulations issued by municipality, state, provincial, federal, or other enforcement or regulatory bodies having jurisdiction at the location of an installation establish the mandatory applicability of the standard rules, in whole or part, within their jurisdiction. Otherwise, compliance with PVHO becomes a matter of contractual agreement.

Question (3): May the standard be modified by simply violating it for a certain period of time?

Reply (3): No.

Question (4): May the standard by modified and change a prior requirement?

Reply (4): Yes. Upon request the PVHO Committee will consider suggestions for revisions along with any supporting documentation.

Question (5): May a PVHO be stamped ASME PVHO-1 when the piping system, cleaned for use with pure breathing oxygen only, is designed to supply alternately through the same piping system compressed air from scuba bottles and pure oxygen in alternation during the same period under pressure?

Reply (5): Yes, see PVHO Sections 4-7.6.4, 4-7.6.5, 4-7.6.6, 4-4.2.6, 4-7.11, 4-7.12, and 4-7.13, separation of breathing gases.

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