ASME BOILER AND PRESSURE VESSEL CODE

Section I POWER BOILERS

Section II MATERIAL SPECIFICATIONS – PART A – FERROUS

Section II MATERIAL SPECIFICATIONS – PART B – NONFERROUS

Section II MATERIAL SPECIFICATIONS – PART C – WELDING RODS, ELECTRODES AND FILLER METALS

Section III NUCLEAR POWER PLANT COMPONENTS

Section IV HEATING BOILERS

Section V NONDESTRUCTIVE EXAMINATION

Section VI RECOMMENDED RULES FOR CARE AND OPERATION OF HEATING BOILERS

Section VII RECOMMENDED RULES FOR CARE OF POWER BOILERS

Section VIII PRESSURE VESSELS – DIVISION 2 – ALTERNATIVE RULES

Section IX WELDING QUALIFICATIONS

Section X FIBERGLASS – REINFORCED PLASTIC PRESSURE VESSELS

Section XI RULES FOR INSERVICE INSPECTION OF NUCLEAR REACTOR COOLANT SYSTEMS

SECTION

VIII

PRESSURE VESSELS

DIVISION 1

9/146

ASME BOILER AND PRESSURE VESSEL CODE

SECTION VIII

Rules for Construction of

PRESSURE VESSELS

DIVISION 1

1971 EDITION

JULY 1, 1971

ASME BOILER AND PRESSURE VESSEL COMMITTEE
SUBCOMMITTEE ON PRESSURE VESSELS

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS
UNITED ENGINEERING CENTER
345 EAST FORTY-SEVENTH STREET, NEW YORK, N.Y. 10017

1971 ASME Boiler and Pressure Vessel Code

Section	Title
I	POWER BOILERS
II	MATERIAL SPECIFICATIONS: PART A – FERROUS PART B – NONFERROUS PART C – WELDING RODS, ELECTRODES, AND FILLER METALS
III	NUCLEAR POWER PLANT COMPONENTS
IV	HEATING BOILERS
V	NONDESTRUCTIVE EXAMINATION
VI	RECOMMENDED RULES FOR CARE AND OPERATION OF HEATING BOILERS
VII	RECOMMENDED RULES FOR CARE OF POWER BOILERS
VIII	PRESSURE VESSELS DIVISION 1 DIVISION 2 – ALTERNATIVE RULES
IX	WELDING QUALIFICATIONS
X	FIBERGLASS-REINFORCED PLASTIC PRESSURE VESSELS
XI	RULES FOR INSERVICE INSPECTION OF NUCLEAR REACTOR COOLANT SYSTEMS

Case Interpretations

The Boiler and Pressure Vessel Committee meets regularly to consider requests for interpretations of the Code and to consider rulings for conditions encountered requiring special provisions. Those which have been adopted are published in a case interpretation booklet.

Interpretation and Addenda Service

Colored Sheet Addenda, which include additions to and revisions of all existing sections of the Code, and subsequent case interpretations in white loose leaf sheets may be obtained from the ASME Order Department on a three-year subscription basis.

Addenda Color Legend

Pink	Summer 1971
Green	Winter 1971
Yellow	Summer 1972
Blue	Winter 1972
Salmon	Summer 1973
Gray	Winter 1973

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Foreword

The American Society of Mechanical Engineers set up a committee in 1911 for the purpose of formulating standard rules for the construction of steam boilers and other pressure vessels. This committee is now called the Boiler and Pressure Vessel Committee.

The Committee's function is to establish rules of safety governing the design, the fabrication, and the inspection during construction of boilers and pressure vessels, and to interpret these rules when questions arise regarding their intent. In formulating the rules, the Committee considers the needs of users, manufacturers, and inspectors of pressure vessels.

The Boiler and Pressure Vessel Committee deals with the care and inspection of boilers and pressure vessels in service only to the extent of providing suggested rules of good practice as an aid to owners and their inspectors.

The rules established by the Committee are not to be interpreted as approving, recommending, or endorsing any proprietary or specific design or as limiting in any way the manufacturer's freedom to choose any method of design or any form of construction that conforms to the Code rules.

The Boiler and Pressure Vessel Committee meets regularly to consider requests for interpretations and revisions of the rules. Inquiries must be in writing and must give full particulars in order to receive consideration. Requests for interpretations which are of a routine nature may be executed by the Secretary of the Boiler and Pressure Vessel Committee without reference to a subcommittee. All other requests are first referred to the proper subcommittee for consideration and for recommendation of action by the Main Committee. The action of the Main Committee becomes effective only after confirmation by letter ballot of the Committee and approval by the Council of the Society.

Interpretations of general interest are published in *Mechanical Engineering* as Code Cases, and inquirers are advised of the action taken. Code revisions approved by the Committee are published in *Mechanical Engineering* as proposed addenda to the Code to invite comments from all interested persons. After final approval by the Committee and adoption by the ASME Council, they are printed in the addenda supplements to the Code.

Code Cases (interpretations) may be used in the construction of vessels to be stamped with the ASME Code symbol beginning with the date of their approval by the ASME Council.

After Code revisions are approved by council they may be used beginning with the date of issuance shown on the addenda. Revisions become mandatory as minimum requirements six months after such date of issuance, except for boilers or pressure vessels contracted for prior to the end of the six-month period.

Manufacturers and users of pressure vessels are cautioned against making use of revisions and Cases that are less restrictive than former requirements without having assurance that they have been accepted by the proper authorities in the jurisdiction where the vessel is to be installed.

Each state and municipality in the United States and each province in the Dominion of Canada that adopts or accepts one or more Sections of the Boiler and Pressure Vessel Code is invited to appoint a representative to act on the Conference Committee to the Boiler and Pressure Vessel Committee. Since the members of the Conference Committee are in active contact with the administration and enforcement of the rules, the requirements for inspection in this Code correspond with those in effect in their respective jurisdictions. The required qualifications for an authorized inspector under these rules may be obtained from the administrative authority of any state, municipality, or province which has adopted these rules.

The Boiler and Pressure Vessel Committee in the formulation of its rules and in the establishment of maximum design and operating pressures considers materials, construction, method of fabrication, inspection, and safety devices. Permission may be granted to regulatory bodies and organizations publishing safety standards to use a complete Section

of the Code by reference. If usage of a Section, such as Section VIII, Div. 1, involves exceptions, omissions, or changes in provisions, the intent of the Code might not be attained.

Where a state or other regulatory body, in the printing of any Section of the ASME Boiler and Pressure Vessel Code, makes additions or omissions, it is recommended that such changes be clearly indicated.

The National Board of Boiler and Pressure Vessel Inspectors is composed of chief inspectors of states and municipalities in the United States and of provinces in the Dominion of Canada that have adopted the Boiler and Pressure Vessel Code. This Board, since its organization in 1919, has functioned to uniformly administer and enforce the rules of the Boiler and Pressure Vessel Code. The cooperation of that organization with the Boiler and Pressure Vessel Committee has been extremely helpful. Its function is clearly recognized and, as a result, inquiries received which bear on the administration or application of the rules are referred directly to the National Board. Such handling of this type of inquiry not only simplifies the work of the Boiler and Pressure Vessel Committee, but action on the problem for the inquirer is thereby expedited. Where an inquiry is not clearly an interpretation of the rules, nor a problem of application or administration, it may be considered both by the Boiler and Pressure Vessel Committee and the National Board.

It should be pointed out that the state or municipality where the Boiler and Pressure Vessel Code has been made effective has definite jurisdiction over any particular installation. Inquiries dealing with problems of local character should be directed to the proper authority of such state or municipality. Such authority may, if there is any question or doubt as to the proper interpretation, refer the question to the Boiler and Pressure Vessel Committee.

The specifications for materials given in Section II of the Code are identical with or similar to those of the American Society for Testing and Materials, as indicated, except in those cases where that organization has no corresponding specification.

Statement of Policy on Use of Code Symbols in Advertising

The American Society of Mechanical Engineers established a series of symbols for the marking of boilers, pressure vessels, and certain appurtenances which have been constructed and inspected in compliance with the ASME Boiler and Pressure Vessel Code. It is the aim of the Society to maintain the standing of the Code Symbols for the benefit of the users, the enforcement jurisdictions, and the holders of the symbols who comply with all requirements. Based on that objective the following policy has been established on the usage in advertising of facsimiles of the symbols and reference to Code construction.

The American Society of Mechanical Engineers does not "approve," "certify," "rate," or "endorse" any product or construction and there shall be no statements or inferences which might so indicate. A manufacturer holding a Code Symbol and a Certificate of Authorization may state in advertising literature that its products "are built in accordance with the requirements of the ASME Boiler and Pressure Vessel Code," or "meet the requirements of the ASME Boiler and Pressure Vessel Code."

The ASME Symbol shall be used only for stamping and nameplates as specifically provided in the Code. However, facsimiles may be used for the purpose of fostering the use of such construction. Such usage may be by an association or a society, or by a holder of a Code Symbol who may also use the facsimile in advertising to show that clearly specified products will carry the symbol. General usage is permitted only when *all* of a manufacturer's products are constructed under the Rules.

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Contents

		Page
U-1	Scope	1
U-2	General	2

SUBSECTION A GENERAL REQUIREMENTS

PART UG – General Requirements for All Methods of Construction and All Materials

UG-5	Materials	4
UG-16	Design	7
UG-36	Openings and Reinforcements	25
UG-47	Braced and Stayed Surfaces	33
UG-53	Ligaments	35
UG-75	Fabrication	37
UG-90	Inspection and Tests	44
UG-115	Stamping and Reports	53
UG-125	Pressure Relief Devices	56

SUBSECTION B REQUIREMENTS PERTAINING TO METHODS OF FABRICATION OF PRESSURE VESSELS

PART UW – Requirements for Pressure Vessels Fabricated by Welding

UW-1	General	63
UW-5	Materials	64
UW-8	Design	64
UW-26	Fabrication	78
UW-46	Inspection and Tests	82
UW-60	Stamping and Reports	87
UW-65	Pressure Relief Devices	87

PART UR – Requirements for Pressure Vessels Fabricated by Riveting

UR-1	General	87
UR-5	Materials	87
UR-10	Design	87
UR-30	Fabrication	90
UR-50	Inspection and Tests	92
UR-60	Stamping and Reports	93
UR-65	Pressure Relief Devices	93

PART UF – Requirements for Pressure Vessels Fabricated by Forging

UF-1	General	93
UF-5	Materials	93
UF-12	Design	94
UF-26	Fabrication	94
UF-45	Inspection and Tests	97
UF-115	Stamping and Reports	98
UF-125	Pressure Relief Devices	98

Page

PART UB – Requirements for Pressure Vessels Fabricated by Brazing

UB-1 General ... 98
UB-5 Materials ... 99
UB-9 Design ... 99
UB-30 Fabrication ... 101
UB-40 Inspection and Tests ... 104
UB-50 Stamping and Reports ... 104
UB-55 Pressure Relief Devices ... 104

SUBSECTION C REQUIREMENTS PERTAINING TO CLASSES OF MATERIALS

PART UCS – Requirements for Pressure Vessels Constructed of Carbon and Low-Alloy Steels

UCS-1 General ... 105
UCS-5 Materials ... 105
UCS-16 Design ... 107
UCS-65 Low-Temperature Operation ... 126
UCS-75 Fabrication ... 127
UCS-90 Inspection and Tests ... 127
UCS-115 Stamping and Reports ... 128
UCS-125 Pressure Relief Devices ... 128

PART UNF – Requirements for Pressure Vessels Constructed of Nonferrous Materials

UNF-1 General ... 128
UNF-5 Materials ... 128
UNF-16 Design ... 129
UNF-75 Fabrication ... 137
UNF-90 Inspection and Tests ... 137
UNF-115 Stamping and Reports ... 137
UNF-125 Pressure Relief Devices ... 151
Nonmandatory Appendix NF ... 151

PART UHA – Requirements for Pressure Vessels Constructed of High-Alloy Steel

UHA-1 General ... 157
UHA-11 Materials ... 157
UHA-20 Design ... 174
UHA-40 Fabrication ... 176
UHA-50 Inspection and Tests ... 176
UHA-60 Stamping and Reports ... 177
UHA-65 Pressure Relief Devices ... 177
UHA-100 Nonmandatory Appendix HA ... 177

PART UCI – Requirements for Pressure Vessels Constructed of Cast Iron

UCI-1 General ... 179
UCI-5 Materials ... 179
UCI-16 Design ... 179
UCI-75 Fabrication ... 181
UCI-90 Inspection and Tests ... 181
UCI-115 Stamping and Reports ... 182
UCI-125 Pressure Relief Devices ... 182

Page

PART UCL – Requirements for Welded Pressure Vessels Constructed of Integrally Clad Plate or With Applied Corrosion Resistant Linings

UCL-1 General ... 182
UCL-10 Materials ... 182
UCL-20 Design ... 183
UCL-30 Fabrication ... 184
UCL-50 Inspection and Tests ... 187
UCL-55 Stamping and Reports ... 187
UCL-60 Pressure Relief Devices ... 187

PART UCD – Requirements for Pressure Vessels Constructed of Cast Ductile Iron

UCD-1 General ... 188
UCD-5 Materials ... 188
UCD-16 Design ... 188
UCD-75 Fabrication ... 190
UCD-90 Inspection and Tests ... 190
UCD-115 Stamping and Reports ... 191
UCD-125 Pressure Relief Devices ... 191

PART UHT – Requirements for Pressure Vessels Constructed of Ferritic Steels With Tensile Properties Enhanced by Heat Treatment

UHT-1 General ... 192
UHT-5 Materials ... 192
UHT-16 Design ... 193
UHT-75 Fabrication ... 198
UHT-90 Inspection and Tests ... 200
UHT-115 Stamping and Reports ... 200
UHT-125 Pressure Relief Devices ... 201

MANDATORY APPENDICES

UA-1 APPENDIX I – Supplementary Design Formulas ... 202
UA-45 APPENDIX II – Rules for Bolted Flanged Connections ... 210
UA-60 APPENDIX III – Definitions ... 238
APPENDIX IV – Porosity Charts ... 242
APPENDIX V – Charts for Determining Shell Thickness of Cylindrical and Spherical Vessels Under External Pressure ... 248
UA-70 APPENDIX VI – Methods for Magnetic Particle Inspection – MT ... 284
UA-80 APPENDIX VII – Inspection and Testing of Steel Castings ... 287
UA-91 APPENDIX VIII – Methods for Liquid Penetrant Examination – PT ... 290
UA-100 APPENDIX IX – Jacketed Vessels ... 293

NONMANDATORY APPENDICES

APPENDIX A – *See Mandatory Appendix IV*
UA-110 APPENDIX B – Approval of New Materials ... 301
UA-130 APPENDIX C – Method for Obtaining Operating Temperature of Vessel Walls in Service ... 302
UA-140 APPENDIX D – Suggested Good Practice Regarding Internal Structures ... 303
UA-155 APPENDIX E – Suggested Good Practice Regarding Corrosion Allowance ... 303
UA-170 APPENDIX F – Suggested Good Practice Regarding Linings ... 304
UA-185 APPENDIX G – Suggested Good Practice Regarding Design of Supports ... 305

		Page
UA-230	APPENDIX J – Capacity Conversion for Safety Valves	307
UA-250	APPENDIX K – Sectioning of Welded Joints	309
UA-270	APPENDIX L – Examples Illustrating the Application of Code Formulas and Rules	311
UA-350	APPENDIX M – Installation and Operation	325
UA-500	APPENDIX P – Basis for Establishing Stress Values for Ferrous Materials	327
UA-600	APPENDIX Q – Basis for Establishing Stress Values for Nonferrous Materials	328
	APPENDIX R – Preheating	328
	APPENDIX S – Design Considerations for Bolted Flange Connections	330
	APPENDIX T – Temperature Protection	332
UA-900	APPENDIX U – Ultrasonic Examination of Welds – UT	332
	INDEX	353

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ASME BOILER and PRESSURE VESSEL CODE

SECTION VIII

PRESSURE VESSELS

DIVISION 1

The 1971 Edition of Section VIII, Pressure Vessels, Division 1, was approved by the Council of The American Society of Mechanical Engineers on August 10, 1970.

SCOPE

U-1 Scope

(*a*) The rules in this Division of Section VIII of the Code cover minimum construction requirements for the design, fabrication, inspection, and certification of pressure vessels other than those covered by Section I, Section III, and Section IV. This section of the Code does not cover Fired Process Tubular Heaters.

Division 1 of Section VIII is divided into three Subsections. Subsection A consists of Part UG covering the general requirements applicable to all pressure vessels. Subsection B covers the specific requirements that are applicable to the various methods used in the fabrication of pressure vessels. It consists of Parts UW, UR, UF, and UB, dealing with welded, riveted, forged, and brazed methods, respectively. Subsection C covers specific requirements applicable to the several classes of materials used in pressure vessel construction. It consists of Parts UCS, UNF, UHA, UCI, UCL, UCD, and UHT dealing with carbon and low-alloy steels, nonferrous metals, high-alloy steels, cast iron, clad and lined material, cast ductile iron, and ferritic steels with properties enhanced by heat treatment, respectively.

(*b*) The rules of this Division of Section VIII of the Code have been formulated on the basis of design principles and construction practices applicable to vessels designed for pressures not exceeding 3000 psi. For pressures above 3000 psi, deviations from and additions to these rules usually are necessary to meet the requirements of design principles and construction practices for these higher pressures. Only in the event that after having applied these additional design principles and construction practices the vessel still complies with all of the requirements of the Code may it be stamped with the Code symbol.

(*c*) It is intended that Code jurisdiction over piping external to a pressure vessel shall terminate at:

(*1*) The first circumferential joint for welding end connections;

(*2*) The face of the first flange in bolted flanged connections;

(*3*) The first threaded joint in that type of connection.

(*d*) The following classifications are not considered to be within the jurisdiction of this Division of Section VIII.

(*1*) Pressure vessels subject to Federal control;

(*2*) Vessels with a nominal water containing capacity of 120 gallons or less for containing water

under pressure, including those containing air, the compression of which serves only as a cushion;

(3) A hot water supply storage tank heated by steam or any other indirect means when none of the following limitations is exceeded:

(a) A heat input of 200,000 Btu per hr,

(b) A water temperature of 200 F,

(c) A nominal water containing capacity of 120 gallons.

(4) Vessels having an internal or external operating pressure not exceeding 15 psi with no limitation on size (see UG-28(e));

(5) Vessels having an inside diameter not exceeding 6 in. with no limitation on pressure.

(e) Unfired steam boilers as defined in Section I shall be constructed in accordance with the rules of Section I or this Division of Section VIII (see UW-2(c)). The following pressure vessels in which steam is generated shall be constructed in accordance with the rules of this Division:

(1) Vessels known as evaporators or heat exchangers.

(2) Vessels in which steam is generated by the use of heat resulting from operation of a processing system containing a number of pressure vessels such as used in the manufacture of chemical and petroleum products.

(f) Pressure vessels not covered by U-1(e)(1) and (2) or by Sections I, III, and IV, and not excluded by U-1(d), shall be constructed in accordance with the rules of this Division.

(g) Any pressure vessel which meets all of the requirements of this Division of Section VIII, including those for inspection, may be stamped with the Code U-symbol even though exempted from such stamping.

(h) Pressure vessels exclusive of those covered in (d) and (e) that are not required by the rules of this Division to be fully radiographed and that do not exceed the following volume and pressure limits, may be exempted from inspection by Inspectors as defined in UG-91, provided that they comply in all other respects with the requirements of this Division:

(1) 5 cu ft in volume and 250 psi design pressure;

(2) $1\frac{1}{2}$ cu ft in volume and 600 psi design pressure.

Vessels exempted from Code inspection by this rule shall be marked with the UM-symbol in Fig. UG-116(b) and with the data required in UG-116. A certificate for vessels exempted from Code inspection shall be furnished by the manufacturer on Form U-3 when requested. In an assembly of vessels the limitations in (1) and (2) apply to each vessel and not to the assembly as a whole.

GENERAL

U-2 General

(a) The user or his designated agent shall establish the design requirements for pressure vessels, taking into consideration factors associated with normal operation, and such other conditions as startup and shutdown.

(b) The manufacturer completing any vessel to be marked with the Code symbol has the responsibility of complying with all of the applicable requirements of this Division and, through proper certification, of assuring that work done by others also complies. The manufacturer shall have available for the Inspector's review the design calculations applicable to the vessel. See UG-90(b).

(c) A vessel may be designed and constructed using any combination of the methods of fabrication and the classes of materials covered by this Division provided the rules applying to each method and material are complied with and the vessel is marked as required by UG-116.

(d) When the strength of any part cannot be computed with a satisfactory assurance of safety, the rules provide procedures for establishing its maximum allowable working pressure.

(e) It is the duty of the Inspector to make all of the inspections specified by the rules of this Division, and of monitoring the quality control and the examinations made by the manufacturer. He shall make such other inspections as in his judgment are necessary to permit him to certify that the vessel has been designed and constructed in accordance with the requirements. The Inspector has the duty of verifying that the applicable calculations have been made and are on file at manufacturer's plant at the time the Data Report is signed. Any questions concerning the calculations raised by the Inspector must be resolved. See UG-90(c)(1).

(f) It is the intent that the fundamental rules for design and the tests prescribed herein shall serve as a sufficient basis for an Inspector, during construction, to judge the safety of the vessel and to justify the application of the Code symbol.

(g) This Division of Section VIII does not contain rules to cover all details of design and construction. Where complete details are not given, it is intended

that the manufacturer, subject to the approval of the Inspector, shall provide details of design and construction which will be as safe as those provided by the rules of this Division.

(h) Applicants for the official Stamp of the American Society of Mechanical Engineers and the Certificate of Authorization, including those manufacturers requesting recertification, must have a system for controlling quality of their product that is satisfactory to the Society. Before issuance of a Certificate of Authorization, the Manufacturer's facilities and organization are subject to review by his inspection agency and the legal jurisdiction concerned. For those areas where there is no jurisdiction or where a jurisdiction does not review a manufacturer's facilities, that function shall be performed by a representative of the National Board of Boiler and Pressure Vessel Inspectors. A written report to the Society will be made by the jurisdiction and the inspection agency employed by the manufacturer to do his Code inspection. See UG-116(m).

SUBSECTION A

GENERAL REQUIREMENTS

PART UG

GENERAL REQUIREMENTS FOR ALL METHODS OF CONSTRUCTION AND ALL MATERIALS

UG-1 Scope

The requirements of Part UG are applicable to all pressure vessels and vessel parts and shall be used in conjunction with the specific requirements in Subsections B and C that pertain to the method of fabrication and the material used.

MATERIALS

UG-5 General

(*a*) Material subject to stress due to pressure shall conform to one of the specifications given in Section II of the Code and shall be limited to those that are permitted in the applicable Part of Subsection C, except as otherwise permitted in UG-10 and UG-11.

(*b*) Material covered by specifications in Section II is not restricted as to the method of production unless so stated in the specification, and so long as the product complies with the requirements of the specification. (See UG-85.)

(*c*) Materials other than those allowed by the Code may not be used, unless data thereon are submitted to and approved by the Boiler and Pressure Vessel Committee in accordance with Appendix B.

(*d*) Materials outside the limits of size and/or thickness given in the title or scope clause of the specifications given in Section II of the Code, and permitted by the applicable part of Subsection C, may be used if the material is in compliance with the other requirements of the specification,[1] and no size or thickness limitation is given in the rules for construction. In those specifications in which chemical composition or mechanical properties vary with size or thickness, materials outside the range shall be required to conform to the composition and mechanical properties shown for the nearest specified range.

(*e*) It is recommended that the user or his designated agent assure himself that materials used for the construction of the vessels will be suitable for the intended service with respect to retention of satisfactory mechanical properties, and resistance to corrosion, erosion, oxidation, and other deterioration during their intended service life.

UG-6 Plate[2]

(*a*) Plate used in the construction of pressure parts of pressure vessels shall conform to one of the specifications in Section II of the Code for which allowable stress values are given in Subsection C, except as otherwise provided in (b) and UG-5, UG-10, and UG-11.

(*b*) Material not identified by mill test reports may be used for nonpressure parts such as skirts, baffles, and supporting lugs. A double-welded butt-joint test plate shall be made from each lot of all such material over $^3/_8$ in. thick that is to be welded.

[1] In some instances the limitations of the scope clause in the material specifications are based on a very realistic maximum. It is recommended that the designer and/or fabricator confer with the material supplier before proceeding, thus assuring himself that except for size or thickness, all requirements of the material specification will be met and so certified.

[2] The term "plate" for the purpose of this usage includes sheet and strip also.

Guided bend specimens made from the test plates shall pass the tests specified in Table Q-13 of Section IX of the Code. The allowable stress value shall not exceed 80 percent of the maximum allowable stress value permitted for similar material in Subsection C. Satisfactory performance of a specimen in these tests shall not make the plate acceptable for use in pressure parts of a vessel.

UG-7 Forgings

Forged and rolled material may be used in pressure vessel construction provided the material has been worked sufficiently to remove the coarse ingot structure. Specifications and maximum allowable stress values for acceptable forging materials are given in Subsection C. (See Part UF for forged vessels.)

UG-8 Castings

Cast material may be used in the construction of pressure vessels and vessel parts. Specifications and maximum allowable stress values for acceptable casting materials are given in Subsection C. These allowable stress values shall be multiplied by the applicable casting quality factor given in UG-24 for all materials except cast iron.

UG-9 Pipe and Tubes

(*a*) Pipe and tubes of seamless or welded[1] construction conforming to one of the specifications given in Section II of the Code may be used for shells and other parts of pressure vessels. Allowable stress values for the materials used in pipe and tubes are given in Subsection C. These stress values may be used without reduction for seamless pipe and tubes, whereas the allowable stress values for welded pipe and tubes shall be as prescribed in the applicable Part of Subsection C.

(*b*) Integrally finned tubes may be made from tubes that conform in every respect with one of the specifications given in Section II except that the pressure test is not required for nonferrous tubes. These tubes may be used under the following conditions:

(*1*) The tubes after finning shall have a temper or condition which conforms to one of those provided in the governing specifications.

(*2*) The maximum allowable stress value for the finned tube shall be that given in Subsection C for the tube before finning, except as permitted in (3).

[1] Pipe and tubing fabricated by fusion welding, with filler metal added, may not be used in Code construction unless it is fabricated in accordance with Code rules as a pressure part.

(*3*) The maximum allowable stress value for a temper or condition that has a higher stress value than that of the tube before finning may be used provided that qualifying tensile tests demonstrate that such a temper or condition is obtained. The qualifying tensile tests shall be made on specimens of finned tube from which the fins have been removed by machining.

(*4*) The maximum allowable internal or external working pressure of the tube shall be based on the minimum wall thickness of the finned section or of the unfinned section, whichever is smaller.

(*5*) In addition to the tests required by the governing specification (except for pressure tests for nonferrous tubes), each tube after finning shall withstand without evidence of leakage an internal pneumatic test of not less than 250 psi for five seconds while immersed in water or other suitable liquid.

UG-10 Materials Not Fully Identified

Any plate material or tubular product not completely identified with a Code-approved specification shall be accepted as satisfying the requirements of a specification to be designated from among those given in Section II, provided that it satisfies the conditions given in either (a) or (b).

(*a*) Each piece is shown to have chemical requirements and physical properties within the permissible range of the designated specification in Section II by an authentic test record and by marking identifying it with that record. When the designated specification requires other tests or more restrictive tests than those of the specification covered by the authentic test record, the material shall be subjected to sufficient additional tests to satisfy the Inspector that it complies with the designated specification.

(*b*) Each piece is tested as follows to show that it complies with the chemical requirements and physical properties of the designated specification in Section II.

(*1*) *Plate.* The chemical check analyses and physical tests of plates shall be made as required in the designated specification with the following modifications. The carbon and manganese contents shall be determined in all check analyses. The Inspector shall decide whether these contents are acceptable when the designated specification does not specify carbon and manganese limits. When the direction of rolling is not definitely known, two tension specimens shall be taken at right angles to each other from a corner of each plate, and two

bend specimens shall be taken from the middle of adjacent sides of each plate. One tension specimen and both bend specimens shall meet the specification requirements.

(2) *Tubes and Pipe.* Each length of tube or pipe shall be sujbected to a chemical check analysis and sufficient physical tests to satisfy the inspector that all the material is identified with a given heat or heat treatment lot, and that the material complies with the chemical and physical requirements of the designated specification. Material specified as suitable for welding, cold bending, close coiling, and similar operations shall be given sufficient check tests to satisfy the Inspector that it is suitable for the fabrication procedure to be used.

(c) When the identity of the material with the designated specification has been established in accordance with (a) or (b), each piece of material (except as alternatively provided in the specification for tubes or pipe) shall be marked to the satisfaction of the Inspector by the manufacturer or the testing agency, with a marking giving the designated specification number and grade or type and a serial S-number identifying the particular lot of material. A suitable report, clearly marked as being a "Report on Tests of Nonidentified Material," shall be furnished, properly filled out and certified by the manufacturer or testing agency, and this report when approved by the Inspector shall constitute authority to use the material as provided in the Code for designated specification.

UG-11 Miscellaneous Pressure Parts

Prefabricated or preformed pressure parts for pressure vessels which are subject to allowable working stresses due to internal or external pressure in the vessel and which are furnished by other than the shop of the manufacturer responsible for the completed vessel shall conform to all applicable requirements of this Division as related to a completed vessel, including inspection in the shop of the parts manufacturer and the furnishing of partial data reports as provided for in UG-120(b) except as permitted in (a), (b), and (c).

(a) Cast, Forged, Rolled, or Die Formed Standard Pressure Parts

(1) Pressure parts such as pipe fittings, valves, flanges, nozzles, welding necks, welding caps, manhole frames, and covers that are wholly formed by casting, forging, rolling, or die forming shall not require inspection, mill test reports, or partial data reports; however, they shall be made of materials permitted under this Division or in an accepted standard (such as American National Standard) covering the particular type of pressure part. Such parts shall be marked with the name or trademark of the manufacturer and such other markings as are required by the several standards. Such markings shall be considered as the manufacturer's certification that the product complies with the material specifications and standards indicated and is suitable for service at the rating indicated. The intent of the paragraph will have been met if, in lieu of the detailed marking on the part itself, the parts described herein have been marked in any permanent or temporary manner that will serve to identify the part with the manufacturer's written listing of the particular items and such listings are available for examination by the Inspector.

(2) Parts of small size falling within this category for which it is difficult or impossible to obtain identified material or which may be stocked and for which mill test reports or certificates cannot be economically obtained and are not customarily furnished, and which do not appreciably affect the safety of the vessel, may be used for relatively unimportant parts or parts stressed to not more than fifty percent of the stress value permitted by this Division provided they are suitable for the purpose intended and meet the approval of the Inspector (See (1) and UG-6(b)). The manufacturer of the completed vessel shall satisfy himself that the part is suitable for the design conditions specified for the completed vessel.

(b) Cast, Forged, Rolled, or Die Formed Nonstandard Pressure Parts. Pressure parts such as shells, heads, removable doors, and pipe coils that are wholly formed by casting, forging, rolling, or die forming may be supplied basically as materials. All such parts shall be made of materials permitted under this Division and the manufacturer of the part shall furnish mill test reports or other acceptable evidence to that effect. Such parts shall be marked with the name or trademark of the manufacturer and with such other markings as will serve to identify the particular parts with accompanying material identification. The manufacturer of the completed vessel shall satisfy himself that the part is suitable for the design conditions specified for the completed vessel.

(c) Welded Standard Pressure Parts for Use Other Than the Shell of a Vessel. Pressure parts such as pipe fittings, nozzles, welding necks, welding caps, valves, and flanges that are fabricated by one of the welding processes recognized by this Division shall

not require inspection, mill test reports, or partial data reports provided:

(1) All such parts are made of materials permitted under this Division of Section VIII or in an accepted standard (such as American National Standard).

(2) If arc or gas welded, the welding complies with UW-26 to UW-40, inclusive.

Such parts shall be marked with the name or trademark of the manufacturer and with such other markings as will serve to identify the materials of which the parts are made. Such markings shall be considered as the manufacturer's certification that the produot complies with (1). A statement by the parts manufacturer that all welding complies with Code requirements shall be accepted as evidence that the product complies with (2).

(3) If radiography or postweld heat treatment is required by UW-10 and UW-11, it may be performed either in the plant of the parts manufacturer or in the plant of the manufacturer of the completed vessel.

If the radiographing is done in the plant of the parts manufacturer, the completed radiographs, properly identified with the respective parts, shall be available to the Inspector. If the radiographs are examined in the plant of the parts manufacturer, parts data sheets shall be executed and forwarded to the vessel manufacturer.

(4) If heat treatment is performed at the plant of the parts manufacturer, a statement by the manufacturer that such treatment was performed shall be accepted as evidence of compliance with applicable Code paragraphs. The manufacturer of the completed vessel shall satisfy himself that the part is suitable for the design conditions specified for the completed vessel.

UG-12 Bolts and Studs

(a) Bolts and studs may be used for the attachment of removable parts, and for bolted joints as provided in UR-19. Specifications, supplementary rules, and maximum allowable stress values for acceptable bolting materials are given in Subsection C.

(b) Studs shall be threaded full length or shall be machined down to the root diameter of the thread in the unthreaded portion.

UG-13 Nuts and Washers

(a) Nuts shall conform to the requirements in the applicable Part of Subsection C (see UCS-11 and UNF-13). They shall engage the threads for the full depth of the nut.

(b) The use of washers is optional. When used, they shall be of wrought materials.

UG-14 Rods and Bars

Rod and bar stock may be used in pressure vessel construction for pressure parts such as flange rings, stiffening rings, frames for reinforced openings, stays and staybolts, and similar parts. Rod and bar materials shall conform to the requirements for bars, bolting, or rivets in the applicable part of Subsection C.

DESIGN

UG-16 General

(a) The design of pressure vessels and vessel parts shall conform to the general design requirements in the following paragraphs and in addition to the specific requirements for *Design* given in the applicable Parts of Subsections B and C.

(b) *Minimum Thickness of Plate.* The thickness after forming of any plate subject to pressure shall be not less than the minimum thickness specified in the applicable Part of Subsection C (see UCS-16(b), UNF-16(b) and UHA-20(b)).

(c) *Mill Undertolerance.* Plate material shall be ordered not thinner than the design thickness (see UA-60(h)(2)). Vessels made of plate furnished with an undertolerance of not more than the smaller value of 0.01 in. or 6 percent of the ordered thickness may be used at the full design pressure for the thickness ordered. If the specification to which the plate is ordered allows a greater undertolerance, the ordered thickness of the materials shall be sufficiently greater than the design thickness so that the thickness of the material furnished is not more than the smaller of 0.01 in. or 6 percent under the design thickness.

(d) *Pipe Undertolerance.* If pipe or tube is ordered by its nominal wall thickness, the manufacturing undertolerance on wall thickness shall be taken into account. The next heavier commerical wall thickness may then be used. The manufacturing undertolerances are given in the several pipe and tube specifications listed in the applicable tables in Subsection C. After the minimum wall thickness is determined, it shall be increased by an amount sufficient to provide the manufacturing undertolerance allowed in the pipe or tube specification.

UG-17 Methods of Fabrication in Combination

A vessel may be designed and constructed by a combination of the methods of fabrication given in this Division, provided the rules applying to the respective methods of fabrication are followed and the vessel is limited to the service permitted by the method of fabrication having the most restrictive requirements (see UG-116).

UG-18 Materials in Combination

A vessel may be designed and constructed of any combination of materials permitted in Subsection C, provided the applicable rules are followed and the requirements in Section IX for welding dissimilar metals are met.

NOTE: Because of the different thermal coefficients of expansion of dissimilar materials, caution should be exercised in design and construction under the provisions of this paragraph in order to avoid difficulties in service under extreme temperature conditions, or with unusual restraint of parts such as may occur at points of stress concentration and also because of metallurgical changes occurring at elevated temperatures. (See also *Galvanic Corrosion* in Appendix NF).

UG-19 Special Constructions

(*a*) *Combination Units.* When a pressure vessel unit consists of more than one independent pressure chamber, operating at the same or different pressures and temperatures, each such pressure chamber (vessel) shall be designed and constructed to withstand the most severe condition of coincident pressure and temperature expected in normal service. Only the parts of chambers which come within the scope of this Division, U-1, need be constructed in compliance with its provisions.

(*b*) *Special Shapes.* Vessels other than cylindrical and spherical and those for which no design rules are provided in this Division may be designed under the conditions set forth in U-2.

(*c*) When no design rules are given and the strength of a pressure vessel or vessel part cannot be calculated with a satisfactory assurance of accuracy, the maximum allowable working pressure of the completed vessel shall be established in accordance with the provisions of UG-101.

UG-20 Design Temperature

(*a*) Except as required in UW-2(d)(3), the temperature used in design shall be not less than the mean metal temperature (through the thickness) expected under operating conditions for the part considered. (See footnotes 1 and 2 of UA-60(g).) If necessary, the metal temperature shall be determined by computation using accepted heat transfer procedures or by measurement from equipment in service under equivalent operating conditions. In no case shall the temperature at the surface of the metal exceed the maximum temperature listed in the stress tables for materials nor exceed the temperature limitations specified elsewhere in this Division of Section VIII.

(*b*) When the occurrence of different metal temperatures during operation can be definitely predicted for different zones of a vessel, the design of the different zones may be based on their predicted temperatures. When sudden cyclic changes in temperature are apt to occur in normal operation with only minor pressure fluctuations, the design shall be governed by the highest probable operating metal temperature (or the lowest, for temperatures below −20 F) and the corresponding pressure (see UA-60(b)).

(*c*) Suggested methods for determining the working temperatures of the wall of vessels already in service are given in Appendix C.

UG-21 Design Pressure[1]

Vessels covered by this Division of Section VIII shall be designed for at least the most severe condition of coincident pressure and temperature expected in normal operation. For this condition, the maximum difference in pressure between the inside and outside of a vessel, or between any two chambers of a combination unit, shall be considered (see UG-98 and UA-60(b)).

UG-22 Loadings

The loadings to be considered in designing a vessel shall include:

(*1*) Internal or external design pressure (as defined in UG-21);

(*2*) Impact loads, including rapidly fluctuating pressures;

(*3*) Weight of the vessel and normal contents under operating or test conditions. (This includes additional pressure due to static head of liquids);

(*4*) Superimposed loads such as other vessels, operating equipment, insulation, corrosion resistant or erosion resistant linings, and piping;

[1]It is recommended that a suitable margin be provided above the pressure at which the vessel will be normally operated to allow for probable pressure surges in the vessel up to the setting of the pressure relieving devices (see UG-133).

(*5*) Wind loads, and earthquake loads where required;

(*6*) Reactions of supporting lugs, rings, saddles or other types of supports (see Appendices D and G);

(*7*) The effect of temperature gradients on maximum stress.

UG-23 Maximum Allowable Stress Values

(*a*) The maximum allowable stress value is the maximum unit stress permitted in a given material used in a vessel constructed under these rules. The maximum allowable tensile stress values permitted for different materials are given in the following tables, which are included in Subsection C.

Table UCS-23 Maximum Allowable Stress Values in Tension for Carbon and Low-Alloy Steel
Table UNF-23 Maximum Allowable Stress Values in Tension for Nonferrous Metals
Table UHA-23 Maximum Allowable Stress Values in Tension for High-Alloy Steel
Table UCI-23 Maximum Allowable Stress Values in Tension for Cast Iron
Table UCD-23 Maximum Allowable Stress Values in Tension for Cast Ductile Iron
Table UHT-23 Maximum Allowable Stress Values in Tension for Ferritic Steels with Properties Enhanced by Heat Treatment
Table UCS-27 Maximum Allowable Stress Values in Tension for Carbon and Low-Alloy Pipe and Tubes of Welded Manufacture

(*b*) The maximum allowable compressive stress to be used in the design of cylindrical shells subjected to loadings that produce longitudinal compressive stress in the shell shall be the smaller of the following values:

(*1*) The maximum allowable tensile stress value permitted in (a);

(*2*) The value of the factor B determined from the applicable chart in Appendix V for determining the required thickness of shells and heads under external pressure, using the following definitions for the symbols on the chart:

t_h = the minimum required thickness of the shell plates, exclusive of corrosion allowances, inches
L_1 = inside radius of cylindrical shell, inches

The value of B shall be determined from the applicable chart of Appendix V in the following manner:

Step 1: Assume a value of t_h. Determine the ratio $L_1/100t_h$.

Step 2: Enter the left-hand side of the chart in Appendix V for the material under consideration at the value $L_1/100t_h$ determined in Step 1.

Step 3: Move horizontally to the line marked Sphere Line.

Step 4: From this intersection move vertically to the material line for the design temperature (see UG-20). (For intermediate temperatures, interpolations may be made between the material lines on the chart.)

Step 5: From this intersection move horizontally to the right and read the value of B. This is the maximum allowable compressive stress value for the value of t_h used in Step 1.

Step 6: Compare this value of B with the computed longitudinal compressive stress in the vessel, using the assumed value of t_h. If the value of B is smaller than the computed stress, a greater value of t_h must be selected and the procedure repeated until a value of B is obtained which is greater than the value computed for the loading on the vessel.

The joint efficiency for butt welded joints may be taken as unity.

(*c*) The wall thickness of a vessel computed by these rules shall be determined so that the maximum direct (membrane) stress due to any combination of loadings listed in UG-22 that are expected to occur simultaneously during normal operation[1] of the vessel does not exceed the maximum allowable stress values permitted at the temperature that is expected to be maintained in the metal under the condition of loading being considered.[2] Values may be interpolated for intermediate temperatures.[3]

UG-24 Castings

(*a*) *Quality Factors.* A casting quality factor as specified below shall be applied to the allowable stress values for cast materials given in Subsection C except for castings permitted by Part UCI. Definitions and radiographic standards are given in Appendix VII.

(*1*) A factor not to exceed 80 percent shall be applied to static castings which are examined in

[1]See Definitions—UA-60(d) and (h).

[2]It is recognized that high localized and secondary bending stresses may exist in vessels designed and fabricated in accordance with these rules. In so far as practical, design rules for details have been written to hold such stresses at a safe level consistent with experience.

[3]For the basis on which the tabulated stress values have been established, see Appendix P for steels, and Appendix Q for a similar basis applying only to nonferrous metals.

accordance with the minimum requirements of the material specification. In addition to the minimum requirements of the material specification, all surfaces of centrifugal castings shall be machined after heat treatment to a finish not coarser than 250 microinches arithmetical average deviation, and a factor not to exceed 85 percent shall be applied.

(2) For nonferrous and ductile cast iron materials, a factor not to exceed 90 percent shall be applied if in addition to the minimum requirements of UG-24(a)(1)

(a) Each casting is subjected to a thorough examination of all surfaces, particularly such as are exposed by machining or drilling, without revealing any injurious defects;

(b) At least three pilot castings[1] representing the first lot of five castings made from a new or altered design are sectioned or radiographed at all critical sections (see Note 1, Appendix VII) without revealing any injurious defects;

(c) One additional casting taken at random from every subsequent lot of five is sectioned or radiographed at all critical sections without revealing any injurious defects; and

(d) All castings other than those which have been radiographed are examined at all critical sections by a procedure using magnetic particles per Appendix VI, or liquid penetrant, or by grinding or machining and etching.

(3) For nonferrous and ductile cast iron materials, a factor not to exceed 90 percent may be used for a single casting which has been radiographed at all critical sections and found free of injurious defects.

(4) For nonferrous and ductile cast iron materials, a factor not to exceed 90 percent may be used for a casting which has been machined to the extent that all critical sections are exposed for examination for the full wall thickness; as in tube sheets drilled with holes spaced no farther apart than the wall thickness of the casting. The examination afforded may be taken in lieu of destructive or radiographic testing required in (2)(b).

(5) For carbon, low-alloy or high-alloy steels, higher quality factors may be applied if in addition to the minimum requirements of UG-24 (a)(1), additional examinations are made as follows:

(a) For centrifugal castings, a factor not to exceed 90 percent may be applied if the castings are examined by the magnetic particle or liquid penetrant methods in accordance with the requirements of Appendix VII.

(b) For static and centrifugal castings a factor not to exceed 100 percent may be applied if the castings are examined in accordance with all of the requirements of Appendix VII.

(*b*) *Defects.* Serious defects shall be the basis of rejection of the casting. The Inspector shall have the right to demand a similar examination of any number of additional castings from the same heat until acceptable castings are consistently produced where a 90 or 100 percent quality factor is used. Where defects not impairing the strength of the casting have been repaired by welding, the completed repair shall be subject to reexamination and, when required by either the rules of this Section or the requirements of the castings specification, the repaired casting shall be postweld heat treated and to obtain a 90 or 100 percent factor, the repaired casting shall be stress relieved.

(*c*) *Identification and Marking.* Castings to which a quality factor of 90 or 100 percent is to be applied shall be marked with the manufacturer's and materials identification marking and in addition, the quality factor shall be clearly stamped on the casting. Test reports or certificates furnished by the manufacturer shall certify that the castings conform to the requirements of this Division.

[1]Pilot casting—Any one casting, usually one of the first from a new pattern, poured of the same material and using the identical foundry procedure (riserng, gating, pouring, and melting) as the castings it is intended to represent. Any pilot casting or castings taken to represent a lot and the castings of that lot shall be poured from a heat of metal from which the castings on the current order are poured.

UG-25 Corrosion

(*a*) Vessels or parts of vessels subject to thinning by corrosion, erosion, or mechanical abrasion shall have provision made for the desired life of the vessel by a suitable increase in the thickness of the material over that determined by the design formulas, or by using some other suitable method of protection. (See Appendix E.)

NOTE: When using high alloys and nonferrous materials either for solid wall or clad or lined vessels, refer to UHA-6, UCL-3, and UNF-4, as appropriate.

(*b*) Material added for these purposes need not be of the same thickness for all parts of the vessel if different rates of attack are expected for the various parts.

(*c*) Except as required in UCS-25, no additional thickness need be provided when previous experience

in like service has shown that corrosion does not occur or is of only a superficial nature.

(*d*) *Telltale Holes.* Telltale holes may be used to provide some positive indication when the thickness has been reduced to a dangerous degree. When telltale holes are provided they shall be at least $^3/_{16}$ in. in diameter and have a depth not less than 80 percent of the thickness required for a seamless shell of like dimensions. These holes shall be provided in the surface opposite to that where deterioration is expected. (For telltale holes in clad or lined vessels, see UCL-25(b).)

(*e*) *Openings for Drain.* Vessels subject to corrosion shall be supplied with a suitable drain opening at the lowest point practicable in the vessel; or a pipe may be used extending inward from any other location to within $^1/_4$ in. of the lowest point.

UG-26 Linings

Corrosion resistant or abrasion resistant linings, whether or not attached to the wall of a vessel, shall not be considered as contributing to the strength of the wall except as permitted in Part UCL (see Appendix F).

UG-27 Thickness of Shells Under Internal Pressure

(*a*) The thickness of shells under internal pressure shall be not less than that computed by the following formulas.[1] In addition, provision shall be made for any of the other loadings listed in UG-22, when such loadings are expected. (See UG-16.)

(*b*) The symbols defined below are used in the formulas of this paragraph.

t = minimum required thickness of shell plates, exclusive of corrosion allowance (see UG-25), inches

P = design pressure, pounds per square inch (see UG-21), (or maximum allowable working pressure for existing vessels, see UG-98)

R = inside radius of the shell course under consideration, before corrosion allowance is added, inches

S = maximum allowable stress value, pounds per square inch (see applicable table of stress values in Subsection C)

E = joint efficiency for or the efficiency of appropriate joint in cylindrical shells and any joint in spherical shells, or the efficiency of liga-

ments between openings, whichever is less:

For welded vessels, use the efficiency specified in UW-12.

For riveted joints, use the efficiency specified in UR-15

Where there is no joint normal to the direction of stress under consideration (e.g., no longitudinal joint when circumferential stress formulas are used), $E=1$. For ligaments between openings, use the efficiency calculated by the rules given in UG-53

(*c*) *Cylindrical Shells.* The minimum thickness or maximum allowable working pressure of cylindrical shells shall be the greater thickness or lesser pressure as given by (1) or (2):

(*1*) *Circumferential stress (longitudinal joints).* When the thickness does not exceed one-half of the inside radius, or P does not exceed $0.385\,SE$, the following formulas shall apply:

$$t=\frac{PR}{SE-0.6P} \quad \text{or} \quad P=\frac{SE\,t}{R+0.6t} \qquad (1)$$

(*2*) *Longitudinal stress (circumferentidl joints).*[2] When the thickness does not exceed one-half of the inside radius, or P does not exceed $1.25\,SE$, the following formulas shall apply:

$$t=\frac{PR}{2SE+0.4P} \quad \text{or} \quad P=\frac{2SE\,t}{R-0.4t} \qquad (2)$$

(*d*) *Spherical Shells.* When the thickness of the shell of a wholly spherical vessel does not exceed $0.356\,R$, or P does not exceed $0.665\,SE$, the following formulas shall apply:

$$t=\frac{PR}{2SE-0.2P} \quad \text{or} \quad P=\frac{2SE\,t}{R+0.2t}$$

(*e*) When necessary, vessels shall be provided with stiffeners or other additional means of support to prevent overstress or large distortions under the external loadings listed in UG-22 other than pressure and temperature.

(*f*) A stayed jacket shell that extends completely around a cylindrical or spherical vessel shall also meet the requirements of UG-47 (c).

[1]Formulas in terms of the outside radius and for thicknesses and pressures beyond the limits fixed in this paragraph are given in UA-1 to UA-3.

[2]These formulas will govern only when the circumferential joint efficiency is less than one-half the longitudinal joint efficiency, or when the effect of supplementary loadings (UG-22) causing longitudinal bending or tension in conjunction with internal pressure is being investigated. An example illustrating this investigation is given in Appendix L (UA-274(a) and (b)).

(*g*) Any reduction in thickness within a shell course or spherical shell shall be in accordance with UW-9.

UG-28 Thickness of Shells Under External Pressure

(*a*) The rules for the design of shells under external pressure given in this Division are limited to spherical shells and cylindrical shells either with or without stiffening rings. Three typical forms of cylindrical shells are shown in Fig. UG-28. Charts for determining the required thickness of shells and heads are given in Appendix V.

(*b*) The symbols defined below are used in the formulas of this paragraph:

t = minimum required thickness of cylindrical shell plates, exclusive of corrosion allowance, inches

t_h = minimum required thickness of spherical shell plates, exclusive of corrosion allowance, inches

L = design length of a vessel section, using the applicable definition below.

(1) the distance between head-bend lines plus one-third of the depth of each head if there are no stiffening rings; (2) the greatest center-to-center distance between any two adjacent stiffening rings; or (3) the distance from the center of the first stiffening ring to the head-bend line plus one-third of the depth of the head, all measured parallel to the axis of the vessel, inches

L_1 = inside radius of spherical shells, inches

D_o = outside diameter of the cylindrical shell course under consideration, inches

P = external design pressure, pounds per square inch (see UG-28(e) and (f)), (maximum allowable working pressure for existing vessels in operating position)

(*c*) *Cylindrical Shells.* The required thickness of a cylindrical shell under external pressure, either seamless or with longitudinal butt joints, shall not be less than that determined by the following procedure:

Step 1: Assume a value for t. Determine the ratios L/D_o and D_o/t.

Step 2: Enter the left-hand side of the chart in Appendix V for the material under consideration at the value of L/D_o determined in Step 1.

Step 3: Move horizontally to the line representing D_o/t determined in Step 1.

Step 4: From this intersection move vertically to the material line for the design temperature (see UG-20). (For intermediate temperatures, interpolations may be made between the lines on the chart.)

Step 5: From this intersection move horizontally to the right and read the value of B.

Step 6: Compute the maximum allowable working pressure P_a by the following formula:

$$P_a = \frac{B}{D_o/t}$$

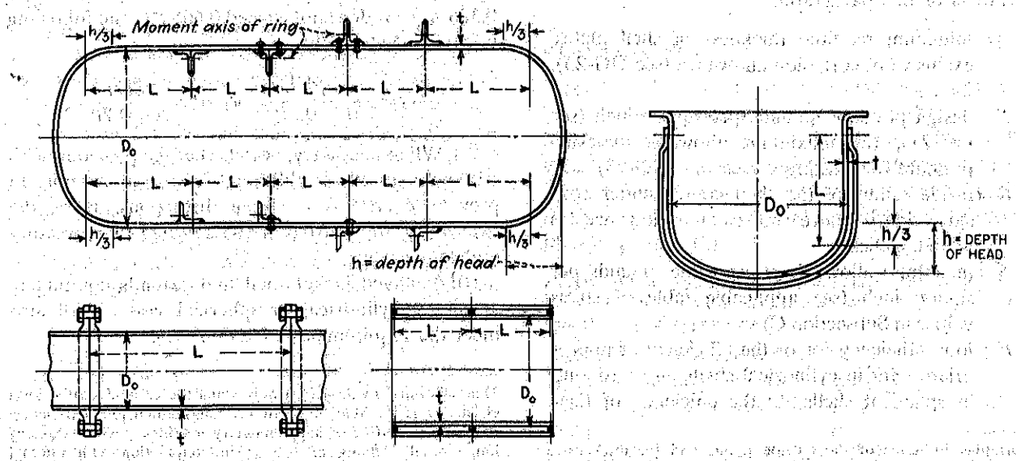

FIG. UG-28 DIAGRAMMATIC REPRESENTATION OF VARIABLES FOR DESIGN OF CYLINDRICAL VESSELS SUBJECTED TO EXTERNAL PRESSURE

Step 7: Compare P_a with P. If P_a is smaller than P a greater value for t must be selected and the design procedure repeated until a value for P_a is obtained that is equal to or greater than P. An example illustrating the use of this procedure is given in Appendix L (UA-270(a)).

(*d*) *Spherical Shells.* The required thickness of a spherical shell under external pressure, either seamless or of built-up construction with butt joints, shall not be less than that determined by the following procedure:

Step 1: Assume a value for t_h. Determine the ratios L_1/t_h and $L_1/100t_h$.

Step 2: Enter the left-hand side of the chart in Appendix V for the material under consideration at the value of $L_1/100t_h$ determined in Step 1.

Step 3: Move horizontally to the line marked Sphere Line.

Step 4: From this intersection move vertically to the material line for the design temperature (see UG-20). (For intermediate temperatures, interpolations may be made between the lines on the chart.)

Step 5: From this intersection move horizontally to the right and read the value of B.

Step 6: Compute the maximum allowable working pressure P_a by the following formula:

$$P_a = \frac{B}{L_1/t_h}$$

Step 7: Compare P_a with P. If P_a is smaller than P a greater value for t_h must be selected and the design procedure repeated until a value for P_a is obtained that is equal to or greater than P. An example illustrating the use of this procedure is given in Appendix L (UA-270(b)).

(*e*) The design pressure or maximum allowable working pressure shall not be less than the maximum expected difference in operating pressure that may exist between the outside and the inside of the vessel at any time.

(*f*) Vessels intended for service under external working pressures of 15 psi or less, which are to be stamped with the Code symbol denoting compliance with the rules for external pressure, shall be designed for a maximum allowable external pressure of 15 psi or 25 percent more than the maximum possible external pressure, whichever is smaller.

NOTE: Except as covered in UCS-66(c)(2) and UHA-51(b), a vessel which is designed and constructed to Code requirements for internal pressure and which may at times be subjected to an external pressure of 15 psi or less need not be constructed to Code requirements for the external pressure condition. Such a vessel may bear the Code symbol for the internal pressure condition.

(*g*) When there is a longitudinal lap joint in a cylindrical shell or any lap joint in a spherical shell under external pressure, the thickness of the shell shall be determined by the rules in this paragraph, except that $2P$ shall be used instead of P in the calculations for the required thickness.

(*h*) Circumferential joints in cylindrical shells may be of any type permitted by the Code and shall be designed for the imposed loads.

(*i*) Those portions of pressure chambers of vessels which are subject to a collapsing pressure and which have a shape other than that of a complete circular cylinder or formed head, and also jackets of cylindrical vessels which extend over only a portion of the circumference, shall be fully staybolted in accordance with the requirements of UG-47 through UG-50 or shall be proof tested in compliance with UG-101(p).

(*j*) When necessary, vessels shall be provided with stiffeners or other additional means of support to prevent overstress or large distortions under the external loadings listed in UG-22 other than pressure and temperature.

UG-29 Stiffening Rings for Cylindrical Shells Under External Pressure

(*a*) Except as exempted below in (f), the required moment of inertia of a circumferential stiffening ring shall not be less than that determined by the formula:

$$I_s = \frac{D_o^2 L_s \left(t + \frac{A_s}{L_s}\right) A}{14}$$

where

I_s = required moment of inertia of the stiffening ring about its neutral axis parallel to the axis of the shell, inches⁴

A_s = cross-sectional area of the stiffening ring, square inches

A = factor determined from the appropriate chart in Appendix V for the material used in the stiffening ring, corresponding to the Factor B (see below) and the design temperature for the shell under consideration

L_s = one-half of the distance from the centerline of the stiffening ring to the next line of support on one side, plus one-half of the center-

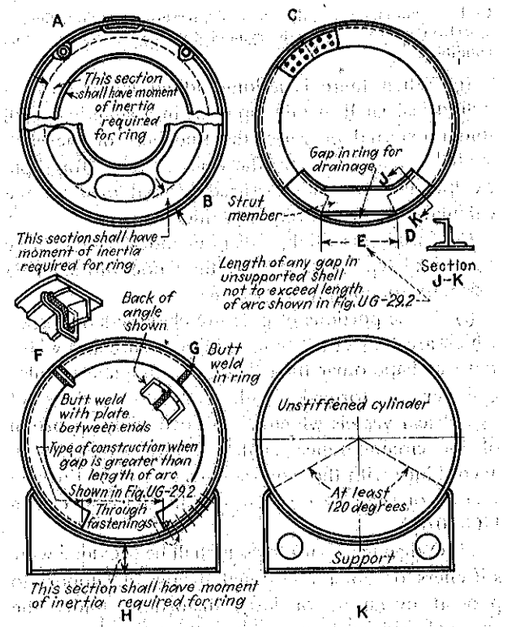

FIG. UG-29.1 VARIOUS ARRANGEMENTS OF STIFFENING RINGS FOR CYLINDRICAL VESSELS SUBJECTED TO EXTERNAL PRESSURE

line distance to the next line of support, if any, on the other side of the stiffening ring, both measured parallel to the axis of the vessel, in. A line of support is (1) a stiffening ring that meets the requirements of this paragraph, (2) a circumferential connection to a jacket, or (3) a circumferential line on a head at one-third the depth of the head from the head-bend line, as shown in Fig. UG-28

P, D_o and t are as defined in UG-28 (b)

The moment of inertia for a stiffening ring shall be determined by the following procedure:

Step 1: Assuming that the shell has been designed and D_o, L_s, and t are known, select a member to be used for the stiffening ring and determine its area, A_s, and moment of inertia, I. Then calculate B by the formula:

$$B = \frac{PD_o}{t + \frac{A_s}{L_s}}$$

B = factor on the right-hand side of the appropriate chart in Appendix V for the material used in the stiffening ring.

Step 2: Enter the right-hand side of the chart in Appendix V for the material under consideration at the value of B determined by Step 1.

Step 3: Follow horizontally to the material line for the design temperature.

Step 4: Move vertically to the bottom of the chart and read the value of A.

Step 5: Compute the value of the required moment of inertia, I_s, from the formula given above.

Step 6: If the required I_s is greater than the moment of inertia, I, for the section selected in Step 1, a new section with a larger moment of inertia must be selected and a new I_s determined.

If the required I_s is smaller than I for the section selected in Step 1, that section should be satisfactory.

An example illustrating the use of this procedure is given in Appendix L (UA-272).

(*b*) Stiffening rings shall extend completely around the circumference of the vessel. Any joints between the ends or sections of such rings, similar to those shown at C, D, F, and G in Fig. UG-29.1, and any connections between adjacent portions of a stiffening ring lying inside or outside the shell as shown at H in Fig. UG-29.1, shall be made so that the required moment of inertia of the ring is maintained.

(*c*) Stiffening rings placed on the inside of a vessel may be arranged as shown at A and B in Fig. UG-29.1, provided that the moment of inertia required for the ring (see (a) above) is maintained within the sections indicated. The moment of inertia of each section shall be taken about its own neutral axis. However, any gap in that portion of a stiffening ring supporting the shell, as shown at A and E in Fig. UG-29.1, shall not exceed the length of arc as given in Fig. UG-29.2 unless additional reinforcement is provided as shown at H in Fig. UG-29.1 or unless:

(*1*) The length of unsupported shell arc does not exceed 90 deg; and

(*2*) The unsupported shell arcs in adjacent stiffening rings are staggered 180 deg; and

(*3*) The dimension L, defined in UG-28 (b) is taken as the larger of the following: the greatest distance between alternate stiffening rings, or the distance from the head-bend line to the second stiffening ring plus one-third of the head depth.

(*d*) When internal plane structures perpendicular to the longitudinal axis of the cylinder, such as bubble trays or baffle plates, are used in a vessel, they may also be considered to act as stiffening

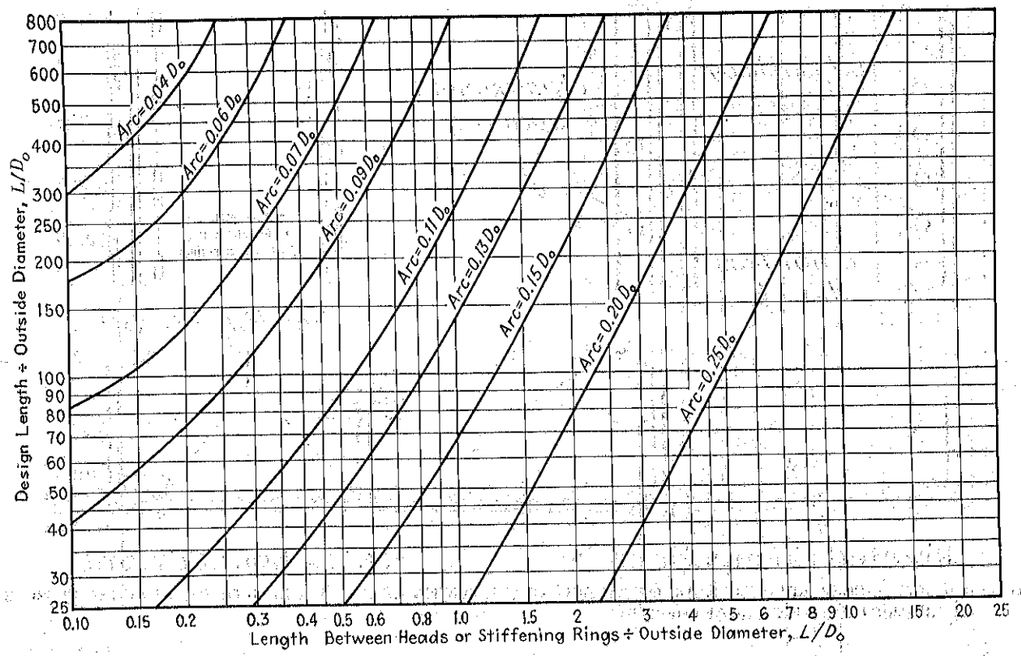

FIG. UG-29.2 MAXIMUM ARC OF SHELL LEFT UNSUPPORTED BECAUSE OF GAP IN STIFFENING RING OF CYLINDRICAL SHELL UNDER EXTERNAL PRESSURE

rings provided they are designed to function as such.

(*e*) Any internal stays or supports for any purpose shall not bear against the shell of the vessel except through the medium of a substantially continuous ring.

NOTE: Attention is called to the objection to supporting vessels through the medium of legs or brackets, the arrangement of which may cause concentrated loads to be imposed on the shell. Vertical vessels should be supported through a substantial ring secured to the shell (see UA-187). Horizontal vessels, unless supported at or close to the ends (heads) or at stiffening rings, should be supported through the medium of substantial members extending over at least one-third of the circumference, as shown at K in Fig. UG-29.1.

Attention is called also to the hazard of imposing highly concentrated loads by the improper support of one vessel on another or by the hanging or supporting of heavy weights directly on the shell of the vessel. (See Appendix G.)

(*f*) When closure bars or other rings are attached to both the inner shell and outer jacket of a vessel, with pressure in the space between the jacket and inner shell, this construction has adequate inherent stiffness, and therefore the rules of this paragraph do not apply.

UG-30 Attachment of Stiffening Rings to Shell

(*a*) Stiffening rings, when used, may be placed on the inside or outside of a vessel, and shall be attached to the shell by welding, brazing, riveting, or bolting. Brazing may be used if the vessel is not to be later stress relieved. The ring should be in contact with the shell.

(*b*) Stiffening rings may be attached to the shell either by continuous or intermittent welding. The total length of the intermittent welding on each side of the stiffening ring shall be (1) not less than one-half the outside circumference of the vessel for rings on the outside; and (2) not less than one-third of the circumference of the vessel for rings on the inside. Acceptable arrangements and spacings of intermittent welds are shown in Fig. UG-30. Welds on opposite sides of the stiffener may be either staggered or in-line as indicated.

(*c*) If the rings are on the outside and riveted to the shell, the nominal diameter of the rivets shall be not less than the thickness of the shell plate, and the center-to-center distance of the rivet holes shall not exceed that required by Fig. UG-30.

(*d*) All attachments welding of stiffening rings shall comply with the requirements of this Code

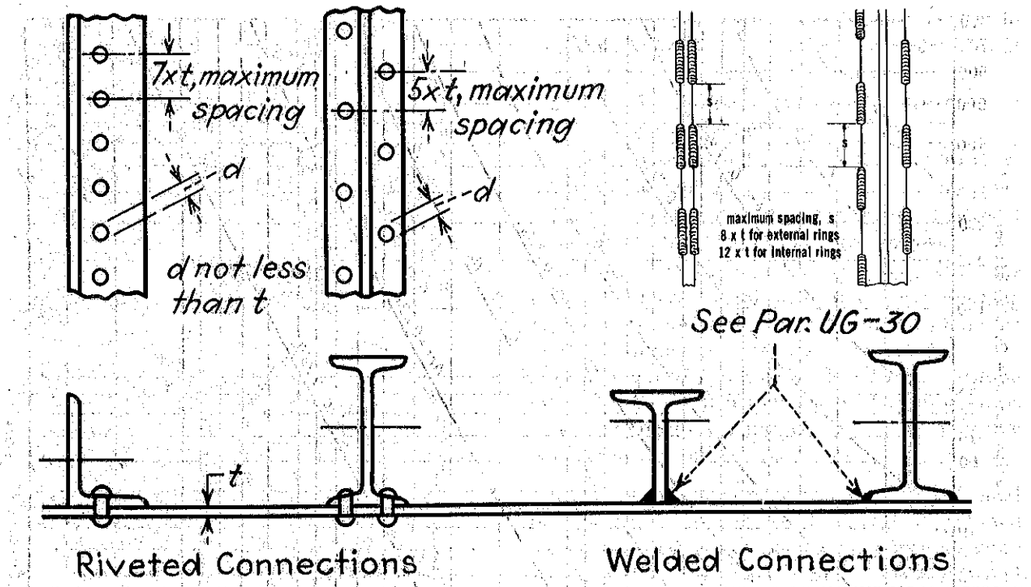

FIG. UG-30 SOME ACCEPTABLE METHODS OF ATTACHING STIFFENING RINGS TO SHELLS OF CYLINDRICAL VESSELS SUBJECTED TO EXTERNAL PRESSURE

for the type of vessel under construction. Where corrosion must be provided for, the stiffening rings shall be attached to the shell with a continuous fillet or seal weld.

UG-31 Tubes, and Pipe When Used as Tubes

(*a*) *Internal Pressure.* The required wall thickness for tubes and pipe under internal pressure shall be determined in accordance with the rules for shells in UG-27.

(*b*) *External Pressure.* The required wall thickness for tubes and pipe under external pressure shall be determined in accordance with Fig. UG-31.

(*c*) The thickness as determined under (a) or (b) shall be increased when necessary to meet the following requirements:

(*1*) Additional wall thickness should be provided when corrosion, erosion, or wear due to cleaning operations is expected;

(*2*) Where tube ends are threaded, additional wall thickness is to be provided in the amount of $0.8/n$ in. (where n equals the number of threads per inch).

NOTE: The requirements for rolling, expanding, or otherwise seating tubes in tube plates may require additional wall thickness and careful choice of materials because of possible relaxation due to differential expansion stresses.

UG-32 Formed Heads, Pressure on Concave Side

(*a*) The required thickness at the thinnest point after forming[1] of ellipsoidal, torispherical, conical, and hemispherical heads under pressure on the concave side (plus heads), shall be computed by the appropriate formulas in this paragraph[2] (see UG-16). In addition, provision shall be made for any of the other loadings given in UG-22.

(*b*) The thickness of an unstayed ellipsoidal or torispherical head shall in no case be less than the required thickness of a seamless hemispherical head divided by the efficiency of the head-to-shell joint.

(*c*) The symbols defined below are used in the formulas of this paragraph:

t = minimum required thickness of head after forming, exclusive of corrosion allowance, inches

[1] In order to insure that a finished head is not less than the minimum thickness required, it is customary to use a thicker plate to take care of possible thinning during the process of forming. The neck of an opening in a head with an integrally flanged opening will thin out due to the fluing operation. This is permissible provided the neck thickness is not less than the thickness required for a cylindrical shell having a diameter equal to the maximum diameter of the opening. (See UG-46(j).)

[2] Formulas in terms of outside dimensions and for heads of other proportions are given in UA-4 together with illustrative examples.

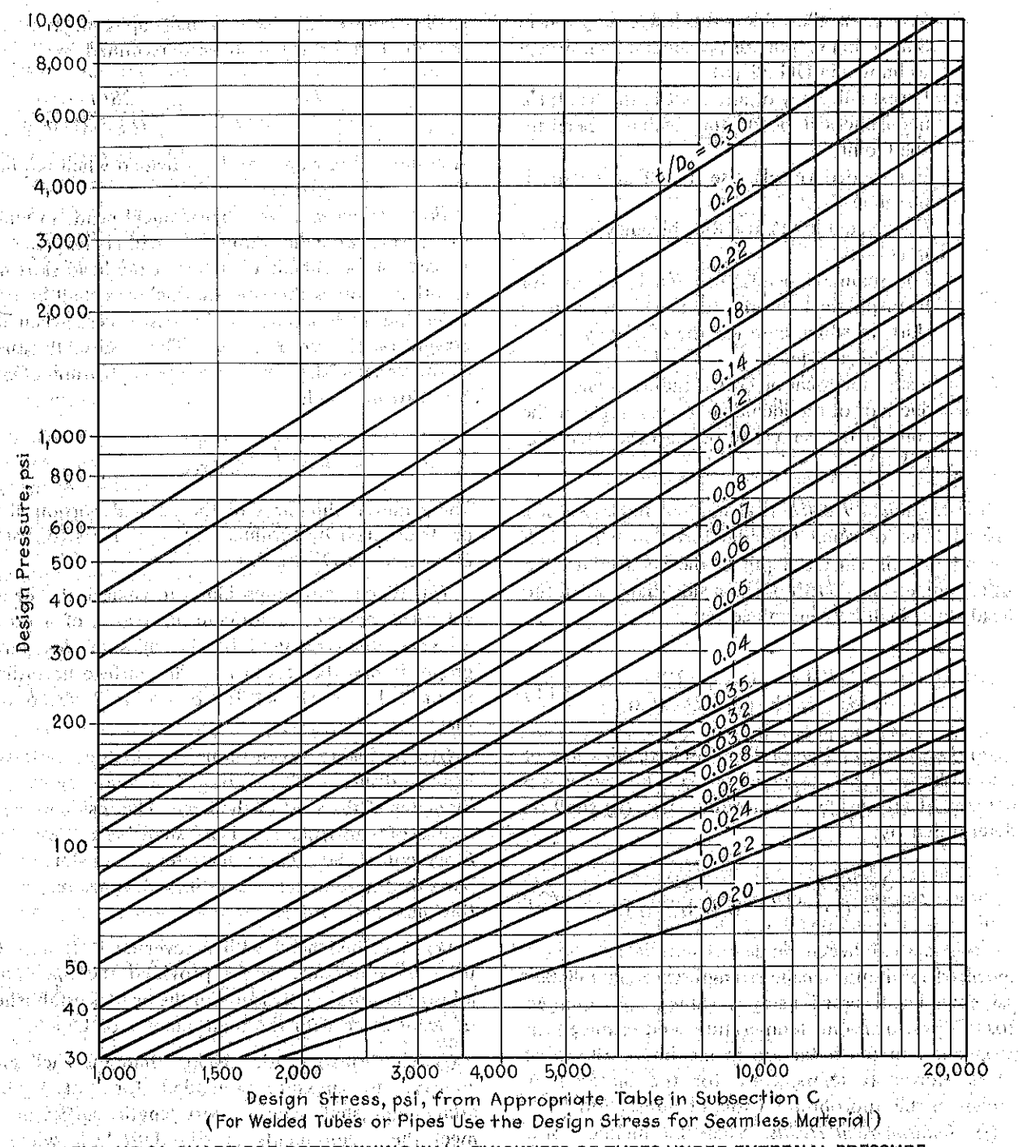

FIG. UG-31 CHART FOR DETERMINING WALL THICKNESS OF TUBES UNDER EXTERNAL PRESSURE

P = design pressure, pounds per square inch (see UG-21), (or maximum allowable working pressure for existing vessels, see UG-98)

D = inside diameter of the head skirt; or inside length of the major axis of an ellipsoidal head; or inside diameter of a cone head at the point under consideration, measured perpendicular to the longitudinal axis, inches (measurements to be taken before corrosion allowance is added)

D_1 = inside diameter of the conical portion of a toriconical head at its point of tangency to the knuckle, measured perpendicular to the axis of the cone, inches

S = maximum allowable stress value as given in Subsection C, pounds per square inch except as limited in UG-32 (e)

E = lowest efficiency of any joint in the head; for hemispherical heads this includes head-to-shell joint;
For welded vessels, use the efficiency specified in UW-12,
For riveted joints, use the efficiency specified in UR-15
For seamless heads, use $E=1$, except for hemispherical heads furnished without a skirt, in which case use the efficiency of the head-to-shell joint

L = inside spherical or crown radius, inches

α = one-half of the included (apex) angle of the cone at the centerline of the head (see Fig. UA-4)

(*d*) *Ellipsoidal Heads.* The required thickness of a dished head of semiellipsoidal form, in which half the minor axis (inside depth of the head minus the skirt) equals one-fourth of the inside diameter of the head skirt, shall be determined by:

$$t=\frac{PD}{2SE-0.2P} \text{ or } P=\frac{2SEt}{D+0.2t} \quad (1)$$

(*e*) *Torispherical Heads.* The required thickness of a torispherical head, in which the knuckle radius is 6 percent of the inside crown radius, (see (j)) shall be determined by:

$$t=\frac{0.885PL}{SE-0.1P} \text{ or } P=\frac{SEt}{0.885L+0.1t} \quad (2)$$

Torispherical heads made of materials having a specified minimum tensile strength exceeding 80,000 psi shall be designed using a value of S equal to 20,000 psi at room temperature and reduced in proportion to the reduction in maximum allowable stress values at temperature for the material as shown in the appropriate Table of Subsection C.

(*f*) *Hemispherical Heads.* When the thickness of a hemispherical head does not exceed $0.356L$, or P does not exceed $0.665SE$, the following formulas shall apply:

$$t=\frac{PL}{2SE-0.2P} \text{ or } P=\frac{2SEt}{L+0.2t} \quad (3)$$

(*g*) *Conical Heads (Without Transition Knuckle).* The required thickness of conical heads or conical shell sections that have a half apex-angle α not greater than 30 deg shall be determined by:

$$t=\frac{PD}{2\cos\alpha(SE-0.6P)} \text{ or } P=\frac{2SEt\cos\alpha}{D+1.2t\cos\alpha} \quad (4)$$

A compression ring shall be provided when required by the rule in UA-5(b) and (c).

(*h*) *Toriconical Heads.* Toriconical heads in which the inside knuckle radius is neither less than 6 percent of the outside diameter of the head skirt nor less than 3 times the knuckle thickness shall be used when the angle α exceeds 30 deg except when the design complies with UA-5(e). The required thickness of the knuckle shall be determined by formula (3) of UA-4(d) in which

$$L=\frac{D_1}{2\cos\alpha}$$

The required thickness of the conical portion shall be determined by formula (4) in (g) above, using D_1 in place of D (see (c)).

(*i*) When an ellipsoidal, torispherical, hemispherical, conical, or toriconical head is of a lesser thickness than required by the rules of this paragraph, it shall be stayed as a flat surface according to the rules of UG-47 for braced and stayed flat plates.

(*j*) The inside crown radius to which an unstayed head is dished shall be not greater than the outside diameter of the skirt of the head. The inside knuckle radius of a torispherical head shall be not less than 6 percent of the outside diameter of the skirt of the head but in no case less than 3 times the head thickness.

(*k*) A dished head with a reversed skirt may be used in a pressure vessel provided the maximum allowable working pressure for the head is established in accordance with the requirements of UG-101.

(*l*) All formed heads, thicker than the shell and concave to pressure, intended for butt-welded attachment shall have a skirt length, sufficient to meet the requirements of Fig. UW-13.1, when a tapered transition is required.

(*m*) Heads concave to pressure, intended for attachment by riveting or brazing, shall have a skirt length sufficient to meet the requirements for circumferential joints in Part UR and Part UB, respectively.

(*n*) Any taper at a welded joint within a formed head shall be in accordance with UW-9. The taper at a circumferential welded joint connecting a formed head to a main shell shall meet the requirements of UW-13 for the respective type of joint shown therein.

(*o*) *All formed heads* concave to pressure and intended for butt welded attachment need not have an integral skirt *when the thickness of the head is equal to or less than the thickness of the shell.* When a skirt is provided, its thickness shall be at least that required for a seamless shell of the same diameter.

(*p*) If a torispherical, ellipsoidal, or hemispherical head is formed with a flattened spot or surface, the diameter of the flat spot shall not exceed that permitted for flat heads as given by the formula in UG-34, using $C = 0.25$.

(*q*) Openings in formed heads under internal pressure shall comply with the requirements of UG-36 through UG-46.

(*r*) A stayed jacket that completely covers a formed inner head or any of the types included in this paragraph shall also meet the requirements of UG-47(c).

UG-33 Formed Heads, Pressure on Convex Side

(*a*) The required thickness at the thinnest point after forming of ellipsoidal or torispherical heads under pressure on the convex side (minus heads) shall be the greater of the following thicknesses:

(*1*) The thickness as computed by the procedure given in UG-32 for heads with the pressure on the concave side (plus heads) using a design pressure 1.67 times the external design pressure, assuming the joint efficiency $E = 1.00$ for all cases; or

(*2*) The thickness as computed by the appropriate procedure given in (d) or (e).

When checking an existing design of an ellipsoidal or torispherical head to determine its maximum allowable working pressure, this pressure shall be determined by reversing the procedures in (1) and (2) above and using the smaller value obtained.

The required thickness of hemispherical heads under pressure on the convex side shall be determined by the rules given in (c).

The required thickness of conical heads under pressure on the convex side shall be determined by the rules given in (f).

In addition, provision shall be made for any other loadings given in UG-22. Fig. UA-4 shows principal dimensions of typical heads. (See note 1, UG-32(a).)

(*b*) The symbols defined below are used in the formulas of this paragraph:

t_h = minimum required thickness of head after forming, exclusive of corrosion allowance, inches

P = external design pressure, pounds per square inch (see UG-28(e) and (f)), (maximum allowable working pressure for a vessel in its operating position)

L_1 = for hemispherical heads, the inside radius, inches
for ellipsoidal heads, the equivalent inside spherical radius taken as K_1D_0, inches
for torispherical heads, the inside radius of the crown portion of the head, inches

D_0 = outside diameter of the head skirt; or the outside diameter of a cone head at the point under consideration, measured perpendicular to the longitudinal axis of the cone, inches (see (f).)

K_1 = a factor depending upon the ellipsoidal head proportions, given in Table UG-37

(*c*) *Hemispherical Heads.* The required thickness of a hemispherical head having pressure on the convex side shall be determined in the same manner as outlined in UG-28(d) for determining the thickness for a spherical shell. An example illustrating the use of this procedure is given in Appendix L (UA-276(c)).

(*d*) *Ellipsoidal Heads.* The required thickness of an ellipsoidal head having pressure on the convex side, either seamless or of built-up construction with butt joints, shall not be less than that determined by the following procedure:

Step 1: Assume a value for t_h. *Determine the ratios* $L_1/100t_h$ and L_1/t_h.

Step 2: Enter the left-hand side of the chart in Appendix V for the material under consideration with the value of $L_1/100t_h$ determined in Step 1.

Step 3: Move horizontally to the line marked Sphere Line.

Step 4: From this intersection move vertically to the material line for the design temperature (see UG-20). (For intermediate temperatures, interpolations may be made between the lines on the chart.)

Step 5: From this intersection move horizontally to the right and read the value of B.

Step 6: Compute the maximum allowable working pressure P_a by the following formula:

$$P_a = \frac{B}{L_1/t_h}$$

Step 7: Compare P_a with P. If P_a is smaller than P, a greater value for t_h must be selected and the design procedure repeated until a value for P_a is obtained that is equal to or greater than P. An example illustrating the use of this procedure is given in Appendix L (UA-276(a)).

(*e*) *Torispherical Heads.* The required thickness of a torispherical head having pressure on the convex side, either seamless or of built-up construction with butt joints, shall not be less than that determined by the same design procedure as is used for ellipsoidal heads given in (d), using the appropriate value for L_1. An example illustrating the use of this procedure is given in Appendix L (UA-276(b)).

(*f*) *Conical Heads.* The required thickness of a conical head under pressure on the convex side, either seamless or of built-up construction with butt joints, shall not be less than that determined by the following rules:

(*1*) When one-half of the included (apex) angle of the cone is equal to or less than 22½ deg, the thickness of the cone shall be the same as the required thickness of a cylindrical shell, the length of which equals the axial length of the cone or the axial distance center-to-center of stiffening rings (if used), and the outside diameter of which is equal to the outside diameter at the large end of the cone or section between stiffening rings (see UG-28(c)). An example illustrating the use of this procedure is given in Appendix L (UA-276(d)).

(*2*) When one-half of the included (apex) angle of the cone is greater than 22½ deg and not more than 60 deg, the thickness of the cone shall be the same as the required thickness of a cylindrical shell, the outside diameter of which equals the largest outside diameter of the cone measured perpendicularly to the cone axis, and the length of which equals an axial length that is the least of either the distance center-to-center of stiffening rings (if used) or the largest inside diameter of the section of cone considered (see UG-28(c)).

(*3*) When one-half of the included (apex) angle of the cone is greater than 60 deg, the thickness of the cone shall be the same as the required thickness for a flat head under external pressure, the diameter of which equals the largest outside diameter of the cone (see UG-34).

(*g*) When lap joints are used in formed head construction or for longitudinal joints in a conical head under external pressure, the thickness shall be determined by the rules in this paragraph, except that 2*P* shall be used instead of *P* in the calculations for the required thickness.

(*h*) The required length of skirt on heads convex to pressure shall comply with the provisions of UG-32(l), (m), and (o) for heads concave to pressure.

(*i*) Openings in heads convex to pressure shall comply with the requirements of UG-36 through UG-46.

UG-34 Unstayed Flat Heads and Covers

(*a*) The minimum thickness of unstayed flat heads, cover plates and blind flanges shall conform to the requirements given in this paragraph. These requirements apply to both circular and noncircular[1] heads and covers. Some acceptable types of flat heads and covers are shown in Fig. UG-34. In this figure, the dimensions of the component parts and the dimensions of the welds are exclusive of extra metal required for corrosion allowance.

(*b*) The symbols used in this paragraph and in Fig. UG-34 are defined as follows:

C = a factor depending upon the method of attachment of head, shell dimensions, and other items as listed in (d) below, dimensionless

D = long span of noncircular heads or covers measured perpendicular to short span, inches

d = diameter, or short span, measured as indicated in Fig. UG-34, inches

h_G = gasket moment arm, equal to the radial distance from the center line of the bolts to the line of the gasket reaction, as shown in Table UA-49.2, inches

L = perimeter of noncircular bolted head measured along the centers of the bolt holes, inches

l = length of flange of flanged heads, measured from the tangent line of knuckle, as indicated in Fig. UG-34(a) and (c), inches

m = the ratio $\frac{t_r}{t_s}$, dimensionless

P = design pressure (see UA-60(b)), pounds per square inch

r = inside corner radius on a head formed by flanging or forging, inches

[1]Special consideration shall be given to the design of shells, nozzle necks or flanges to which noncircular heads or covers are attached (see U-2(c)).

S = maximum allowable stress value, pounds per square inch, from applicable table of stress values in Subsection C

t = minimum required thickness of flat head or cover, exclusive of corrosion allowance, inches

t_e = minimum distance from beveled end of vessel, before welding, to outer face of head, as indicated in Fig. UG-34(h) and (i), inches

t_f = actual thickness of the flange on a forged head, at the large end, exclusive of corrosion allowance, as indicated in Fig. UG-34(b), inches

t_h = actual thickness of flat head or cover, exclusive of corrosion allowance, inches

t_r = required thickness of seamless shell, for pressure, inches

t_s = actual thickness of shell, exclusive of corrosion allowance, inches

t_w = thickness through the weld joining the edge of a head to the inside of a vessel, as indicated in Fig. UG-34(g), inches

t_1 = throat dimension of the closure weld, as indicated in Fig. UG-34(r), inches

W = total bolt load, pounds, given for circular heads for Formulas (3) and (4), UA-49(c), Appendix II

Z = a factor of noncircular heads and covers that depends on the ratio of short span to long span, as given in (c) below, dimensionless

(*c*) The thickness of flat unstayed heads, covers, and blind flanges shall conform to one of the following three requirements:[1]

(*1*) Circular blind flanges of ferrous materials conforming to ANSI-B16.5—1968 shall be acceptable for the diameters and pressure-temperature ratings in Tables 2 to 8 of that Standard, when of the types shown in Fig. UG-34(j) and (k).

(*2*) The minimum required thickness of flat unstayed circular heads, covers and blind flanges shall be calculated by the following formula:

$$t = d\sqrt{CP/S} \qquad (1)$$

except when the head, cover, or blind flange is attached by bolts causing an edge moment (Fig. (j) and (k)), in which case the thickness shall be calculated by

$$t = d\sqrt{CP/S + 1.78Wh_G/Sd^3} \qquad (2)$$

When using Formula (2), the thickness t shall be calculated for both operating conditions and gasket seating, and the greater of the two values shall be used. For operating conditions, the value of P shall be the design pressure, and the values of S at the design temperature and W from Formula (3) of UA-49(c) shall be used. For gasket seating, P equals zero, and the values of S at atmospheric temperature and W from Formula (4) of UA-49(c) shall be used.

(*3*) Flat unstayed heads, covers, or blind flanges may be square, rectangular, elliptical, obround, segmental, or otherwise noncircular. Their required thickness shall be calculated by the following formula:

$$t = d\sqrt{ZCP/S} \qquad (3)$$

where

$$Z = 3.4 - \frac{2.4d}{D} \qquad (4)$$

with the limitation that Z need not be greater than two and one half (2.5).

Formula (3) does not apply to noncircular heads, covers, or blind flanges attached by bolts causing a bolt edge moment (Fig. (j) and (k)). For noncircular heads of this type, the required thickness shall be calculated by the following formula:

$$t = d\sqrt{ZCP/S + 6Wh_G/SLd^2} \qquad (5)$$

When using Formula (5), the thickness t shall be calculated in the same way as specified above for Formula (2).

(*d*) For the types of construction shown in Fig. UG-34, the minimum values of C to be used in Formulas (1), (2), (3), and (5) are:

Fig. (a) $C = 0.25$ for flanged circular and noncircular heads forged integral with or butt welded to the vessel with an inside corner radius not less than 3 times the required head thickness, with no special requirement with regard to length of flange, and where the welding meets all the requirements for circumferential joints given in Part UW.

$C = 0.15$ for circular heads, when the flange length for heads of the above design is not less than

$$l = \left(1.1 - 0.8\frac{t_e^2}{t_h^2}\right)\sqrt{dt_h} \qquad (6)$$

$C = 0.15$ for circular heads, when the flange length l is less than the requirement in Formula (6) but the shell thickness is not less than

$$t_s = 1.12t_h\sqrt{1.1 - 1/\sqrt{dt_h}} \qquad (7)$$

[1]The formulas provide safe construction as far as stress is concerned. Greater thicknesses may be necessary if deflection would cause leakage at threaded or gasketed joints.

for a length of at least $2\sqrt{dt_s}$.

When $C = 0.15$ is used, the taper shall be 1:4.

Fig. (b-1) $C = 0.25$ for forged circular and noncircular heads integral with or butt welded to the vessel, where the flange thickness is not less than 2 times the shell thickness, the corner radius on the inside is not less than 3 times the flange thickness, and the welding meets all the requirements for circumferential joints given in part UW.

Fig. (b-2) $C = 0.5m$ but not less than 0.3 for forged circular and noncircular heads integral with or butt welded to the vessel, where the flange thickness is not less than the shell thickness, the corner radius on the inside is not less than 1.5 times the flange thickness, and the welding meets all the requirements for circumferential joints given in Part UW. (See Fig. UW-13.3(a) and (b) for the special case where t_f equals t_s.)

Fig. (c) $C = 0.20$ for circular heads lap welded or brazed to the shell with corner radius not less than 3 t and l not less than required by Formula (6) and the requirements of UW-13 are met.

$C = 0.30$ for circular and noncircular lap welded or brazed construction as above, but with no special requirement with regard to l.

$C = 0.30$ for circular and noncircular riveted construction with corner radius not less than $3t$ and also meeting the requirements of UR-17 and UR-18.

$C = 0.30$ for circular flanged plates screwed over the end of the vessel, with inside corner radius not less than $3t$, in which the design of the threaded joint against failure by shear, tension, or compression, resulting from the end force due to pressure, is based on a factor of safety of at least 4, and the threaded parts are at least as strong as the threads for standard piping of the same diameter. Seal welding may be used, if desired.

Fig. (d) $C = 0.20$ for integral flat circular heads when the dimension d does not exceed 24 in, the ratio of thickness of the head to the dimension d is not less than 0.05 nor greater than 0.25, the head thickness t_h is not less than the shell thickness t_s, the inside corner radius is not less than $0.25t$, and the construction is obtained by special techniques of upsetting and spinning the end of the shell, such as employed in closing header ends.

Figs. (e), (f), and (g) $C = 0.5m$ but not less than 0.3 for circular plates, welded to the inside of a vessel, and otherwise meeting the requirements for the respective types of welded vessels. If a value of m less than 1 is used in calculating t, the shell thickness t_s shall be maintained along a distance inwardly from the inside face of the head equal to at least $2\sqrt{dt_s}$. The throat thickness of the fillet welds in Figs. (e) and (f) shall be at least $0.7t_s$. The size of the weld t_w in Fig. (g) shall be not less than 2 times the required thickness of a seamless shell nor less than 1.25 times the nominal shell thickness but need not be greater than the head thickness; the weld shall be deposited in a welding groove with the root of the weld at the inner face of the head as shown in the figure.

$C = 0.5$ for noncircular plates, welded to the inside of a vessel and otherwise meeting the requirements for the respective types of welded vessels. The throat thickness of the fillet welds in Figs. (e) and (f) shall be at least $0.7t_s$. The size of the weld t_w in Fig. (g) shall be not less than 2 times the required thickness of a seamless shell nor less than 1.25 times the nominal shell thickness but need not be greater than the head thickness; the weld shall be deposited in a welding groove with the root of the weld at the inner face of the head as shown in the figure.

Fig. (h) $C = 0.5$ for circular plates welded to the end of the shell when t_s is at least $1.25t$, and the weld details conform to the requirements of UW-13(e) and Fig. UW-13.2(a) to (g) inclusive. See also UG-93(b)(3).

Fig. (i) $C = 0.5m$ but not less than 0.3 for circular plates if an inside fillet weld with minimum throat thickness of $0.7t_s$ is used and the details of the outside weld conform to the requirements of UW-13(e) and Fig. UW-13.2(a) to (g) inclusive, in which the inside weld can be considered to contribute an amount equal to t_s to the sum of the dimensions a and b. See also UG-93(b)(3).

Figs. (j) and (k) $C = 0.3$ for circular and noncircular heads and covers bolted to the vessel as indicated in the figures. Note that Formula (2) or (5) shall be used because of the extra moment applied to the cover by the bolting.

When the cover plate is grooved for a peripheral gasket, as shown in (k), the net cover plate thickness under the groove or between the groove and the outer edge of the cover plate shall be not less than

$$d\sqrt{1.78Wh_G/Sd^3}$$

for circular heads and covers, nor less than

$$d\sqrt{6Wh_G/SLd^2}$$

for noncircular heads and covers.

Figs. (m), (n), and (o) $C = 0.3$ for a circular plate inserted into the end of a vessel and held in place by a positive mechanical locking arrangement, and

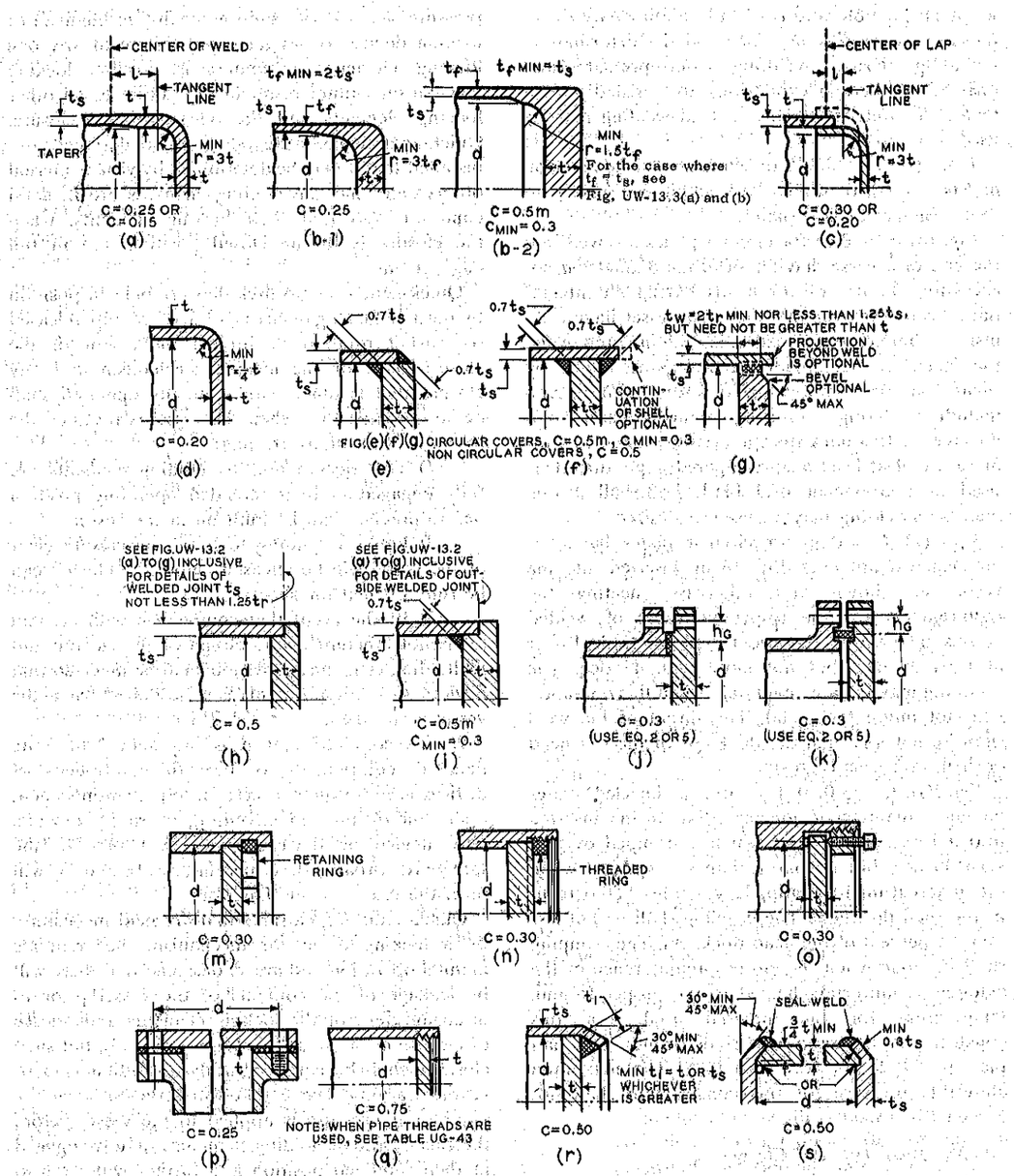

FIG. UG-34 SOME ACCEPTABLE TYPES OF UNSTAYED FLAT HEADS AND COVERS The above illustrations are diagrammatic only. Other designs that meet the requirements of UG-34 are acceptable.

when all possible means of failure (either by shear, tension, compression, or radial deformation, including flaring, resulting from pressure and differential thermal expansion) are resisted with a factor of safety of at least 4. Seal welding may be used, if desired.

Fig. (p) $C = 0.25$ for circular and noncircular covers riveted, or bolted with a full-face gasket, to shells, flanges or side plates.

Fig. (q) $C = 0.75$ for circular plates screwed into the end of a vessel having an inside diameter d not exceeding 12 in.; or for heads having an integral flange screwed over the end of a vessel having an inside diameter d not exceeding 12 in.; and when the design of the threaded joint, against failure by shear, tension, compression, or radial deformation, including flaring, resulting from pressure and differential thermal expansion, is based on a factor of safety of at least 4. If a tapered pipe thread is used, the requirements of Table UG-43 shall also be met. Seal welding may be used, if desired.

Fig. (r) $C = 0.50$ for circular plates having a dimension d not exceeding 18 in. inserted into the vessel as shown and otherwise meeting the requirements for the respective types of welded vessels. The end of the vessel shall be crimped over at least 30 deg, but not more than 45 deg. The crimping may be done cold only when this operation will not injure the metal. The throat of the weld shall be not less than the thickness of the flat head or shell, whichever is greater.

Fig. (s) $C = 0.50$ for circular beveled plates having a diameter d not exceeding 18 in., inserted into a vessel, the end of which is crimped over at least 30 deg, but not more than 45 deg, and when the undercutting for seating leaves at least 80 percent of the shell thickness. The beveling shall be not less than 75 percent of the head thickness. The crimping shall be done when the entire circumference of the cylinder is uniformly heated to the proper forging temperature for the material used. For this construction, the ratio t_s/d shall be not less than the ratio P/S nor less than 0.05. The maximum allowable pressure for this construction shall not exceed $P = S/5d$.

UG-35 Other Types of Closures

(*a*) *Spherical Dished Covers.* Rules for the design of circular spherically dished heads with bolting flanges are given in UA-6.

(*b*) *Quick-Actuating Closures* (*Quick-Opening Closures*). Closures other than the multibolted type designed to provide access to the contents space of a pressure vessel shall have the locking mechanism or locking device so designed that failure of any one locking element or component in the locking mechanism cannot result in the failure of all other locking elements and the release of the closure. Quick-actuating closures shall be so designed and installed that it may be determined by visual external observation that the holding elements are in good condition and that their locking elements, when the closure is in the closed position, are in full engagement.

Quick-actuating closures that are held in position by positive locking devices and that are fully released by partial rotation or limited movement of the closure itself or the locking mechanism and any closure that is other than manually operated shall be so designed that when the vessel is installed the following conditions are met:

(*1*) The closure and its holding elements are fully engaged in their intended operating position before pressure can be built up in the vessel.

(*2*) Pressure tending to force the closure clear of the vessel will be released before the closure can be fully opened for access.

(*3*) In the event that compliance with (1) and (2) is not inherent in the design of the closure and its holding elements, provision shall be made so that devices to accomplish this can be added when the vessel is installed.

It is recognized that it is impractical to write detailed requirements to cover the multiplicity of devices used for quick access, or to prevent negligent operation or the circumventing of safety devices. Any device or devices which will provide the safeguards broadly described in (1), (2), and (3) will meet the intent of this Division.

Quick-actuating closures that are held in position by a locking device or mechanism that requires manual operation and are so designed that there will be leakage of the contents of the vessel prior to disengagement of the locking elements and release of closure need not satisfy (1), (2), and (3), but such closures shall be equipped with an audible and/or visible warning device that will serve to warn the operator if pressure is applied to the vessel before the closure and its holding elements are fully engaged in their intended position and further will serve to warn the operator if an attempt is made to operate the locking mechanism or device before the pressure within the vessel is released.

When installed, all vessels having quick-actuating closures shall be provided with a pressure indicating device visible from the operating area.

OPENINGS AND REINFORCEMENTS[1]

(Typical examples of the application of these rules are given in Appendix L)

UG-36 Openings in Pressure Vessels

(*a*) *Shape of Opening*[2]

(*1*) Openings in cylindrical or conical portions of vessels, or in formed heads, shall preferably be circular, elliptical, or obround.[3] When the long dimension of an elliptical or obround opening exceeds twice the short dimensions, the reinforcement across the short dimensions shall be increased as necessary to provide against excessive distortion due to twisting moment.

(*2*) Openings may be of other shapes than those given in (1), and all corners shall be provided with a suitable radius. When the openings are of such proportions that their strength cannot be computed with assurance of accuracy, or when doubt exists as to the safety of a vessel with such openings, the part of the vessel affected shall be subjected to a proof hydrostatic test as prescribed in UG-101.

(*b*) *Size of Openings*

(*1*) Properly reinforced openings in cylindrical and spherical shells are not limited as to size and shall comply with the provisions which follow, and with the additional provisions of UA-7.

(*2*) Properly reinforced openings in formed heads need not be limited as to size, but when the opening in the end closure of a cylinder is larger than one-half the inside diameter of the shell, it is recommended that the closure be made by a reversed-curve section as shown in sketches (c) and (d) in Fig. UG-36, or by a conical section or a cone with a knuckle radius at the large end as shown in sketches (a) and (b) of Fig. UG-36 and/or with a flare radius at the small end. The design shall comply with all the requirements of the rules for reducer sections (see (e)) in so far as these rules are applicable.

[1]The rules governing openings as given in this Division are based on the stress intensification created by the existence of a hole in an otherwise symmetrical section. They are based on experience with vessels designed with safety factors of 4 and 5 applied to the ultimate strength of the shell material. External loadings such as those due to the thermal expansion or unsupported weight of connecting piping have not been evaluated. These factors should be given attention in unusual designs or under conditions of cyclic loading.

[2]The opening made by a pipe or a circular nozzle, the axis of which is not perpendicular to the vessel wall or head, may be considered an elliptical opening for design purposes.

[3]An obround opening is one which is formed by two parallel sides and semicircular ends.

(*c*) *Strength and Design of Finished Openings*

(*1*) All references to dimensions in this and succeeding paragraphs apply to the finished construction after deduction has been made for material added as corrosion allowance. For design purposes, no metal added as corrosion allowance may be considered as reinforcement.

(*2*) All openings shall be reinforced to satisfy the requirements of UG-37, except as given in (3) below.

(*3*) Single openings in vessels not subject to rapid fluctuations in pressure do not require reinforcement other than that inherent in the construction under the following conditions:

(a) Welded or brazed connections attached in accordance with the applicable rules and not larger than:

3-in. pipe size—in vessel shells or heads $^3/_8$ in. or less.

2-in. pipe size—in vessel shells or heads over $^3/_8$ in.

(b) Threaded, studded, or expanded connections in which the hole cut in the shell or head is not greater than 2-in. pipe size.

(*d*) *Openings Through Welded Joints.* Additional provisions governing openings through welded joints are given in UW-14.

(*e*) *Reducer Sections Under Internal Pressure*

(*1*) The formulas and rules of this paragraph apply to concentric reducer sections wherein all the longitudinal loads are transmitted wholly through the shell of the reducer. Where loads are transmitted in part or as a whole by other elements, e.g., inner shells, stays, or tubes, the rules of this paragraph do not apply.

(*2*) The thickness of each element of a reducer, as defined in (4) below, under internal pressure shall not be less than that computed by the applicable formula. In addition, provisions shall be made for any of the other loadings listed in UG-22, when such loadings are expected.

(*3*) The symbols defined in either UG-32(c) or below are used in this paragraph (see Fig. UG-36).

t = minimum required thickness of the considered element of a reducer after forming, exclusive of corrosion allowance, inches

R_L = inside radius of larger cylinder, inches

R_s = inside radius of smaller cylinder, inches

r_L = inside radius of knuckle at larger cylinder, inches

α = one half of the included (apex) angle of a conical element, degree

r_s = radius to the inside surface of flare at the small end, inches

(4) *Elements of a Reducer.* A transition section reducer consisting of one or more elements may be used to join two cylindrical shell sections of different diameters but with a common axis provided the requirements of this paragraph are met:

(a) Conical Shell Section. The required thickness of a conical shell section, or the allowable working pressure for such a section of given thickness, shall be determined by the formulas given in UG-32(g).

(b) Knuckle Tangent to the Larger Cylinder. Where a knuckle is used at the large end of a reducer section, its shape shall be that of a portion of an ellipsoidal, hemispherical, or torispherical head. The thickness and other dimensions shall satisfy the requirements of the appropriate formulas and provisions of UG-32.

(5) *Combination of Elements to Form a Reducer.* When elements of subsection (4), above, having different thicknesses are combined to form a reducer, the joints including the plate taper required by UW-9(c) shall lie entirely within the limits of the thinner element being joined.

(a) A reducer may be a simple conical shell section, Fig. UG-36(*a*), without knuckle, provided the half-apex angle α is not greater than 30 deg, except as provided for in UA-5(e). A reinforcement ring shall be provided at either or both ends of the reducer when required by the rules of UA-5.

(b) A toriconical reducer, Fig. UG-36(*b*), may be shaped as a portion of a toriconical head, UG-32(h), a portion of a hemispherical head plus a conical section, or a portion of an ellipsoidal head plus a conical section, provided the half-apex angle α is not greater than 30 deg, except as provided for in UA-5(e). A reinforcement ring shall be provided at the small end of the conical reducer element when required by the rules in UA-5.

(c) Reverse curve reducers, Fig. UG-36(c) and (d) may be shaped of elements other than those of UG-36(e)(4). See U-2(c).

UG-37 Reinforcement Required for Openings in Shells and Formed Heads

(*a*) *General.* The rules in this paragraph apply to all openings other than:

(*1*) Small openings covered by UG-36(c)(3).

(*2*) Openings in flat heads covered by UG-39.

(*3*) Openings designed as reducer sections covered by UG-36(e).

(*4*) Large head openings covered by UG-36(b)(2).

(*5*) Tube holes with ligaments between them conforming to the rules of UG-53.

Reinforcement shall be provided in amount and distribution such that the area requirements for reinforcement are satisfied for all planes through the center of the opening and normal to the vessel surface. For a circular opening in a cylindrical shell, the plane containing the axis of the shell is the plane of greatest loading due to pressure.

(*b*) *Design for Internal Pressure.* The total cross-sectional area of reinforcement, A, required in any

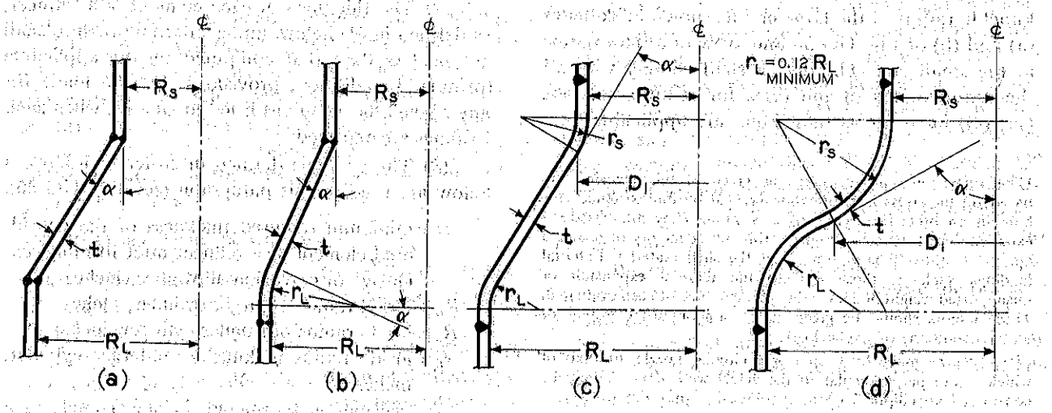

FIG. UG-36 LARGE HEAD OPENINGS—REVERSE-CURVE AND CONICAL SHELL-REDUCER SECTIONS

given plane for a vessel under internal pressure shall be not less than

$$A = d \times t_r \times F$$

where

d = the diameter in the given plane of the finished opening in its corroded condition, inches

F = a correction factor which compensates for the variation in pressure stresses on different planes with respect to the axis of a vessel. A value of 1.00 shall be used for all configurations except that Fig. UG-37 may be used for integrally reinforced openings in cylindrical shells and cones

t_r = the required thickness of a seamless shell or head computed by the rules of this Division for the designated pressure, inches, except that:

(1) When the opening and its reinforcement are entirely within the spherical portion of a torispherical head, t_r is the thickness required by UA-4(d), using $E=1$ and $M=1$.

(2) When the opening is in a cone, t_r is the thickness required for a seamless cone of diameter D measured where the nozzle axis pierces the inside wall of the cone.

(3) When the opening and its reinforcement are in an ellipsoidal head and are located entirely within a circle the center of which coincides with the center of the head and the diameter of which is equal to 80 percent of the shell diameter, t_r is the thickness required for a seamless sphere of radius K_1D, where D is the shell diameter and K_1 is given by Table UG-37.

(4) When the opening is in a vessel built under UW-12(c), the value of S used in computing t_r shall be 80 percent of the allowable stress value prescribed for the material in subsection C.

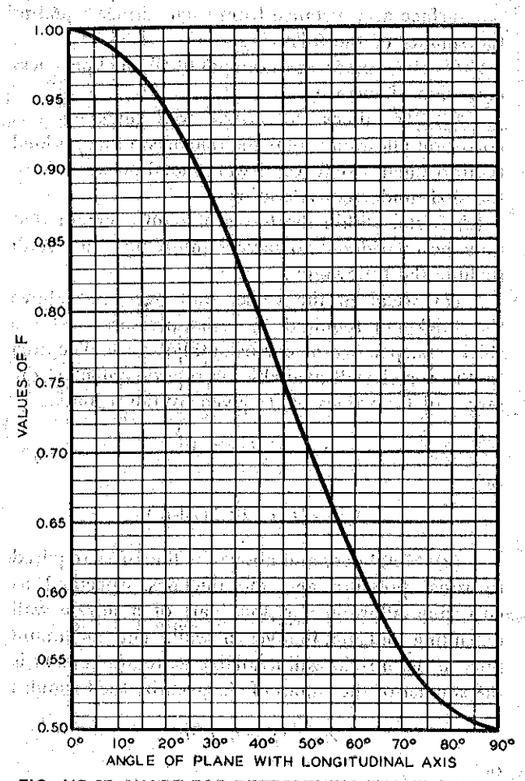

FIG. UG-37 CHART FOR DETERMINING VALUE OF F, AS REQUIRED IN UG-37.

TABLE UG-37
VALUES OF SPHERICAL RADIUS FACTOR K_1

(Equivalent Spherical Radius = $K_1 D$; $D/2h$ = axis ratio. For definitions see UA-4(b). Interpolation permitted for intermediate values.)

$\frac{D}{2h}$	3.0	2.8	2.6	2.4	2.2
K_1	1.36	1.27	1.18	1.08	0.99
$\frac{D}{2h}$	2.0	1.8	1.6	1.4	1.2	1.0
K_1	0.90	0.81	0.73	0.65	0.57	0.50

(*c*) *Design for External Pressure.*

(*1*) The reinforcement required for openings in single-walled vessels subject to external pressure need be only 50 percent of that required in (b) where t_r is the wall thickness required by the rules for vessels under external pressure.

(*2*) The reinforcement required for openings in each shell of a multiple-walled vessel shall comply with (1) when the shell is subject to external pressure, and with (b) when the shell is subject to internal pressure, regardless of whether or not there is a common nozzle secured to more than one shell by strength welds.

(*d*) *Design for Alternate Internal and External Pressure.* Reinforcement of vessels subject to alternate internal and external pressures shall meet the requirements of (b) for internal pressure and of (c) for external pressure.

UG-38 Flued Openings in Formed Heads

(*a*) Flued openings in formed heads made by inward or outward forming of the head plate shall meet the requirements for reinforcement in UG-37.

(*b*) The minimum depth of flange of a flued opening exceeding 6 in. in any inside dimension, when not stayed by an attached pipe or flue, shall equal $3t_r$ or $(t_r + 3)$ in., whichever is less, where t_r is the required head thickness. The depth of flange shall be determined by placing a straight edge across the side opposite the flued opening along the major axis and measuring from the straightedge to the edge of the flanged opening (see Fig. UG-38).

(*c*) The minimum width of bearing surface for a gasket on a self-sealing flued opening shall be in accordance with UG-46(j).

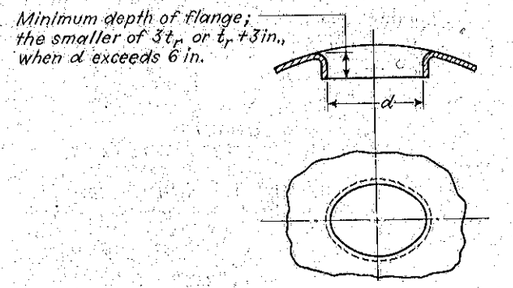

FIG. UG-38 MINIMUM DEPTH FOR FLANGE OF FLUED OPENINGS

UG-39 Reinforcement Required for Openings in Flat Heads

(*a*) *General.* The rules in this paragraph apply to all openings covered by UG-36(c)(3).

(*b*) Flat heads that have an opening with a diameter that does not exceed one-half of the head diameter or shortest span, as defined in UG-34, shall have a total cross-sectional area of reinforcement not less than that given by the formula

$$A = 0.5d \times t$$

where d is defined in UG-37 and t in UG-34.

(*c*) Flat heads that have an opening with a diameter that exceeds one-half of the head diameter or shortest span, as defined in UG-34, shall be designed as a flange in accordance with the *Rules for Bolted Flange Connections* given in Appendix II.

(*d*) As an alternative to (b), the thickness of flat heads may be increased to provide the necessary opening reinforcement as follows:

(*1*) In Formula (1) or (3) of UG-34(c), by using 2C or 0.75 in place of C, whichever is less.

(*2*) In Formula (2) or (5) of UG-34(c), by doubling the quantity under the square root sign.

UG-40 Limits of Reinforcement

(*a*) The boundaries of the cross-sectional area in any plane normal to the vessel wall and passing through the center of the opening within which metal must be located in order to have value as reinforcement are designated as the limits of reinforcement for that plane.

(*b*) The limits of reinforcement, measured parallel to the vessel wall, shall be at a distance, on each side of the axis of the opening, equal to the greater of the following:

(*1*) The diameter of the finished opening in the corroded condition.

(*2*) The radius of the finished opening in the corroded condition plus the thickness of the vessel wall, plus the thickness of the nozzle wall.

(*c*) The limits of reinforcement, measured normal to the vessel wall, shall conform to the contour of the surface at a distance from each surface equal to the smaller of the following:

(*1*) $2\frac{1}{2}$ times the nominal shell thickness less corrosion allowance,

(*2*) $2\frac{1}{2}$ times the nozzle wall thickness less corrosion allowance, plus the thickness of any added reinforcement exclusive of weld metal on the side of the shell under consideration.

(*d*) Metal within the limits of reinforcement that may be considered to have reinforcing value shall include the following:

(*1*) Metal in the vessel wall over and above the thickness required to resist pressure and the thickness specified as corrosion allowance. The area in the vessel wall available as reinforcement is the larger of the values of A_1 given by the formulas

$$A_1 = (E_1 t - F t_r) d$$

or

$$A_1 = 2(E_1 t - F t_r)(t + t_n)$$

(*2*) Metal over and above the thickness required to resist pressure and the thickness specified as corrosion allowance in that part of a nozzle wall extending outside the vessel wall. The maximum area in the nozzle wall available as reinforcement is the smaller of the values of A_2 given by the formulas

$$A_2 = (t_n - t_{rn})\ 5t$$

or

$$A_2 = (t_n - t_{rn})\ (5t_n + 2t_e)$$

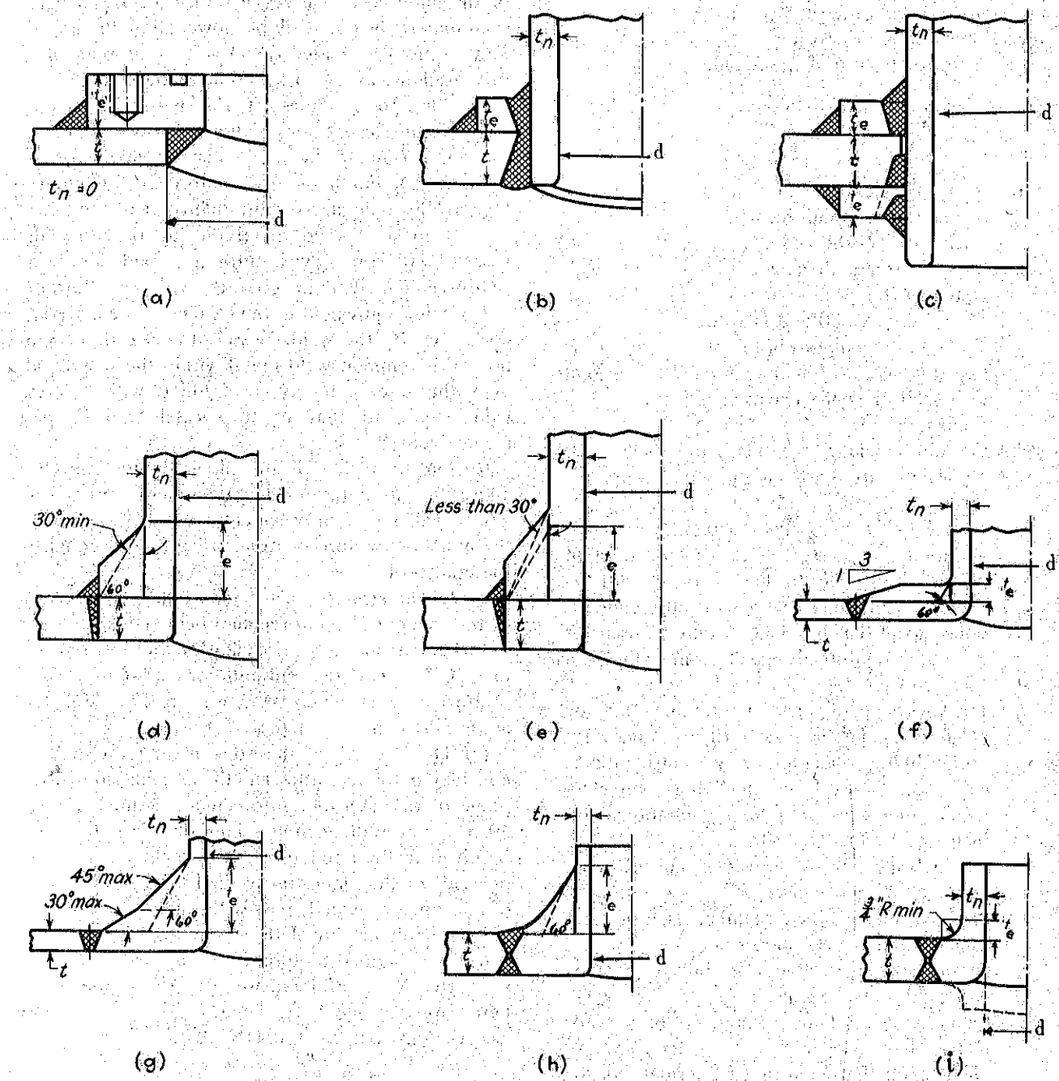

FIG. UG-40 SOME REPRESENTATIVE CONFIGURATIONS DESCRIBING THE t_e REINFORCEMENT DIMENSION

All metal in the nozzle wall extending inside the vessel wall may be included after proper deduction for corrosion allowance on all the exposed surface is made. No allowance shall be taken for the fact that a differential pressure on an inwardly extending nozzle may cause opposing stress to that of the stress in the shell around the opening:

where

A_1 = area in excess thickness in the vessel wall available for reinforcement, square inches. (See Fig. UA-280 and UG-40)

A_2 = area in excess thickness in the nozzle wall available for reinforcement, square inches. (See Fig. UA-280 and UG-40)

E_1 = 1 when an opening is in the plate or when the opening passes through a circumferential joint in a shell or cone (exclusive of head-to-shell joints); or

E_1 = the joint efficiency obtained from Table UW-12 when any part of the opening passes through any other welded joint

F = a correction factor which compensates for the variation in pressure stresses on different planes with respect to the axis of a vessel. A value of 1.00 shall be used for all configurations except that Fig. UG-37 may be used for integrally reinforced openings in cylindrical shells and cones

t_c = Thickness of attached reinforcing pad or height of the largest 60-deg right triangle supported by the vessel and nozzle outside diameter projected surfaces and lying completely within the area of integral reinforcement, inches. (See Fig. UG-40)

t = nominal thickness of the vessel wall, less corrosion allowance, inches

t_r = required thickness of a seamless shell or head as defined in UG-37, inches

t_n = nominal thickness of nozzle wall, less corrosion allowance, inches

t_{rn} = required thickness of a seamless nozzle wall, inches

d = diameter in the plane under consideration of the finished opening in its corroded condition, inches (See UG-37(b), Fig. UG-40, and Fig. UW-16.1)

(3) Metal added as reinforcement, and metal in attachment welds.

UG-41 Strength of Reinforcement

(a) Material used for reinforcement shall have an allowable stress value equal to or greater than that of the material in the vessel wall, except that when such material is not available, lower strength material may be used, provided the area of reinforcement is increased in inverse proportion to the ratio of the allowable stress values of the two materials to compensate for the lower allowable stress value of the reinforcement. No credit may be taken for the additional strength of any reinforcement having a higher allowable stress value than that of the vessel wall. Deposited weld metal outside of either the vessel wall or any reinforcing pad used as reinforcement shall be credited with an allowable stress value equivalent to the weaker of the materials connected by the weld. Vessel-to-nozzle or pad-to-nozzle attachment weld metal within the vessel wall or within the pad may be credited with a stress value equal to that of the vessel wall or pad respectively.

(b) On each side of the plane defined in UG-40(a), the strength of the attachment joining the vessel wall and reinforcement or any two parts of the attached reinforcement shall be at least equal to the smaller of:

(1) The strength in tension of the cross section of the element of reinforcement being considered, or

(2) The strength in tension of the area defined in UG-37 less the strength in tension of the reinforcing area which is integral in the vessel wall as permitted by UG-40(d)(1).

(c) The strength of the attachment joint shall be considered for its entire length on each side of the plane of the area of reinforcement defined in UG-40. For obround openings, consideration shall also be given to the strength of the attachment joint on one side of the plane transverse to the parallel sides of the opening which passes through the center of the semicircular end of the opening.

(d) For detailed requirements for welded, brazed, and riveted reinforcement see the appropriate paragraphs in the Parts devoted to these subjects (see UW-15, UR-25, and UB-19).

UG-42 Reinforcement of Multiple Openings

(a) When any two adjacent openings are spaced at less than 2 times their average diameter so that their limits of reinforcement overlap, the two openings (or similarly for any larger group of openings) shall be reinforced in accordance with

UG-37 with a combined reinforcement that has a strength equal to the combined strength of the reinforcement that would be required for the separate openings. No portion of the cross section shall be considered as applying to more than one opening, or be evaluated more than once in a combined area.

(b) When more than two adjacent openings are to be provided with a combined reinforcement, the minimum distance between centers of any two of these openings shall preferably be at least $1^1/_2$ times their average diameter, and the area of reinforcement between them shall be at least equal to 50 percent of the total required for these two openings.

(c) When two adjacent openings as considered under (b) have a distance between centers less than $1^1/_3$ times their average diameter, no credit for reinforcement shall be given for any of the metal between these two openings.

(d) Any number of closely spaced adjacent openings, in any arrangement, may be reinforced for an assumed opening of a diameter enclosing all such openings.

(e) When a group of openings is reinforced by a thicker section butt-welded into the shell or head, the edges of the inserted section shall be tapered as prescribed in UW-9(c).

(f) When there is a series of tube openings in a pressure vessel and it is impractical to reinforce each opening, the construction will be acceptable provided the ligaments between openings are calculated by the rules given in UG-53.

UG-43 Methods of Attachment of Pipe and Nozzle Necks to Vessel Walls

(a) *General.* Nozzles may be attached to the shell or head of a vessel by any of the methods of attachment given in this paragraph, except as limited in UG-36.

(b) *Welded Connections.* Attachment by welding shall be in accordance with the requirements of UW-15 and UW-16.

(c) *Riveted Connections.* Attachment by riveting shall be in accordance with the requirements of UR-23 through UR-25.

(d) *Brazed Connections.* Attachment by brazing shall be in accordance with the requirements of UB-17 through UB-19.

(e) *Studded Connections.* Connections may be made by means of studs. The vessel shall have a flat surface machined on the shell, or on a built-up pad, or on a properly attached plate or fitting. Drilled holes to be tapped shall not penetrate within one-fourth of the wall thickness from the inside surface of the vessel after deducting corrosion allowance, unless at least the minimum thickness required as above is maintained by adding metal to the inside surface of the vessel. The tapped holes shall also conform to the requirements of UG-44(b). Studded connections shall meet the requirements for reinforcement in UG-36 through UG-42 and the requirements for attachment in UR-25.

(f) *Threaded Connections.* Pipes, tubes, and other threaded connections that conform to the ANSI Standard for Pipe Threads (ANSI B2.1—1968) may be screwed into a threaded hole in a vessel wall, provided the pipe engages the minimum number of threads specified in Table UG-43 after allowance has been made for curvature of the vessel wall. A built-up pad or a properly attached plate or fitting may be used to provide the metal thickness and number of threads required in Table UG-43, or to furnish reinforcement when required.

Threaded connections larger than 4-in. pipe size shall not be used in vessels that contain liquids having a flash-point below 110 F, or flammable vapors, or flammable liquids at temperatures above that at which they boil under atmospheric pressure.

Threaded connections larger than 3-in. pipe size shall not be used when the maximum allowable working pressure esceeds 125 psi, except that this 3-in. pipe size restriction does not apply to plug closures used for inspection openings, end closures, or similar purposes, or to integrally forged openings in vessel heads meeting the requirement of UF-43.

TABLE UG-43
MINIMUM NUMBER OF PIPE THREADS FOR CONNECTIONS

Size of pipe connection, in.	⅛ & ¼	⅜, ½ & ¾	1, 1¼ & 1½	2	2½ & 3	4–6	8	10	12
Threads engaged	6	7	7	8	8	10	12	13	14
Min plate thickness required, in.	0.43	0.54	0.61	0.70	1.0	1.25	1.5	1.62	1.75

(*g*) *Expanded Connections.* A pipe, tube, or forging may be attached to the wall of a vessel by inserting through an unreinforced opening and expanding into the shell, provided the diameter is not greater than 2-in. pipe size. A pipe, tube, or forging not exceeding 6 in. in outside diameter may be attached to the wall of a vessel by inserting through a reinforced opening and expanding into the shell.

Such connections shall be:

(*1*) Firmly rolled in and beaded; or

(*2*) Rolled in, beaded, and seal-welded around the edge of the bead; or

(*3*) Expanded and flared not less than 1/8 in. over the diameter of the hole; or

(*4*) Rolled, flared, and welded; or

(*5*) Rolled and welded without flaring or beading, provided:

(a) The ends extend at least 1/4 in., but no more than 3/8 in., through the shell;

(b) The throat of the weld is at least 3/16 in., but no more than 5/16 in.

When the tube or pipe does not exceed 1 1/2 in. in outside diameter, the shell may be chamfered or recessed to a depth at least equal to the thickness of the tube or pipe and the tube or pipe may be rolled into place and welded. In no case shall the end of the tube or pipe extend more than 3/8 in. beyond the shell.

Grooving of shell openings in which tubes and pipe are to be rolled or expanded is permissible.

Expanded connections shall not be used as a method of attachment to vessels used for the processing or storage of flammable and/or noxious gases and liquids unless the connections are seal-welded.

UG-44 Bolted Flange and Studded Connections

(*a*) It is recommended that the dimensional requirements of bolted flange connections to external piping conform to ANSI Standard B16.5-1968, Steel Pipe Flanges and Flanged Fittings; ANSI B16.24-1963, Brass or Bronze Flanges and Flanged Fittings 150 and 300 lb; MSS SP-42-1953, 150 lb Corrosion Resistant Cast Flanged Valves; or to API Standard 605-1967, Large Diameter Carbon Steel Flanges. Such flanges and flanged fittings may be used for the pressure-temperature ratings given in the appropriate standard. Flanges and flanged fittings to other standards are acceptable provided they have been designed in accordance with the rules of Appendix II of this Division of Section VIII for the vessel design conditions and are used within the pressure temperature ratings so determined.

(*b*) Where tapped holes are provided for studs, the threads shall be full and clean and shall engage the stud for a length not less than the larger of d_s or

$$0.75\,d_s \times \frac{\text{Maximum allowable stress value of stud material at design temperature}}{\text{Maximum allowable stress value of tapped material at design temperature}}$$

in which d_s is the diameter of the stud, except that the thread engagement need not exceed $1\frac{1}{2}\,d_s$.

UG-45 Nozzle Neck Thickness

The wall thickness of a nozzle neck or other connection shall not be less than the thickness computed for the applicable loadings in UG-22 plus the thickness added for corrosion allowance on the connection and, except for access openings and openings for inspection only, not less than the smaller of the following:

(*1*) The required thickness (assuming $E = 1$) of the shell (or head) to which the connection is attached plus the corrosion allowance provided in the shell (or head) adjacent to the connection but in no case less than the minimum thickness specified for the material in the applicable part of Subsection C (for example: see UCS-16(b)).

(*2*) The minimum thickness[1] of standard wall pipe plus the corrosion allowance on the connection.

UG-46 Inspection Openings[2]

(*a*) All pressure vessels for use with compressed air, except as permitted otherwise in this paragraph, and those subject to internal corrosion, or having parts subject to erosion or mechanical abrasion (see UG-25), shall be provided with suitable manhole, handhole, or other inspection openings for examination and cleaning.

Compressed air as used in this paragraph is not intended to include air which has had moisture removed to the degree that it has an atmospheric dew point of —50 F or less. The manufacturer's Data Report shall include a statement "for noncorrosive service" when inspection openings are not provided.

(*b*) When provided with telltale holes complying with the provisions of UG-25, inspection openings as required in (a) may be omitted in vessels subject only to corrosion. This provision does not apply to vessels for compressed air.

(*c*) Vessels over 12 in. in inside diameter under air pressure which also contain other substances which will prevent corrosion need not have openings for inspection only, providing the vessel contains suitable openings through which inspection can be made conveniently, and providing such openings are equivalent in size and number to the requirements for inspection openings in (f).

(*d*) For vessels 12 in. or less in inside diameter, openings for inspection only may be omitted if there are at least two removable pipe connections not less than 3/4-in. pipe size.

(*e*) Vessels over 12 in. but not over 16 in. in inside diameter, that are to be installed so that they must be disconnected from an assembly to permit inspection, need not be provided with openings for inspection only, if there are at least two removable pipe connections not less than 1 1/2-in. pipe size.

(*f*) Vessels that require access or inspection openings shall be equipped as follows: [1]

(*1*) All vessels less than 18 in. and over 12 in. in inside diameter shall have at least two handholes or two plugged, threaded inspection openings of not less than 1 1/2-in. pipe size;

(*2*) All vessels 18 to 36 in., inclusive, in inside diameter shall have a manhole or at least two handholes or two threaded pipe plug inspection openings of not less than 2 in. pipe size;

(*3*) All vessels over 36 in. in inside diameter shall have a manhole, except that those whose shape or use makes one impracticable shall have at least two handholes 4 × 6 in. or two equal openings of equivalent area;

(*4*) When handholes or pipe plug openings are permitted for inspection openings in place of a manhole, one handhole or one pipe plug opening shall be in each head or in the shell near each head;

(*5*) Openings with removable heads or cover plates intended for other purposes may be used in place of the required inspection openings provided they are equal at least to the size of the required inspection openings;

(*6*) A single opening with removable head or cover plate may be used in place of all the smaller inspection openings provided it is of such size and location as to afford at least an equal view of the interior.

(*g*) When inspection or access openings are required, they shall comply at least with the following requirements:

(*1*) An elliptical or obround manhole shall be not less than 11 × 15 in., or 10 × 16 in. A circular manhole shall be not less than 15 in. inside diameter.

(*2*) A handhole opening shall be not less than 2 × 3 in., but should be as large as is consistent with the size of the vessel and the location of the opening.

(*h*) All access and inspection openings in a shell or unstayed head shall be designed in accordance with the rules of this Division for openings.

(*i*) When a threaded opening is to be used for inspection or cleaning purposes, the closing plug or cap shall be of a material suitable for the pressure and no material shall be used at a temperature exceeding the maximum temperature allowed in this Division for that material. The thread shall be a standard taper pipe thread except that a straight thread of equal strength may be used if other sealing means to prevent leakage are provided.

(*j*) Manholes of the type in which the internal pressure forces the cover plate against a flat gasket shall have a minimum gasket bearing width of 11/16 in.

BRACED AND STAYED SURFACES

UG-47 Braced and Stayed Surfaces

(*a*) The minimum thickness and maximum allowable working pressure for braced and stayed flat plates and those parts which, by these rules, require staying as flat plates with braces or staybolts of uniform diameter symmetrically spaced, shall be calculated by the following formulas:

$$t = p\sqrt{\frac{P}{SC}} \qquad (1)$$

$$P = \frac{t^2 SC}{p^2} \qquad (2)$$

where

t = minimum thickness of plate, exclusive of corrosion allowance, inches

P = design pressure (or maximum allowable working pressure for existing vessels), pounds per square inch

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[1] The minimum thickness for all materials is the nominal wall thickness listed in Table 2 of ANSI B36.10-1970 less 12 1/2 percent. For diameters other than those listed in the table, this shall be based upon the next larger pipe size.

[2] All dimensions given, for size of vessel on which inspection openings are required, are nominal.

[1] Dimensions referred to are nominal.

S = maximum allowable stress value given in Subsection C, pounds per square inch
p = maximum pitch measured between straight lines passing through the centers of the staybolts in the different rows, which lines may be horizontal, vertical, or inclined, inches
C = 2.1 for welded stays or stays screwed through plates not over 7/16 in. in thickness with ends riveted over
C = 2.2 for welded stays or stays screwed through plates over 7/16 in. in thickness with ends riveted over
C = 2.5 for stays screwed through plates and fitted with single nuts outside of plate, or with inside and outside nuts, omitting washers
C = 2.8 for stays with heads not less than 1.3 times the diameter of the stays screwed through plates or made a taper fit and having the heads formed on the stays before installing them, and not riveted over, said heads being made to have a true bearing on the plate
C = 3.2 for stays fitted with inside and outside nuts and outside washers where the diameter of washers is not less than $0.4p$ and thickness not less than t

(*b*) The minimum thickness of plates to which stays may be applied, in other than cylindrical or spherical outer shell plates, shall be 5/16 in. except for welded construction covered by UW-19.

(*c*) If a stayed jacket extends completely around a cylindrical or spherical vessel, or completely covers a formed head, it shall meet the requirements given above in (a), and shall also meet the applicable requirements for shells or heads in UG-27(c) and (d) and UG-32.

(*d*) If a flat plate not less than 3/8 in. in thickness is strengthened with a securely riveted doubling plate covering the full area of the stayed surface and having a thickness of not less than 2/3 t, then the value of t in the formula shall be three-fourths of the combined thickness of the plate and doubling plate but not more than 1 1/2 times the thickness of the plate, and the value of C given above may be increased 15 percent.

(*e*) When two plates are connected by stays and but one of these plates requires staying, the value of C shall be governed by the thickness of the plate requiring staying.

(*f*) Acceptable proportions for the ends of through stays with washers are indicated in Fig. UG-47.

(*g*) The maximum pitch shall be 8 1/2 in., except that for welded-in staybolts the pitch may be greater provided it does not exceed 15 times the diameter of the staybolt.

(*h*) When the staybolting of shells is unsymmetrical by reason of interference with butt straps or other construction, it is permissible to consider the load carried by each staybolt as the area calculated by taking the distance from the center of the spacing on one side of the bolt to the center of the spacing on the other side.

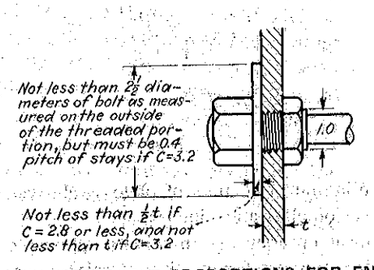


FIG. UG-47 ACCEPTABLE PROPORTIONS FOR ENDS OF THROUGH STAYS

UG-48 Staybolts

(*a*) The ends of staybolts or stays screwed through the plate shall extend beyond the plate not less than two threads when installed, after which they shall be riveted over or upset by an equivalent process without excessive scoring of the plates, or they shall be fitted with threaded nuts through which the bolt or stay shall extend.

(*b*) The ends of steel stays upset for threading shall be fully annealed.

(*c*) Requirements for welded-in staybolts are given in UW-19.

UG-49 Location of Staybolts

(*a*) The distance from the edge of a staybolt hole to a straight line tangent to the edges of the rivet holes may be substituted for p for staybolts adjacent to the riveted edges bounding a stayed surface.

(*b*) When the edge of a flat stayed plate is flanged, the distance from the center of the outermost stays to the inside of the supporting flange shall not be greater than the pitch of the stays plus the inside radius of the flange.

UG-50 Dimensions of Staybolts

(*a*) The required area of a staybolt at its minimum cross section[1] and exclusive of any allowance for

[1]The minimum cross section is usually at the root of the thread.

corrosion shall be obtained by dividing the load on the staybolt computed in accordance with (b) by the allowable stress value for the material used, as given in Subsection C, and multiplying the result by 1.10.

(*b*) *Load Carried by Stays.* The area supported by a stay shall be computed on the basis of the full pitch dimensions, with a deduction for the area occupied by the stay. The load carried by a stay is the product of the area supported by the stay and the maximum allowable working pressure.

(*c*) Stays made of parts joined by welding shall be checked for strength using a joint efficiency of 60 percent for the weld.

LIGAMENTS

UG-53 Ligaments

(*a*) The symbols used in the formulas and charts of this paragraph are defined as follows:

p = longitudinal pitch of tube holes, inches
p_1 = unit length of ligament, inches
p' = diagonal pitch of tube holes, inches
d = diameter of tube holes, inches
n = number of tube holes in length p_1

(*b*) When a cylindrical shell is drilled for tubes in a line parallel to the axis of the shell for substantially the full length of the shell as shown in Figs. UG-53.1 through UG-53.3, the efficiency of the ligaments between the tube holes shall be determined as follows:

(*1*) When the pitch of the tube holes on every row is equal (see Fig. UG-53.1), the formula is:

$$\frac{p-d}{p} = \text{efficiency of ligament}$$

(*2*) When the pitch of tube holes on any one row is unequal (as in Figs. UG-53.2 and UG-53.3), the formula is:

$$\frac{p_1-nd}{p_1} = \text{efficiency of ligament}$$

(*c*) The strength of ligaments between tube holes measured circumferentially shall be at least 50 percent of the strength of ligaments of similar dimensions taken in a line parallel to the axis of the cylindrical shell.

(*d*) When a cylindrical shell is drilled for tube holes so as to form diagonal ligaments as shown in Fig. UG-53.4, the efficiency of these ligaments shall be that given by the diagram in Fig. UG-53.5. The pitch of tube holes shall be measured either on the flat plate before rolling, or on the middle line of the plate after rolling.

To use the diagram in Fig. UG-53.5, compute the value of p'/p_1 and also the efficiency of the

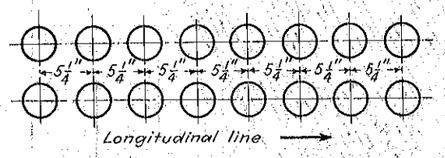


FIG. UG-53.1 EXAMPLE OF TUBE SPACING WITH PITCH OF HOLES EQUAL IN EVERY ROW

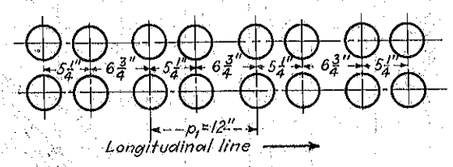


FIG. UG-53.2 EXAMPLE OF TUBE SPACING WITH PITCH OF HOLES UNEQUAL IN EVERY SECOND ROW

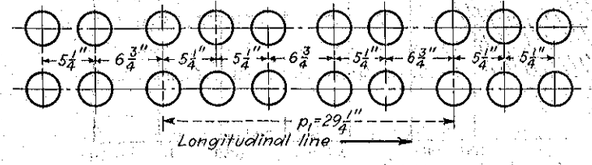


FIG. UG-53.3 EXAMPLE OF TUBE SPACING WITH PITCH OF HOLES VARYING IN EVERY SECOND AND THIRD ROW

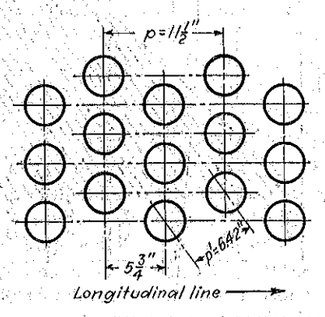


FIG. UG-53.4 EXAMPLE OF TUBE SPACING WITH TUBE HOLES ON DIAGONAL LINES

longitudinal ligament. Next find in the diagram the vertical line corresponding to the longitudinal efficiency of the ligament and follow this line vertically to the point where it intersects the diagonal line representing the ratio of p'/p. Then project this point horizontally to the left, and read the diagonal efficiency of the ligament on the scale at the edge of the diagram. The shell thickness and the maximum allowable working pressure shall be based on the ligament that has the lower efficiency.

(*e*) When tube holes in a cylindrical shell are arranged in symmetrical groups which extend a distance greater than the inside diameter of the shell along lines parallel to the axis and the same spacing is used for each group, the efficiency for one of the groups shall be not less than the efficiency on which the maximum allowable working pressure is based.

(*f*) The average ligament efficiency in a cylindrical shell, in which the tube holes are arranged along lines parallel to the axis with either uniform or

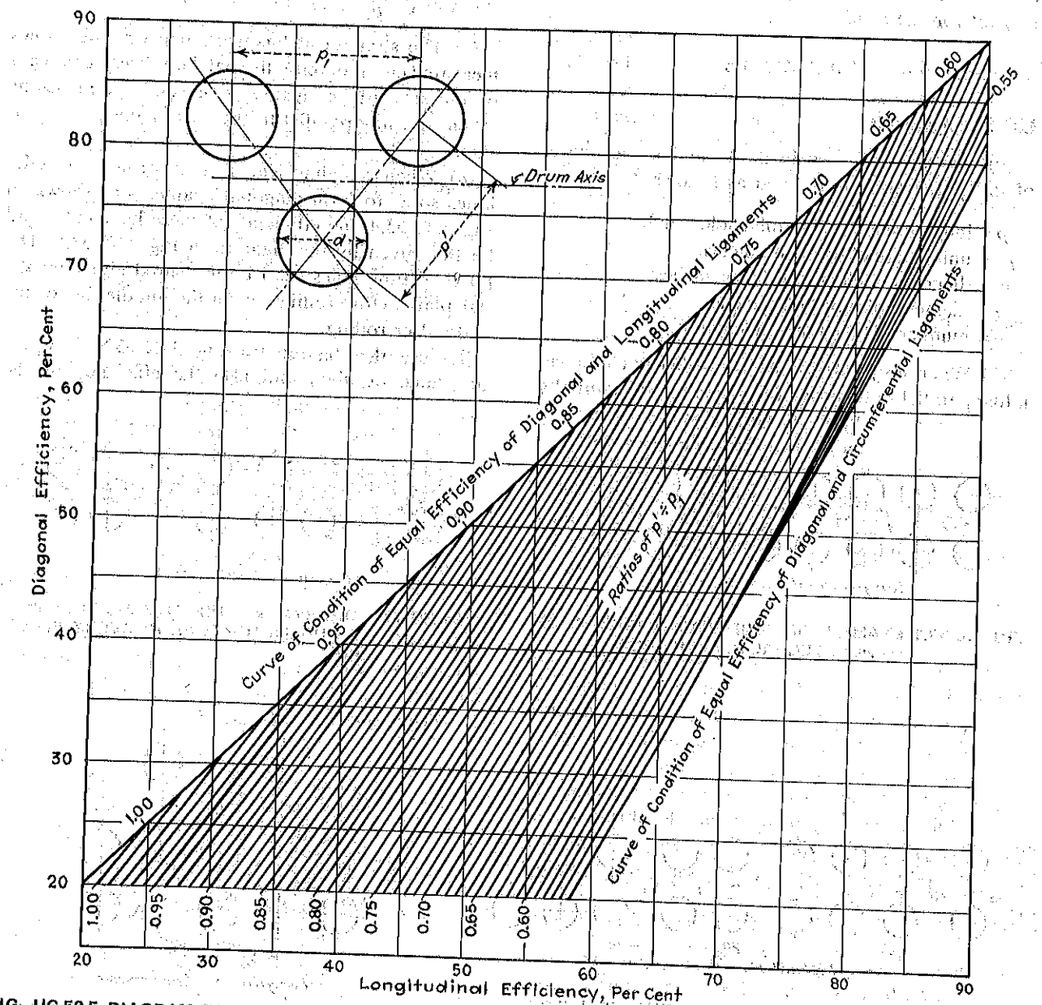


FIG. UG-53.5 DIAGRAM FOR DETERMINATION OF THE EFFICIENCY OF LONGITUDINAL AND DIAGONAL LIGAMENTS BETWEEN TUBE HOLES IN CYLINDRICAL TUBE SHEETS

nonuniform spacing, shall be computed by the following rules and shall satisfy the requirements of both:[1]

(*1*) For a length equal to the inside diameter of the shell for the position which gives the minimum efficiency, the efficiency shall be not less than that on which the maximum allowable working pressure is based. When the diameter of the shell exceeds 60 in., the length shall be taken as 60 in. in applying this rule;

(*2*) For a length equal to the inside radius of the shell for the position which gives the minimum efficiency, the efficiency shall be not less than 80 percent of that on which the maximum allowable working pressure is based. When the radius of the shell exceeds 30 in., the length shall be taken as 30 in. in applying this rule.

(*g*) For holes which are not in line, placed longitudinally along a cylindrical shell, the above rules for calculating efficiency shall hold, except that the equivalent longitudinal width of a diagonal ligament shall be used. To obtain the equivalent width, the longitudinal pitch of the two holes having a diagonal ligament shall be multiplied by the efficiency of the diagonal ligament. The efficiency to be used for the diagonal ligaments is given in Fig. UG-53.6.

(*h*) Examples illustrating the application of the rules in this paragraph are given in Appendix L.

UG-54 Supports

(*a*) All vessels shall be so supported and the supporting members shall be arranged and/or attached to the vessel wall in such a way as to provide for the maximum imposed loadings (see UG-22).

(*b*) Appendix G contains suggested rules for the design of supports.

UG-55 Lug for Platforms, Ladders, and Other Attachments to Vessel Walls

(*a*) Lugs or clips may be welded, brazed, riveted, or bolted to the outside or inside of the vessel to support ladders, platforms, piping, and attachment of insulating jackets. The material of the lugs or clips need not conform to the specifications for the materials to which they are attached or to a material specification permitted in this Division, but if attached to the vessel by welding shall be of weldable quality (see UG-6(c), UG-11(c), and UW-5(a)).

(*b*) External piping connected to a pressure vessel should be installed so as not to overstress the vessel wall.

[1]The rules in this paragraph apply to ligaments between tube holes and not to single openings. They may give lower efficiencies in some cases than those for symmetrical groups which extend a distance greater than the inside diameter of the shell as covered in (e). When this occurs, the efficiencies computed by the rules under (b) shall govern.

FABRICATION

UG-75 General

The fabrication of pressure vessels and vessel parts shall conform to the general fabrication requirements in the following paragraphs and to the specific requirements for *Fabrication* given in the applicable Parts of Subsections B and C.

UG-76 Cutting Plates and Other Stock

(*a*) Plates, edges of heads, and other parts may be cut to shape and size by mechanical means such as machining, shearing, grinding, or by oxygen or arc cutting. After oxygen cutting, all slag and detrimental discoloration of material which has been molten shall be removed by mechanical means prior to further fabrication or use.

(*b*) Ends of nozzles or manhole necks which are to remain unwelded in the completed vessel may be cut by shearing provided sufficient additional material is removed by any other method that produces a smooth finish.

(*c*) Exposed inside edges shall be rounded (grinding permitted) to a radius of at least $1/8$ in. as shown in Fig. UW-16.1 or may be chamfered at 45 deg to at least $5/32$ in. flat.

UG-77 Material Identification (see UG-85)

(*a*) Material for pressure parts preferably should be laid out so that when the vessel is completed, one complete set of the original identification markings required in the specifications for the material will be plainly visible. In case the original identification markings are unavoidably cut out, or the material is divided into two or more parts, one set shall either be accurately transferred prior to cutting by the pressure vessel manufacturer to a location where the markings will be visible on the completed vessel, or a coded marking shall be used to assure identification of each piece of material during fabrication and subsequent identification of the markings on the completed vessel. In either case an as-built sketch or a tabulation of materials shall be made, identifying

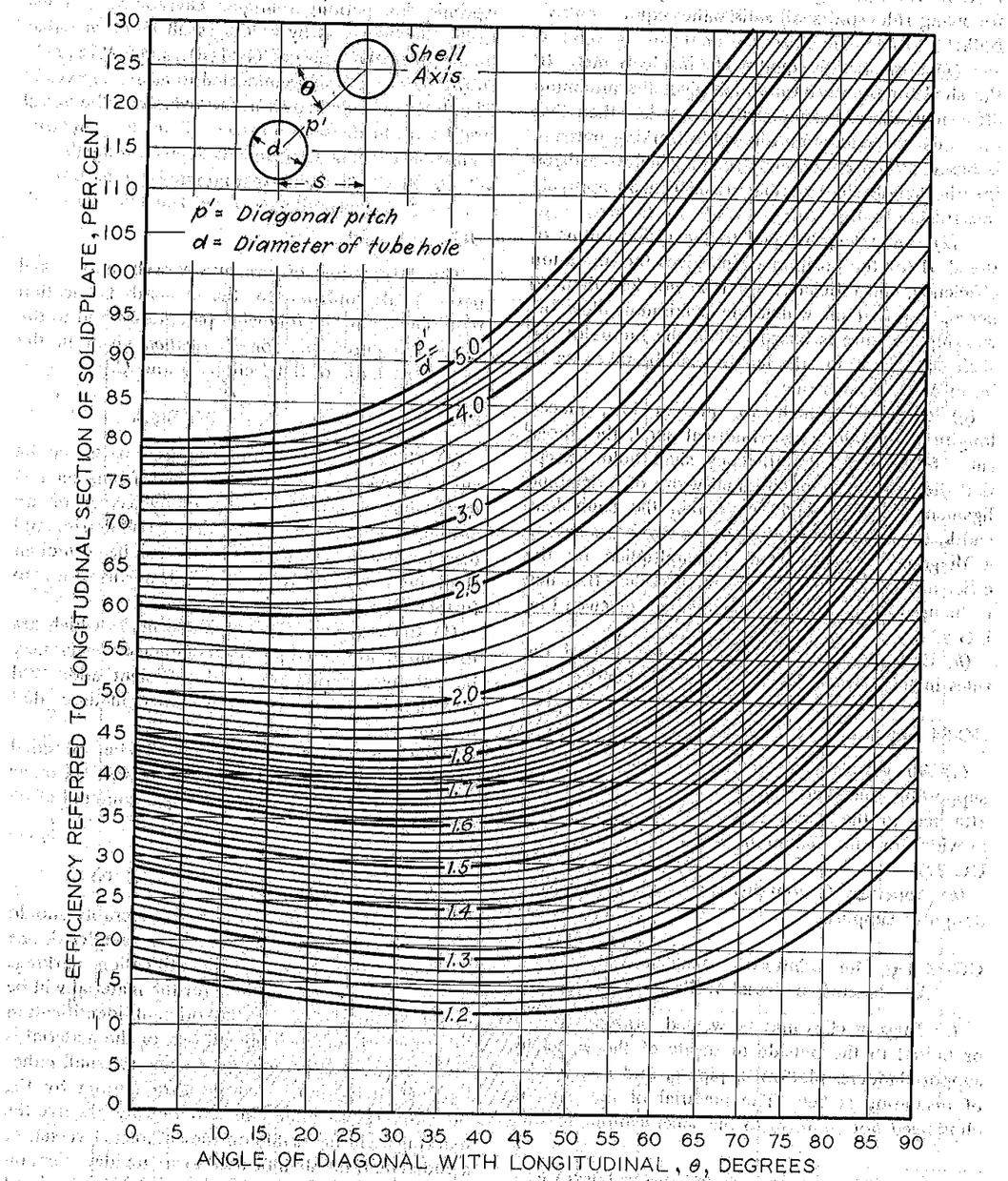


FIG. UG-53.6 DIAGRAM FOR DETERMINING EFFICIENCY OF DIAGONAL LIGAMENTS IN ORDER TO OBTAIN EQUIVALENT LONGITUDINAL EFFICIENCY

each piece of material with the mill test report and the coded marking. Except as indicated in (b), material may be marked by any method acceptable to the Inspector. The Inspector need not witness the transfer of the marks but shall satisfy himself that it has been correctly done.

(*b*) To guard against the formation of incipient cracks in ferrous material less than 1/4 in. in thickness and nonferrous material less than 1/2 in. in thickness, the materials manufacturers' markings shall be transferred in some manner other than by deep die stamping. Very light die stamping may be used if identifiable until final test and acceptance by the Inspector. Any other method acceptable to the Inspector, which will identify the material may be used.

(*c*) When material is formed into shapes by anyone other than the manufacturer of the completed pressure vessel, and the original markings as required by the applicable material specification are unavoidably cut out, or the material is divided into two or more parts, one set shall be accurately transferred by the manufacturer of the shape. The mill certification of the physical and chemical requirements of this material, in conjunction with the above modified marking requirements shall be considered sufficient to identify these shapes. Manufacturers Partial Data Reports and Parts Stamping are not a requirement unless there has been fabrication to the shapes that include welding, except as exempted by UG-11.

UG-78 Repair of Defects in Materials

Minor defects in material may be repaired provided approval of the Inspector is first obtained for the method and extent of repairs. Defective material that cannot be satisfactorily repaired shall be rejected.

UG-79 Forming Shell Sections and Heads

(*a*) All plates for shell sections and for heads shall be formed to the required shape by any process that will not unduly impair the physical properties of the material. Limits are provided on cold working of P-1 and UHT materials only,[1] see UCS-79(d) and UHT-79(a).

(*b*) If the plates are to be rolled, the adjoining edges of longitudinal joints of cylindrical vessels shall first be shaped to the proper curvature by preliminary rolling or forming in order to avoid having objectionable flat spots along the completed joints (see UG-80).

[1]Because of the limited data available, specific rules for P-1 and UHT materials only are given herein.

UG-80 Permissible Out-of-Roundness of Cylindrical Shells

(*a*) *Internal Pressure.* The shell of a completed vessel shall be substantially round. The difference between the maximum and minimum inside diameters at any cross section shall not exceed one percent of the nominal diameter at the cross section under consideration. The diameters may be measured on the inside or outside of the vessel. If measured on the outside the diameters shall be corrected for the plate thickness at the cross section under consideration (see Fig. UG-80.2).

When the cross section passes through an opening the permissible difference in inside diameters given above may be increased by two percent of the inside diameter of the opening.

For vessels with longitudinal lap joints the permissible difference in inside diameters may be increased by the nominal plate thickness.

(*b*) *External Pressure.* The shell of a completed vessel to operate under external pressure shall meet the following requirements at any cross section:

(*1*) The out-of-roundness limitations prescribed in (a).

(*2*) The maximum plus-or-minus deviation from the true circular form, measured radially on the outside or inside of the vessel, shall not exceed the maximum permissible deviation e obtained from Fig. UG-80.1. Measurements shall be made from a segmental circular template having the design inside or outside radius (depending upon where the measurements are taken) and a chord length equal to twice the arc length obtained from Fig. UG-29.2. The value of L in Figs. UG-29.2 and UG-80.1 shall be determined as follows:

(a) For cylinders, L as defined in UG-28(b).

(b) For cones or conical sections, use the applicable definition below: (1) the axial length of the cone or the greatest center-to-center distance between any two adjacent stiffening rings (if used); or (2) the distance from the end of the cone, or the bend line, if a transition knuckle is used, to the centerline of the first stiffening ring. D_o is the outside diameter, in inches, at the large end of the cone or conical section, taken perpendicular to the axis of revolution.

The value of t shall be determined as follows:

(a) For vessels with butt joints, t is the nominal plate thickness, less corrosion allowance;

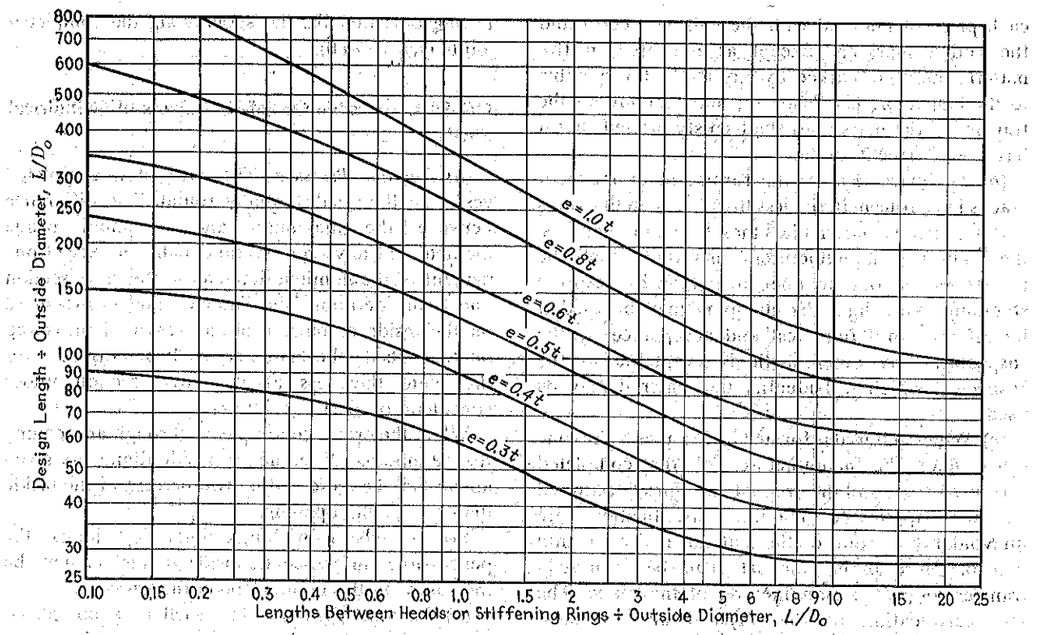


FIG. UG-80.1 MAXIMUM PERMISSIBLE DEVIATION FROM A CIRCULAR FORM "e," FOR VESSELS UNDER EXTERNAL PRESSURE

(b) For vessels with longitudinal lap joints, t is the nominal plate thickness and the permissible deviation is $(t + e)$.

(c) Where the shell at any cross section is made of plates having different thicknesses, t is the nominal thickness of the thinnest plate, less corrosion allowance.

(*c*) Measurements shall be taken on the surface of the base metal and not on welds or other raised parts of the material.

(*d*) The dimensions of a completed vessel may be brought within the requirements of this paragraph by any process which will not impair the strength of the material.

(*e*) Sharp bends and flat spots shall not be permitted unless provision is made for them in the design.

(*f*) Vessels fabricated of pipe may have permissible variations in diameter (measured outside) in accordance with those permitted under the specification covering its manufacture.

(*g*) An example illustrating the application of these rules for a vessel under external pressure is given in Appendix L (UA-271).

UG-81 Tolerance for Formed Heads

(*a*) The inner surface of a head shall not deviate from the specified shape by more than $1\frac{1}{4}$ percent of the inside diameter of the head skirt. Such deviations shall not be abrupt changes, shall be outside of the theoretical shape, and shall be measured perpendicular to the specified shape.

(*b*) The skirts of heads shall be sufficiently true to round so that the difference between the maximum and minimum diameters shall not exceed 1 percent of the nominal diameter.

(*c*) When the skirt of any unstayed formed head is machined to make a close and accurate fit into or over a shell, the thickness shall not be reduced to less than 90 percent of that required for a blank head (see UW-13). When so machined, the transition from the machined thickness to the original thickness of the head shall not be abrupt but shall be tapered for a distance of at least 4 times the difference between the thicknesses.

UG-82 Lugs and Fitting Attachments

All lugs, brackets, saddle type nozzles, manhole frames, reinforcement around openings, and other

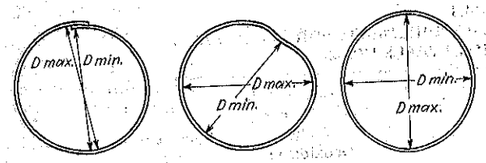


FIG. UG-80.2 EXAMPLE OF DIFFERENCES BETWEEN MAXIMUM AND MINIMUM DIAMETERS IN CYLINDRICAL SHELLS

appurtenances shall conform reasonably to the curvature of the shell or surface to which they are attached.

UG-83 Holes for Screw Stays

Holes for screw stays shall be drilled full size or punched not to exceed $\frac{1}{4}$ in. less than full diameter of the hole for plates over $\frac{5}{16}$ in. in thickness and $\frac{1}{8}$ in. less than the full diameter of the hole for plates not exceeding $\frac{5}{16}$ in. in thickness, and then drilled or reamed to the full diameter. The holes shall be tapped fair and true with a full thread.

UG-84 Charpy Impact Tests

(*a*) *General.* Charpy impact tests in accordance with the provisions of this paragraph shall be made on weldments and all materials for shells, heads, nozzles, and other vessel parts subject to stress due to pressure for which impact tests are required by the rules in Subsection C.

(*b*) *Test Procedures*

(*1*) Impact test procedures and apparatus shall conform to the applicable paragraphs of SA-370.

(*2*) Impact test specimens shall be cooled to a temperature not higher than the lowest temperature to which the vessel may be subjected in its operating cycle. The test piece, as well as the handling tongs, shall be cooled for a sufficient length of time to reach the test temperature.

The impact test made by the material manufacturer or the vessel fabricator may be conducted at temperatures other than those minimums established in the material specifications of Section II.

(*c*) *Test Specimens*

(*1*) Each set of impact test shall consist of three specimens.

(*2*) The impact test specimens shall be of the Charpy V-notch type and shall conform in all respects to Fig. UG-84. The standard 10 mm × 10 mm specimens shall be used where attainable for thickness of $\frac{1}{2}$ in. or greater.

(*3*) For material of thickness less than 0.394 in. (10 mm), Charpy impact tests may be performed on specimens of full material thickness. Alternatively, such material may be reduced in thickness to produce the largest possible of the following Charpy subsize specimens: $\frac{3}{4}$, $\frac{2}{3}$, $\frac{1}{2}$, $\frac{1}{3}$ or $\frac{1}{4}$. Toughness tests are not required where the maximum obtainable Charpy specimen has a width along the notch less than 0.099 in. (2,5 mm). For material of thickness greater than 0.394 in., the test material shall, wherever possible, be cut to produce full-size (10 mm × 10 mm) Charpy V-notch specimens. If, because of material shape, full-size bars are not obtainable, the following alternatives are permitted:

(a) Charpy bars cut to the largest possible size within the geometric limits of the material, or

(b) Charpy bars cut to the largest possible fractional subsize specimen ($\frac{3}{4}$, $\frac{2}{3}$, $\frac{1}{2}$, $\frac{1}{3}$ or $\frac{1}{4}$).

(*4*) (a) The applicable minimum energy requirement for all specimen sizes shall be that shown in Table UG-84.1, multiplied by the ratio of the actual specimen width along the notch to the width of a full-size specimen (10 mm).

(b) The applicable minimum lateral expansion opposite the notch for all specimen sizes for Table UCS-23 materials, having a specified minimum tensile strength of 100,000 psi or more, and Table UHA-23 materials shall be as required in UHT-6(a)(3) through UHT-6(a)(5). All requirements UHT-6(a)(3) through UHT-6(a)(5) shall apply.

(*5*) For all Charpy impact tests the following test temperature criteria shall be observed:

(a) For Materials of Thickness Equal To or Greater Than 0.394 in.: Where the largest attainable Charpy V-notch specimen has a width along the notch of at least 8 mm, the Charpy test using such a specimen shall be conducted at a temperature not warmer than the minimum design temperature. Where the largest possible test specimen has a width along the notch less than 8 mm, the test shall be conducted at a temperature lower than the minimum design temperature by the amount shown in Table UG-84.2 for that specimen width.

(b) For Materials of Thickness Less Than 0.394 in.: Where the largest attainable Charpy V-notch specimen has a width along the notch of at least 80 percent of the material thickness, the Charpy test of such a specimen shall be conducted at a temperature not warmer than the minimum design temperature. Where the largest possible test specimen has a width along the notch of less than 80 percent of the material thickness, the test shall be conducted at a temperature lower than the minimum design temperature by an amount equal to the difference

TABLE UG-84.1
MINIMUM CHARPY V-NOTCH IMPACT TESTS REQUIREMENTS FOR CARBON AND LOW ALLOY STEELS LISTED IN TABLE UCS-23

Specified Minimum Tensile Strength		Charpy V-Notch Impact Energy ft lbs: Fully Deoxidized Steel	Charpy V-Notch Impact Energy ft lbs: Other than Fully Deoxidized
65,000 psi and less	Average for 3 specimens	13	10
	Minimum for 1 specimen	10	7
Over 65,000 to 75,000 psi inclusive	Average for 3 specimens	15	13
	Minimum for 1 specimen	12	10
Over 75,000 to but not including 100,000 psi*	Average for 3 specimens	20	—
	Minimum for 1 specimen	15	—
100,000 psi and over	Minimum for 3 specimens	Lateral expansion 0.015 in. (15 mils)	

* The values of lateral expansion opposite the notch and fracture appearance in percentage of shear shall be recorded for information and these shall be retained for a period of two years.

(referring to Table UG-84.2) between the temperature reduction corresponding to the actual material thickness and the temperature reduction corresponding to the Charpy specimen width actually tested.

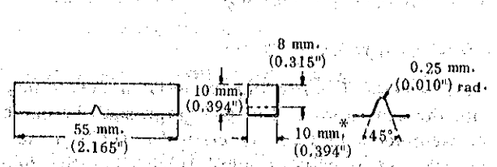
(6) When the average value of the three specimens equals or exceeds the minimum value permitted for a single specimen and the value for more than one specimen is below the required average value, or when the value for one specimen is below the minimum value permitted for a single specimen, a retest of three additional specimens shall be made. The value for each of these retest specimens shall equal or exceed the required average value.

TABLE UG-84.2
CHARPY IMPACT TEST TEMPERATURE REDUCTION BELOW MINIMUM DESIGN TEMPERATURE WHEN THE SUBSIZE CHARPY IMPACT WIDTH IS LESS THAN 80 PERCENT OF THE MATERIAL THICKNESS

Actual Material Thickness (See UG-84(c)(5)(b)) or Charpy Impact Specimen Width Along the Notch*: Inches	Millimeters	Temperature Reduction Degrees F
0.394	10 (Full-size standard bar)	0
0.354	9	0
0.315	8	0
0.295	7.5 (3/4 size bar)	5
0.276	7	8
0.262	6.67 (2/3 size bar)	10
0.236	6	15
0.197	5 (1/2 size bar)	20
0.158	4	30
0.131	3.33 (1/3 size bar)	35
0.118	3	40
0.099	2.5 (1/4 size bar)	50

* Straight line interpolation for intermediate values is permitted.

When an erratic result is caused by a defective specimen or there is uncertainty in test procedure, a retest will be allowed.



*See UG-84(c) for thickness of reduced-size specimen.

FIG. UG-84 SIMPLE BEAM IMPACT TEST SPECIMENS (CHARPY-TYPE TEST)

(d) *Impact Tests of Material*

(1) Certified reports of impact tests by the materials manufacturer will be acceptable evidence that the material meets the requirements of this paragraph, provided:

(a) The specimens taken are representative of the material delivered (see UCS-66(d)), and the material is not subjected to heat treatment during or following fabrication that will materially reduce its impact properties, or

(b) The materials from which the specimens are to be removed are heat treated separately such that they are representative of the material in the finished vessel (See UG-85.)

(2) The manufacturer of the vessel may have impact tests made to prove the suitability of a material which the materials manufacturer has not impact tested provided the number of tests and the method of taking the test specimens shall be as specified for the materials manufacturer.

(e) *Procedural*

(1) *Product Form Procedural Requirements.* Impact testing of each form of material shall comply with the requirements of the specifications listed in Table UG-84.3 in all respects, except that the Charpy V-notch specimen shall be used (see UG-84(c)).

TABLE UG-84.3
SPECIFICATIONS FOR IMPACT TESTED MATERIALS IN VARIOUS PRODUCT FORMS

Product Form	Specification
Plate	SA-300
Pipe	SA-333
Tubes	SA-334
Forgings	SA-350
Castings	SA-352
Bolting Materials (and bars)	SA-320

(2) *Small Parts.* The manufacturer of small parts, either cast or forged, may certify a lot of not more than 20 duplicate parts by reporting the results of one set of impact specimens taken from one such part selected at random, provided the same specification and heat of material and the same process of production, including heat treatment were used for all of the lot. When the part is too small to provide the three specimens of at least minimum size shown in Fig. UG-84, no impact test need be made.

(3) *Small Vessels.* For small vessels not exceeding the volume limitations defined in U-1(g), one set of impact specimens of the material may represent all vessels from the same heat of material not in excess of 100 vessels or one heat-treatment furnace batch whichever is smaller.

(f) *Impact Testing of Welds*

(1) For steel vessels of welded construction the impact toughness of welds and heat affected zones of procedure qualification test plates and vessel impact test plates (production impact test plates) shall be determined as required herein.

(2) All test plates shall be subjected to heat treatment, including cooling rates and aggregate time at temperature or temperatures, essentially (see UG-85, UCS-85, UHT-81, and UHT-82; heat treatment requirements of these paragraphs shall apply to the weld test plates) the same as established by the manufacturer for use in actual manufacture.

(g) *Location, Orientation, Temperature, and Values of Weld Impact Tests.* All weld impact tests shall comply with the following:

(1) Each set of weld metal impact specimens shall be taken across the weld with the notch in the weld metal. Each specimen shall be oriented so that the notch is normal to the surface of the material and one face of the specimen shall be within 1/16 in. of the surface of the material.

(2) Each set of heat affected zone impact specimens shall be taken across the weld and of sufficient length to locate, after etching, the notch in the heat affected zone. The notch shall be cut approximately normal to the material surface in such a manner as to include as much heat affected zone material as possible in the resulting fracture.

(3) The test temperature for welds and heat affected zones shall not be higher than required for the base materials.

(4) Impact values shall be at least as high as those required for the base materials.

(h) *Impact Tests of Welding Procedures*

(1) *General.* For steel vessels of welded construction the impact toughness of the welds and heat affected zones of the procedure qualification test plates shall be determined in accordance with paragraph (g) and the following subparagraphs:

(2) *When Required.* Welding procedure impact tests shall be made when welding those base materials required to be impact tested by paragraphs UCS-66, UHA-51, or UHT-6.

If impact tests are required for the deposited weld metal, but the base material is exempted from impact tests, (as in UHA-51), welding procedure test plates shall be made. The test plate material shall be material of the same specification used in the vessel. One set of impact specimens shall be taken with the notch in the weld metal; the heat affected zone need not be impact tested.

(3) *Material Over 1 1/2 in. Thick.* When procedure tests are made on material over 1 1/2 in. in thickness, two sets of impact specimens shall be taken from the weld with one set located near (within 1/16 in.) the surface of one side of the material and one set taken as near as practical midway between the surface and the center of thickness of the opposite side as described in UG-84(g)(1).

(4) *Essential Variables.* The additional essential variables specified in Section IX, Q-11, for impact testing are required.

(i) *Vessel (Production) Impact Test Plates*

(1) *General.* In addition to the requirements of (h), impact tests of welds and heat affected zones shall be made in accordance with (g) for each qualified welding procedure used on each vessel or group of vessels as defined in subparagraph (3) below. The vessel impact test plate shall be from one of the heats of steel used for the vessel or group of vessels. For Category A joints, the test plate shall,

where practicable, be welded as an extension to the end of a production joint so that the test plate weldment will represent as nearly as practicable the quality and type of welding in the vessel joint. For Category B joints that are welded using a different welding procedure than used on Category A joints, a test plate shall be welded under the production welding conditions used for the vessel, using the same type of equipment and at the same location and using the same procedures as used for the joint, and it shall be welded concurrently with the production welds or immediately prior to the start of production welding.

(2) *When Required.* Vessel (production impact test plates shall be made when welding those base materials required to be impact tested by UCS-66, UHA-51 or UHT-6.

If impact tests are required for the deposited weld metal, but the material is exempted from impact tests (as in UHA-51), vessel impact test plates shall be made. The test plate material shall be material of the same specification used in the vessel. One set of impact specimens shall be taken with the notch in the weld metal; the heat affected zone need not be impact tested.

(3) *Number of Vessel Impact Test Plates Required*

(a) For each vessel one test plate shall be made for each welding procedure used for joints of Categories A and B, unless the vessel is one of several as defined in (b) or (c).

In addition, for Category A and B joints the following requirements shall apply:

(1) If automatic or semiautomatic welding is performed, a test plate shall be made in each position employed in the vessel welding.

(2) If manual welding is also employed, a test plate shall be made in the flat position only, except if welding is to be performed in other positions a test plate need be made in the vertical position only (where the major portions of the layers of welds are deposited in the vertical upward direction). The vertically welded test plate will qualify the manual welding in all positions.

(b) For several vessels or parts of vessels, welded within any three-month period at one location, the plate thickness of which does not vary by more than 1/4 in., or 25 percent, whichever is greater, and of the same specification and grade of material, a test plate shall be made for each 400 feet of joints welded by the same procedure.

(c) For small vessels not exceeding the volume limitations defined in U-1(h), made from one heat of material requiring impact tests, one welded test joint made from the same heat of material and welded with the same electrode and the same welding procedure, may represent one lot of 100 vessels or less, or each heat treatment furnace batch, whichever is smaller.

(*j*) *Rejection.* If the vessel test plate fails to meet the impact requirements, the welds represented by the plate shall be unacceptable. Reheat treatment and retesting are permitted.

UG-85 Heat Treatment

When material is subjected to heat treatment during fabrication, the test specimens required by the applicable SA material specification shall be obtained from sample coupons which have been heat treated in the same manner as the material, including such heat treatments as were applied by the producer before shipment. The required tests may be performed by the material producer or the fabricator.

When plate specification heat treatments are not performed by the Mill they shall be performed by or under the control of the fabricator who shall then place the letter "T" following the letter "G" in the Mill plate marking (See SA-20) to indicate that the material specification heat treatments have been performed. The fabricator shall also show by a supplement to the appropriate Mill Test Report that the specified heat treatment has been performed.

INSPECTION AND TESTS

UG-90 General

(*a*) The inspection and testing of pressure vessels to be marked with the Code U-symbol and the testing of vessels to be marked with the Code UM-symbol shall conform to the general requirements for inspection and testing in the following paragraphs and in addition to the specific requirements for *Inspection and Tests* given in the applicable Parts of Subsections B and C.

(*b*) The manufacturer has the responsibility of providing the Inspector with all specified information and of assuring that the quality control, the detailed examination and the tests, required by this Division are performed at the stages of construction necessary to permit them to be meaningful. These shall include, but are not limited to, the following:

(*1*) The Certificate of Authorization from the ASME Boiler and Pressure Vessel Committee authorizing the manufacturer to fabricate the class of vessel being constructed (UG-116(m)).

(*2*) The drawings and design calculations for the vessel or part (U-2(b)).

(*3*) The mill test report or Material Certification for all material used in the fabrication of the vessel or part (UG-93).

(*4*) Any partial data reports when required by UG-120(c).

(*5*) Access for the Inspector to those parts of his plant concerned with the supply or fabrication of materials for the vessel, keeping the Inspector informed of the progress of the work so the required inspections can be performed in the proper sequence (UG-92).

(*6*) Evidence of examination of all materials before fabrication to make certain it has the required thickness (UG-27) for detection of unacceptable defects (UG-93(b) and UF-46), to make certain the material is one of the acceptable materials permitted by this Section (UG-5); and that identification traceable to the mill test report or material certification has been maintained (UG-77).

(*7*) Documentation of impact tests when such tests are required (UG-84).

(*8*) Concurrence of the Inspector prior to any repairs (UG-78, UF-37, and UF-38).

(*9*) Examination of shell and head sections to confirm they have been properly formed to the specified shapes within permissible tolerances (UG-79, UG-80, UG-81, UF-13, UF-27, UF-29, and UW-13).

(*10*) Qualification of the welding and/or brazing procedures before thay are used in fabrication (UG-84(h), UW-28(b), and UW-47).

(*11*) Qualification of all welders and welding operators and brazers before using the welders or brazers in production work (UW-29 and UB-43).

(*12*) Examination of all parts prior to joining to make certain they have been properly fitted for welding or brazing and that the surfaces to be joined have been cleaned and the alignment tolerances are maintained (UG-80, UW-31, UW-32, UW-33, and UB-17).

(*13*) Examine parts as fabrication progresses for material identification (UG-94), that surface defects are not evident (UG-95), that dimensional geometrics are maintained (UG-96 and UF-30).

(*14*) Provide records of all heat treatments performed on the vessel or vessel parts (UW-49 and UF-31).

(*15*) Provide records of NDT examinations performed on the vessel or vessel parts. This shall include the radiographic film if radiographic examinations are performed (UW-51 and UW-52).

(*16*) Subject vessel to required hydrostatic or pneumatic test and have the required inspection performed during such test (UG-99, UG-100, and UW-50).

(*17*) Affix the required stamping and/or nameplate to the vessel and make certain it is affixed to proper vessel (UG-116, UG-118, and UG-119).

(*18*) Prepare required manufacturers data report and have it certified by the Inspector (UG-120).

(*c*)(*1*) The Inspector shall make all inspections specifically required of him plus such other inspections as he believes are necessary to enable him to certify that all vessels which he authorizes to be stamped with the Code symbol have been designed and constructed in accordance with the requirements of this Division of the Code. The required inspections and verifications shall include, but are not limited to, the following:

(a) That the manufacturer has a valid Certificate of Authorization (UG-116(g)).

(b) That the applicable design calculations are available (U-2(b), U-2(c)).

(c) Materials used in the construction of the vessel comply with the requirements of UG-5 through UG-14 (UG-93(a)).

(d) All welding and brazing procedures have been qualified (UW-28 and UB-31).

(e) All welders, welding operators, brazers, and brazing operators have been qualified (UW-29 and UB-32).

(f) That the heat treatments, including PWHT, have been performed (UG-85, UW-40, and UF-52, UW-49).

(g) Material imperfections repaired by welding were acceptably repaired (UG-78, UW-52(d)(2)(c), UF-37, and UF-47(c)).

(h) Required NDT examinations and tests have been performed and that the results are acceptable (UG-84, UW-50, UW-51, UW-52, UB-44).

(i) Visual inspection of vessel to confirm that the material identification numbers have been properly transferred (UG-77, UG-94, UG-95).

(j) Performing internal and external inspections and witnessing the hydrostatic or pneumatic tests (UG-97, UG-99, UG-100, and UG-101).

(k) Verify that the nameplate stamping is

proper, and that the nameplate has been attached to the proper vessel (UG-119(b)).

(l) Sign the Certificate of Inspection on the Manufacturers Data Report when the vessel, to the best of his knowledge and belief, is complete and in compliance with all the provisions of this Code.

(2) When multiple duplicate pressure vessel fabrication makes it impracticable for the Inspector to personally check each item of inspection and test as required in UG-90(c)(1), the manufacturer, in collaboration with the authorized Inspector, shall prepare an inspection procedure setting forth in complete detail the methods by which the requirements of this Division will be maintained. This procedure shall be submitted to and shall have received the approval of the inspection agency. It then shall be submitted by the inspection agency to the appropriate authority under which the Inspector is commissioned, for written approval. This inspection procedure shall be used in the plant of the named manufacturer by the inspection agency submitting it, and shall be carried out by the Inspector in the employ of that inspection agency unless modified by agreement between the appropriate authority and the inspection agency. The data report for such a vessel shall include under Remarks the statement "Constructed under the provisions of UG-90(c)(2)."

UG-91 The Inspector

All references to "Inspectors" throughout this Division mean the authorized Inspector as defined in this paragraph. All inspections required by this Division of Section VIII shall be by an Inspector employed by a State or Municipality of the United States, a Canadian Province, an Inspector regularly employed by an insurance company authorized to write boiler and pressure vessel insurance or an Inspector continuously employed by a company for making inspections of pressure vessels to be used exclusively by such company and not for resale. See UG-116(a)(1). The Inspector shall not be in the employ of the manufacturer. All Inspectors shall have been qualified by a written examination under the rules of any State of the United States or Province of Canada which has adopted the Code.

UG-92 Access for Inspector

The manufacturer of the vessel shall arrange for the Inspector to have free access to such parts of all plants as are concerned with the supply or manufacture of materials for the vessel, when so requested. The Inspector shall be permitted free access, at all times while work on the vessel is being performed, to all parts of the manufacture's shop that concern the construction of the vessel and to the site of field erected vessels during the period of assembly and testing of the vessel. The manufacturer shall keep the Inspector informed of the progress of the work and shall notify him reasonably in advance when vessels will be ready for any required tests or inspections.

UG-93 Inspection of Materials

(a) The vessel manufacturer shall obtain the certified test report or certificate of compliance as provided for in the Material Specification and the Inspector shall examine the certified test report or certificate of compliance and shall determine that it represents the material and meets the requirements of the Material Specification except as otherwise provided in UG-6, UG-10, or UG-11.

(b) All materials to be used in constructing a pressure vessel shall be examined before fabrication for the purpose of detecting, as far as possible, defects which would affect the safety of the vessel.

(1) Particular attention should be given to cut edges and other parts of rolled plate which would disclose the existence of serious laminations, shearing cracks, and other objectionable defects.

(2) All materials that are to be tested in accordance with the requirements of UG-84 shall be examined for surface cracks.

(3) When a pressure part is to be welded to a forged or rolled plate thicker than $1/2$ in. to form a corner joint under the provisions of UW-13(e), the plate shall be inspected before welding, on all cut edges, including those for weld joint preparation, by magnetic particle or liquid penetrant examination. After welding, reinspection shall be made on all such edges that remain exposed. Where the material is nonmagnetic, only liquid penetrant methods shall be used.

(c) The Inspector shall assure himself that the thickness and other dimensions of material comply with the requirements of this Division.

(d) The Inspector shall satisfy himself that the inspection and marking requirements of UG-24 have been complied with for those castings assigned a casting quality factor exceeding 80 percent.

UG-94 Marking on Materials

(a) The Inspector shall inspect materials used in the construction to see that they bear the

identification required by the applicable material specification, except as otherwise provided in UG-6, UG-10, or UG-11. Should the identifying marks be obliterated or the material be divided into two or more parts, the marks shall be properly transferred by the manufacturer as provided in UG-77(a). See UG-85.

(b) The Inspector shall inspect steel plate material less than $1/4$ in. in thickness and nonferrous plate less than $1/2$ in. in thickness for deep die stamping (see UG-77(b)).

UG-95 Examination of Surfaces During Fabrication

As fabrication progresses, all materials used in the construction shall be examined for defects that have been uncovered during fabrication as well as to determine that the work has been done properly.

UG-96 Dimensional Check of Component Parts

(a) The manufacturer shall examine the pressure retaining parts to make certain they conform to the prescribed shape and meet the thickness requirements after forming. The manufacturer of the vessel shall furnish accurately formed templates as required by the Inspector for verification. See UG-80.

(b) Before attaching nozzles, manhole frames, nozzle reinforcement and other appurtenances to the inside or outside of the vessel they shall be examined to make certain they properly fit the vessel curvature. See UG-82.

UG-97 Inspection During Fabrication

(a) When conditions permit entry into the vessel, as complete an examination as possible shall be made before final closure.

(b) The Inspector shall make an external inspection of the completed vessel at the time of the final hydrostatic test or pneumatic test.

UG-98 Maximum Allowable Working Pressure

(a) The maximum allowable working pressure for a vessel is the maximum pressure permissible at the top of the vessel in its normal operating position at the operating temperature specified for that pressure. It is the least of the values found for maximum allowable working pressure for any of the essential parts of the vessel by the principles given in (b), and adjusted for any difference in static head that may exist between the part considered and the top of the vessel. (See UA-60(a).)

(b) The maximum allowable working pressure for a vessel part is the maximum internal or external pressure, including the static head thereon, as determined by the rules and formulas in this Division, together with the effect of any combination of loadings listed in UG-22 which are likely to occur, for the designated coincident operating temperature, excluding any metal thickness specified as corrosion allowance. (See UG-25.)

(c) Maximum allowable working pressure may be determined for more than one designated operating temperature, using for each temperature the applicable allowable stress value.

UG-99 Standard Hydrostatic Test

(a) All completed vessels, except those tested in accordance with the requirements of UG-100 or UG-101 shall satisfactorily pass the hydrostatic test prescribed in this paragraph.

(b) Except as otherwise permitted in (a) and (k), vessels designed for internal pressure shall be subjected to a hydrostatic test pressure which at every point in the vessel is at least equal to $1\,1/2$ times the maximum allowable working pressure [1] to be marked on the vessel multiplied by the lowest ratio (for the materials of which the vessel is constructed) of the stress value S for the test temperature on the vessel to the stress value S for the design temperature (see UG-21). All loadings that may exist during this test shall be given consideration.

(c) A hydrostatic test based on a calculated pressure may be used by agreement between the user and the manufacturer. The hydrostatic test pressure at the top of the vessel shall be the minimum of the test pressures calculated by multiplying the basis for calculated test pressure as defined in UA-60(e) for each pressure element by $1\,1/2$ and reducing this value by the hydrostatic head on that element. When this pressure is used, the Inspector shall reserve the right to require the manufacturer or the designer to furnish the calculations used for determining the hydrostatic test pressure for any part of the vessel.

(d) The requirements of (b) represent the minimum standard hydrostatic test pressure required by this Division. The requirements of (c) represent a special test based on calculations. Any intermediate value of pressure may be used. This Division does not specify an upper limit for hydrostatic test pressure.

[1] The maximum allowable working pressure may be assumed to be the same as the design pressure when calculations are not made to determine the maximum allowable working pressure.

However, if the hydrostatic test pressure is allowed to exceed, either intentionally or accidentally, the value determined as prescribed in (c) to the degree that the vessel is subjected to visible permanent distortion, the Inspector shall reserve the right to reject the vessel.

(e) Combination units (see UG-19(a) and UG-21) shall be tested by one of the following methods:

(1) Pressure chambers of combination units that have been designed to operate independently shall be hydrostatically tested as separate vessels; that is, each chamber shall be tested without pressure in the adjacent chamber.

(2) When pressure chambers of combination units have their common elements designed for the maximum differential pressure that can possibly occur during startup, operation, and shutdown, and the differential pressure is less than the higher pressure in the adjacent chambers, the common elements shall be subjected to a hydrostatic test pressure of at least 1½ times the differential pressure to be marked on the unit, corrected for temperature as in UG-99(b).

Following the test of the common elements and their inspection as required by UG-99(g), the adjacent chambers shall be hydrostatically tested simultaneously (see UG-99(b) or UG-99(c)). Care must be taken to limit the differential pressure between the chambers to the pressure used when testing the common elements.

The vessel stamping and the vessel data report must describe the common elements and their limiting differential pressure. See UG-116(j) and UG-120(b).

(f) Single-wall vessels designed for a vacuum or partial vacuum only, and chambers of multichamber vessels designed for a vacuum or partial vacuum only, shall be subjected to an internal hydrostatic test or when a hydrostatic test is not practicable, to a pneumatic test in accordance with the provisions of UG-100. Either type of test shall be made at a pressure not less than $1^1/_2$ times the difference between normal atmospheric pressure and the minimum design internal absolute pressure.

(g) Following the application of the hydrostatic test pressure an inspection shall be made of all joints and connections. This inspection shall be made at a pressure not less than two-thirds of the test pressure.

The visual inspection of joints and connections for leaks at two-thirds of the required hydrostatic test pressure may be waived provided:

(1) A suitable gas leak test is applied,

(2) A substitution of the gas leak test is by agreement reached between manufacturer and Inspector.

(3) All welded seams which will be hidden by assembly be given a visual examination for workmanship prior to assembly.

(4) The vessel will not contain a "lethal" substance.

(h) Any nonhazardous liquid at any temperature may be used for the hydrostatic test if below its boiling point. Combustible liquids having a flash point less than 110 F, such as petroleum distillates, may be used only for near atmospheric temperature tests. It is recommended that the liquid temperature be not less than 60 F where practicable.[1] The test pressure shall not be applied until the vessel and its contents are at about the same temperature.[2]

(i) Vents shall be provided at all high points of the vessel in the position in which it is to be tested to purge possible air pockets while the vessel is filling.

(j) Before applying pressure, the test equipment shall be examined to see that it is tight and that all low-pressure filling lines and other appurtenances that should not be subjected to the test pressure have been disconnected.

(k) The test pressure for enameled vessels shall be at least equal to, but need not exceed, the maximum allowable working pressure to be marked on the vessel.

(l) Vessels which are to be galvanized may be pressure-tested either before or after galvanizing.

UG-100 Pneumatic Test[1,3] (See UW-50)

(a) The pneumatic test prescribed in this paragraph may be used in lieu of the hydrostatic test prescribed in UG-99, as follows:

(1) For vessels that are so designed and/or supported that they cannot safely be filled with water.

(2) For vessels, not readily dried, that are to be used in services where traces of the testing liquid cannot be tolerated and the parts of which have, where possible, been previously tested by hydrostatic pressure to the pressure required in UG-99.

(b) Except for enameled vessels, for which the pneumatic test pressure shall be at least equal to, but need not exceed, the maximum allowable working pressure to be marked on the vessel, the pneumatic test pressure shall be at least equal to 1.25 times the maximum allowable working pressure to be stamped on the vessel multiplied by the lowest ratio (for the materials of which the vessel is constructed) of the stress value S for the test temperature of the vessel to the stress value S for the design temperature (see UG-21). In no case shall the pneumatic test pressure exceed 1.25 times the basis for calculated test pressure as defined in UA-60(e).

(c) The pressure in the vessel shall be gradually increased to not more than one-half of the test pressure. Thereafter, the test pressure shall be increased in steps of approximately one-tenth of the test pressure until the required test pressure has been reached. Then the pressure shall be reduced to a value equal to four-fifths of the test pressure and held for a sufficient time to permit inspection of the vessel.

The visual inspection of the vessel at four-fifths of the required test pressure may be waived provided:

(1) A suitable gas leak test is applied.

(2) Substitution of the gas leak test is by agreement reached between manufacturer and Inspector.

(3) All welded seams which will be hidden by assembly be given a visual examination for workmanship prior to assembly.

(4) The vessel will not contain a "lethal" substance.

UG-101 Proof Tests to Establish Maximum Allowable Working Pressure

(a) *General*

(1) The maximum allowable working pressure for vessels or vessel parts for which the strength cannot be computed with a satisfactory assurance of accuracy (see U-2) shall be established in accordance with the requirements of this paragraph, using one of the test procedures applicable to the type of loading and to the material used in construction.

(2) Provision is made in these rules for two types of tests to determine the internal maximum allowable working pressure: (a) Tests based on yielding of the part to be tested. These tests are limited to materials with a ratio of minimum specified yield to minimum specified ultimate strength of 0.625 or less. (b) Tests based on bursting of the part.

(3) Safety of testing personnel should be given serious consideration when conducting proof tests, and particular care should be taken during bursting tests in (m).

(b) The tests in these paragraphs may be used only for the purpose of establishing the maximum allowable working pressure of those elements or component parts for which the thickness cannot be determined by means of the design rules given in this Division. The maximum allowable working pressure of all other elements or component parts shall not be greater than that determined by means of the applicable design rules.

(c) The vessel or vessel part for which the maximum allowable working pressure is to be established shall not previously have been subjected to a pressure greater than 1½ times the desired or anticipated maximum allowable working pressure, adjusted for operating temperature as provided in (k).

(d) When the maximum allowable working pressure of a vessel or vessel part has been established by a proof test, duplicate parts of the same materials, design and construction need not be proof tested but shall be given a hydrostatic test in accordance with UG-99 or a pneumatic test in accordance with UG-100 except as otherwise provided in UCI-101 and UCD-101. The dimensions and minimum thickness of the structure to be tested shall not vary materially from those actually used. A geometrically similar part may be qualified by a series of tests covering the complete size range of the pressure part.

(e) Tests to establish the maximum allowable working pressure of vessels or vessel parts shall be witnessed and approved by the Inspector.

(f) A retest shall be allowed on a duplicate vessel or vessel part if errors or irregularities are obvious in the test results.

(g) As a check that the measurements are being taken on the most critical areas, the Inspector may require a lime wash or other brittle coating to be applied on all areas of probable high stress concentrations in the test procedures given in (n) and (o). The surfaces shall be suitably cleaned before

[1] For vessels constructed of steels whose resistance to brittle fracture at low temperature has not been enhanced, test temperatures above 60 F may be useful in minimizing risk of brittle fracture during hydrostatic or pneumatic testing.

[2] CAUTION: A small liquid relief valve set to $1^1/_3$ times the test pressure is recommended for the pressure test system, in case a vessel, while under test, is likely to be warmed up materially with personnel absent.

[3] In some cases it is desirable to test vessels when partly filled with liquids. For such vessels a combined hydrostatic and pneumatic test may be used as an alternative to the pneumatic test of this paragraph, provided the liquid level is set so that the maximum stress including the stress produced by pneumatic pressure at any point in the vessel (usually near the bottom) or in the support attachments, does not exceed 1.5 times the allowable stress value of the material multiplied by the applicable joint efficiency. After setting the liquid level to meet this condition, the test is conducted as prescribed in (b) and (c).

Air or gas is hazardous when used as a testing medium. It is therefore recommended that special precautions be taken when air or gas is used for test purposes.

the coating is applied in order to obtain satisfactory adhesion. The technique shall be suited to the coating material.

NOTE: Strains should be measured as they apply to membrane stresses and to bending stresses within the range covered by Note 2 to UG-23(c).

(*h*) *Application of Pressure.* In the procedures given in (l), the Brittle Coating Test, (n), the Strain Measurement Test, and (o), the Displacement Measurement Test, the hydrostatic pressure in the vessel or vessel part shall be increased gradually until approximately one-half the anticipated working pressure is reached. Thereafter, the test pressure shall be increased in steps of approximately one-tenth or less of the anticipated maximum allowable working pressure until the pressure required by the test procedure is reached. The pressure shall be held stationary at the end of each increment for a sufficient time to allow the observations required by the test procedure to be made, and shall be released to zero to permit determination of any permanent strain after any pressure increment that indicates an increase in strain or displacement over the previous equal pressure increment.

(*i*) *Corrosion Allowance.* The test procedures in this paragraph give the maximum allowable working pressure for the thickness of material tested. When the thickness as tested includes extra thickness as provided in UG-25, the maximum allowable working pressure at which the vessel shall be permitted to operate shall be determined by multiplying the maximum allowable working pressure obtained from the test by the ratio

$$(t-c)/t$$

where

t = nominal thickness of the material at the weakest point, inches
c = allowance added for corrosion, erosion, and abrasion, inches

(*j*) *Determination of Yield Strength and Tensile Strength*

(*1*) For proof tests based on yielding, (l), (n) or (o), the yield strength (or yield point for those materials which exhibit that type of yield behavior indicated by a "sharp-kneed" portion of the stress-strain diagram) of the material in the part tested, shall be determined in accordance with the method prescribed in the applicable material specification and as described in ASTM Specification E8, Tension Testing of Metallic Materials. For proof tests based on bursting, (m), the tensile strength instead of the yield strength of the material in the part tested shall be similarly determined.

(*2*) Yield or tensile strength so determined shall be the average from three or four specimens cut from the part tested after the test is completed. The specimens shall be cut from a location where the stress during the test has not exceeded the yield strength. The specimens shall not be flame cut because this might affect the strength of the material. If yield or tensile strength is not determined by test specimens from the pressure part tested, alternative methods are given in (l), (m), (n), and (o) for evaluation of proof test results to establish the maximum allowable working pressure.

(*3*) When excess stock from the same piece of wrought material is available and has been given the same stress relieving heat treatment as the pressure part, the test specimens may be cut from this excess stock. The specimen shall not be removed by flame cutting or any other method involving sufficient heat to affect the properties of the specimen.

(*k*) *Maximum Allowable Working Pressure at Higher Temperatures.* The maximum allowable working pressure for vessels and vessel parts that are to operate at temperatures at which the allowable stress value of the material is less than at the test temperature shall be determined by the following formula:

$$P_o = P_t \frac{S_o}{S_t}$$

where

P_o = maximum allowable working pressure at the operating temperature, pounds per square inch
P_t = maximum allowable working pressure at test temperature, pounds per square inch
S_o = maximum allowable stress value at the operating temperature, as given in Subsection C, pounds per square inch
S_t = maximum allowable stress value at test temperature as given in Subsection C, pounds per square inch

(*l*) *Brittle-Coating Test Procedure*

(*1*) Subject to the limitations of (a)(2)(*a*), this procedure may be used only for vessels and vessel parts under internal pressure, constructed of materials having a definitely determinable yield point. The component parts that require proof testing shall be coated with a lime wash or other brittle coating in

accordance with (g). Pressure shall be applied in accordance with (h). The parts being proof tested shall be examined between pressure increments for signs of yielding as evidenced by flaking of the brittle coating, or by the appearance of strain lines. The application of pressure shall be stopped at the first sign of yielding, or if desired, at some lower pressure.

(*2*) The maximum allowable working pressure P in pounds per square inch at test temperature for parts tested under this paragraph shall be computed by one of the following formulas:

(a) If the average yield strength is determined in accordance with (j):

$$P = 0.5H\frac{Y_s}{Y_a}$$

(b) To eliminate the necessity of cutting tensile specimens and determining the actual yield strength of the material under test, one of the following formulas may be used to determine the maximum allowable working pressure:

(1) For carbon steel meeting an acceptable Code Specification, with a specified minimum tensile strength of not over 70,000 psi:

$$P = 0.5H\left(\frac{S}{S+5000}\right)$$

(2) For any acceptable material listed in this Division:

$$P = 0.4H$$

where

H = hydrostatic test pressure at which the test was stopped, pounds per square inch
Y_s = specified minimum yield strength, pounds per square inch
Y_a = actual average yield strength from test specimens, pounds per square inch
S = specified minimum tensile strength, pounds per square inch

When formula (*b*)(1) or (*b*)(2) is used, the material in the pressure part shall have had no appreciable cold working or other treatment that would tend to raise the yield strength above the normal.

The maximum allowable working pressure at other temperatures shall be determined as provided in (k).

(*m*) *Bursting Test Procedure*

(*1*) This procedure may be used for vessels or vessel parts under internal pressure when constructed of any material permitted to be used under the rules of this Division. The maximum allowable working pressure of any component part proof tested by this method shall be established by a hydrostatic test to failure by rupture of a full-size sample of such pressure part. The hydrostatic pressure at which rupture occurs shall be determined.

(*2*) The maximum allowable working pressure P pounds per square inch at test temperature for parts tested under this paragraph shall be computed by one of the following formulas:

(a) Parts constructed of materials other than cast materials:

$$P = \frac{B}{5} \times \frac{SE}{S_a} \text{ or } P = \frac{B}{5} \times \frac{SE}{S_m}$$

(b) Parts constructed of cast iron—see UCI-101. Parts constructed of nodular cast iron—see UCN-101.

(c) Parts constructed of cast materials, except cast iron and cast nodular iron:

$$P = \frac{Bf}{5} \times \frac{SE}{S_a} \text{ or } P = \frac{Bf}{5} \times \frac{SE}{S_m}$$

where

B = bursting test pressure, pounds per square inch
E = efficiency of welded joint, if used (see Table UW-12)
f = casting quality factor as specified in UG-24
S = specified minimum tensile strength, pounds per square inch
S_a = average actual tensile strength of test specimens, pounds per square inch
S_m = maximum tensile strength of range of specification, pounds per square inch

The maximum allowable working pressure at other temperatures shall be determined as provided in (k).

(*n*) *Strain Measurement Test Procedure*

(*1*) Subject to limitations of (a)(2)(*a*), this procedure may be used for vessels or vessel parts under internal pressure, constructed of any material permitted to be used under the rules of this Division. Strains shall be measured in the direction of the maximum stress at the most highly stressed parts (see (g)) by means of strain gages of any type capable of indicating strains to 0.00005 in. per in. Pressure shall be applied as provided in (h).

(*2*) After each increment of pressure has been applied, readings of the strain gages and the hydrostatic pressure shall be taken and recorded. The pressure shall be released and any permanent

strain at each gage shall be determined after any pressure increment that indicates an increase in strain for this increment over the previous equal pressure increment. Only one application of each increment of pressure is required.

(3) Two curves of strain against test pressure shall be plotted for each gage line as the test progresses, one showing the strain under pressure and one showing the permanent strain when the pressure is removed. The test may be discontinued when the test pressure reaches the value H which will, by the formula, justify the desired working pressure, but shall not exceed the pressure at which the plotted points for the most highly strained gage line reaches the value given below for the material used:

(a) 0.2 percent permanent strain for aluminum-base and nickel-base alloys.

(b) 0.2 percent permanent strain for carbon low-alloy and high-alloy steels.

(c) 0.5 percent strain under pressure for copper-base alloys.

(4) The maximum allowable working pressure P in pounds per square inch at test temperature for parts tested under this paragraph shall be computed by one of the following formulas:

(a) If the average yield strength is determined in accordance with (j):

$$P=0.5H\left(\frac{Y_s}{Y_a}\right)$$

(b) If the actual average yield strength is not determined by test specimens:

$$P=0.4H$$

where

H = hydrostatic test pressure at which the test was stopped in accordance with (n)(3), pounds per square inch

Y_s = specified minimum yield strength, pounds per square inch

Y_a = actual average yield strength from test specimens, pounds per square inch

The maximum allowable working pressure at other temperatures shall be determined as provided in (k).

(o) Displacement Measurement Test Procedure

(1) Subject to the limitations of (a)(2)(a), this procedure may be used only for vessels and vessel parts under internal pressure, constructed of materials having a definitely determinable yield point. Displacement shall be measured at the most highly stressed parts (see (g)) by means of measuring devices of any type capable of measuring to 0.001 in. The displacement may be measured between two diametrically opposed reference points in a symmetrical structure, or between a reference point and a fixed base point. Pressure shall be applied as provided in (h).

(2) After each increment of pressure has been applied, readings of the displacement and hydrostatic test pressure shall be taken and recorded. The pressure shall be released and any permanent displacement shall be determined after any pressure increment that indicates an increase in measured displacement for this increment over the previous equal pressure increment. Only one application of each increment is required. Care must be taken to assure that the readings represent only displacements of the parts on which measurements are being made and do not include any slip of the measuring devices or any movement of the fixed base points or of the pressure part as a whole.

(3) Two curves of displacement against test pressure shall be plotted for each reference point as the test progresses, one showing the displacement under pressure and one showing the permanent displacement when the pressure is removed. The application of pressure shall be stopped when it is evident that the curve through the points representing displacement under pressure has deviated from a straight line.

(4) The pressure coincident with the proportional limit of the material shall be determined by noting the pressure at which the curve representing displacement under pressure deviates from a straight line. The pressure at the proportional limit may be checked from the curve of permanent displacement by locating the point where the permanent displacement begins to increase regularly with further increases in pressure. Permanent deformation at the beginning of the curve that results from the equalization of stresses and irregularities in the material may be disregarded.

(5) The maximum allowable working pressure P in pounds per square inch at test temperature for parts tested under this paragraph shall be computed by one of the following formulas:

(a) If the average yield strength is determined in accordance with (j):

$$P=0.5H\left(\frac{Y_s}{Y_a}\right)$$

(b) To eliminate the necessity of cutting tensile specimens and determining the actual yield strength of the material under test, one of the following formulas may be used to determine the maximum allowable working pressure:

(1) For carbon steel, meeting an acceptable

Code specification, with a specified minimum tensile strength of not over 70,000 pounds per square inch:

$$P=0.5H\left(\frac{S}{S+5000}\right)$$

(2) For any acceptable material listed in this Division.

$$P=0.4H$$

where

H = hydrostatic test pressure coincident with the proportional limit of the weakest element of the component part tested, pounds per square inch

Y_s = specified minimum yield strength, pounds per square inch

Y_a = actual average yield strength, from test specimens, pounds per square inch

S = specified minimum tensile strength, pounds per square inch

When formula (b)(1) or (b)(2) is used, the material in the pressure part shall have had no appreciable cold working or other treatment that would tend to raise the yield strength above the normal. The maximum allowable working pressure at other temperatures shall be determined as provided in (k).

(p) Procedure for Vessels Having Chambers of Special Shape Subject to Collapse

(1) Pressure chambers of vessels, portions of which have a shape other than that of a complete circular cylinder or formed head, and also jackets of cylindrical vessels which extend over only a portion of the circumference, which are not fully staybolted as required by UG-28(i), shall withstand without excessive deformation a hydrostatic test of not less than 3 times the desired maximum allowable working pressure.

(2) The maximum allowable working pressure at other temperatures shall be determined as provided in (k).

UG-102 Test Gages

(a) An indicating gage shall be connected directly to the vessel. If the indicating gage is not readily visible to the operator controlling the pressure applied, an additional indicating gage shall be provided where it will be visible to the operator throughout the duration of the test. For large vessels, it is recommended that a recording gage be used in addition to indicating gages.

(b) Indicating pressure gages used in testing shall preferably have dials graduated over a range of about double the intended maximum test pressure, but in no case shall the range be less than 1½ times that pressure.

(c) All gages shall be calibrated against a standard deadweight tester or a calibrated master gage. Gages shall be recalibrated at any time that there is reason to believe that they are in error.

UG-103 Nondestructive Testing

Where magnetic particle examination is prescribed in this Division it shall be done in accordance with Appendix VI. Where liquid penetrant examination is prescribed it shall be done in accordance with Appendix VIII.

STAMPING AND REPORTS

UG-115 General

The marking and certification of all pressure vessels built under this Division of Section VIII of the Code shall comply with the requirements of the following paragraphs, and in addition with the requirements for *Stamping and Reports* given in the applicable Parts of Subsections B and C.

UG-116 Required Marking

(a) Each pressure vessel shall be marked with the following:

(1)(a) The official Code U-symbol shown in Fig. UG-116 (a) on vessels inspected in accordance with the requirements in UG-90 through UG-97 (when inspected by a user's Inspector as provided in UG-91, the word USER shall be marked above the Code symbol); or

(b) The official Code UM-symbol shown in Fig. UG-116(b) on vessels constructed in accordance with the provisions in U-1(h).

(2) Manufacturer's name.

(3) Maximum allowable working pressure[1,2] _____psi at _____F.

(4) Manufacturer's serial number.

(5) Year built.

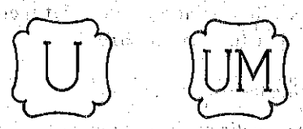
(b) Vessels designed to operate at temperatures

[1]When a pressure vessel is expected to operate at more than one pressure and temperature condition, other values of maximum allowable working pressure with the coincident permissible temperature may be added as required.

[2]The maximum allowable working pressure may be assumed to be the same as the design pressure when calculations are not made to determine the maximum allowable working pressure.

below —20 F shall be marked as required by the other sections of this paragraph except for the following:

(*1*) When impact tests in accordance with UG-84 are required:



(a) (b)

FIG. UG-116 OFFICIAL SYMBOLS FOR STAMP TO DENOTE THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS' STANDARD

(a) Add to Item (a)(3) above "minimum allowable temperature" giving minimum temperature for which the vessel is suitable.

(b) Add the initials I T after the figures for the minimum allowable temperature when the material in the vessel has passed the impact tests required under the provisions of UG-84.

(*2*) When in accordance with UCS-66(c)(2) or UHA-51(b) no impact test is performed, the vessel shall be marked as required by other sections of this paragraph for the maximum allowable working pressure for coincident temperatures of —20 F and above and in addition shall be marked for the operating pressure (prior to multiplying by two and one-half to obtain the design pressure) at the lowest coincident temperature below —20 F, such marking to be followed by the lettering UCS-66 or UHA-51.

(*c*) The type of construction used for the main longitudinal and/or circumferential joints of a vessel shall be indicated directly under the Code symbol by applying the appropriate lettering listed below:

Arc or gas welded	W
Riveted	R
Brazed	B
Forge welded	F
Resistance welded	RES
Seamless	S

Vessels embodying a combination of types of construction shall be marked to indicate all of the types of construction used.

(*d*) The maximum allowable working pressure and temperature to be indicated on vessels embodying a combination of types of construction and material shall be based on the most restrictive detail of construction and material used.

(*e*)(*1*) The letters RT shall be applied under the Code symbol to those vessels of welded construction with joints which have been completely radiographed to the extent required by the Code.

(*2*) The letters PRT shall be applied under the Code symbol when only a part of the vessel has been radiographed as provided in UW-11 (a). The extent of radiographing and use of radiographic joint efficiency shall be noted on Form U-1.

(*f*)(*1*) The letters HT shall be applied under the Code symbol when the whole vessel has been postweld heat treated as provided in UW-10.

(*2*) The letters PHT shall be applied under the Code symbol when only part of the vessel has been postweld heat treated as provided in UW-10. The extent of the postweld heat treatment shall be noted on Form U-1.

(*g*) The manufacturer who completes the vessel shall apply the Code symbol and shall have a valid certificate of authorization for its use. After the hydrostatic test or pneumatic test, and with the approval of the Inspector, the Code U-symbol may be applied. The UM-symbol shall be applied after the vessel has passed the hydrostatic test or its permissible equivalent. The application of the Code symbol together with the final certification (See U-1(h) and UG-120) shall indicate that all of this Division requirements have been met.

(*h*) Parts of vessels for which partial data reports are required in UG-120(c) shall be marked by the parts manufacturer with the following:

(*1*) The official Code Symbol shown in Fig. UG-116(a), above the word "PART."

(*2*) The manufacturer's name.

(*3*) The manufacturer's serial number.

This requirement does not apply to such items as handhole covers, manhole covers and accessories.

(*i*) All required markings shall be located in a conspicuous place on the vessel, preferably near a manhole or handhole (see UA-352, Appendix M).

(*j*) Either of the following arrangements may be used in markings vessels having two or more independent pressure chambers designed for the same or different operating conditions. Each detachable chamber shall be marked so as to identify it positively with the combined unit.

(*l*) The marking may be grouped in one location on the vessel provided it is arranged so as to indicate clearly the data applicable to each chamber including the maximum differential pressure for the common elements when this pressure is less than the higher pressure in the adjacent chambers.

(*2*) The complete required marking may be applied to each independent pressure chamber, provided additional marking, such as stock space,

jacket, tubes, or channel box, is used to indicate clearly to which chamber the data apply.

(*k*) In multiple-chamber vessels, only the parts of those chambers which are required to be built under this Division (see U-1) need bear the required marking. However, it is recommended that manufacturers indicate on such vessels the working conditions for which the non-Code chambers were designed.

(*l*) Removable pressure parts shall be permanently marked in a manner to identify them with the vessel or chamber of which they form a part. This does not apply to manhole covers, handhole covers, and their accessory parts.

(*m*) Permission to use the official Code symbols shown in Fig. UG-116 will be granted by the Society pursuant to the provisions of this paragraph.

(*1*) Any manufacturer of pressure vessels may apply to the Boiler and Pressure Vessel Committee of the Society, upon forms issued by the Society, for permission to use either or both stamps. Each applicant must agree that if permission to use any such stamp is granted, it will be used according to the rules and regulations of this Division of Section VIII of the Code and that any such stamps will be promptly returned to the Society upon demand, or in case the applicant discontinues the manufacture of the above, or in case the certificate of authorization issued to such applicant has expired and no new certificate has been issued. The holder of any such stamps shall not permit any other manufacturer to use his stamp.

When a manufacturer builds Code equipment in plants in more than one geographical area, he may submit separate applications for each plant or a single application listing the addresses of all such plants. Each application shall identify the agency providing authorized Code Inspection at each plant. A separate Certificate of Authorization will be prepared and a separate fee charged by the Society for each plant.

(*2*) Permission to use the stamp may be granted or withheld by the Society in its absolute discretion. If permission is given, and the proper administrative fee paid, a certificate of authorization evidencing permission to use such symbol, expiring on the triennial anniversary date thereafter, except for the UM Certificate, will be forwarded to the applicant. Each such certificate will be signed by the Chairman and Secretary, or other duly authorized officer of officers, of the Boiler and Pressure Vessel Committee. Six (6) months prior to the date of expiration of any such certificate, the applicant must apply for a renewal of such permission and the issuance of a new certificate.

Any manufacturer of boilers or pressure vessels who holds an "S" or "U" stamp may apply to the Boiler and Pressure Vessel Committee of the Society for permission to use the "UM" stamp. Each applicant must agree that if permission to use the stamp is granted, it will be used according to the rules and regulations of this Division of Section VIII of the Code during the period for which he legitimately holds and uses the "S" or "U" stamp. Such applicant shall satisfy the Inspector that he has established a procedure adequate to assure compliance with Code requirements in the manufacture of vessels to which the "UM" symbol is to be applied. The certificate of authorization for the "UM" symbol shall be renewed annually, subject to review of the manufacturers procedure by the authorized inspector. The stamp will be promptly returned to the Society upon demand, or in case the applicant discontinues the manufacture of the above, or in case the certificate of authorization issued to such applicant has expired and no new certificate has been issued. The Holder of the "UM" stamp shall not permit any other manufacturers to use his stamp.

(*3*) The Society reserves the absolute right to cancel or refuse to renew such permission, returning fees paid for the prorated unexpired term.

(*4*) The Boiler and Pressure Vessel Committee may at any time and from time to time make such regulations concerning the issuance and use of such stamps as it deems appropriate, and all such regulations shall become binding upon the holders of any valid certificate of authorization.

(*n*) All steel stamps for applying the Code symbol shall be obtained from the Society.

UG-117 Methods of Marking

The required marking shall be stamped directly on the vessel as provided in UG-118 or on a separate nameplate as provided in UG-119.

UG-118 Stamping

(*a*) When the marking required by UG-116 is applied directly to the vessel, it shall be stamped with letters and figures at least $^{5}/_{16}$ in. high.

(*b*) The stamping shall be arranged as shown in Fig. UG-118 when space permits.

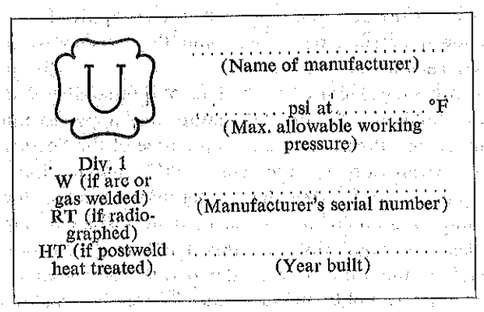


FIG. UG-118 FORM OF STAMPING

UG-119 Nameplates

(*a*) Nameplates bearing the marking called for in UG-116 shall be used on vessels constructed of steel plates less than ¼ in. thick or of nonferrous plates less than ½ in. thick in lieu of stamping these data directly on the vessel, and may be used on vessels constructed of thicker plates. The arrangements shall be substantially as shown in Fig. UG-118. The Code symbol and the manufacturer's serial number shall be stamped on the nameplate, but the other required data may be stamped, etched, cast, or impressed thereon.

(*b*) The required data on a nameplate shall be in characters not less than $^{5}/_{32}$ in. high.

(*c*) Required nameplates shall be permanently attached by suitable means to the vessel in some conspicuous place (see UG-116(i)).

(*d*) The nameplate may be marked before it is affixed to the vessel, in which case the manufacturer shall see that the nameplate with the correct marking has been applied to the proper vessel, and the Inspector shall satisfy himself that this has been done.

UG-120 Data Reports

(*a*) A data sheet shall be filled out on Form U-1 or Form U-1A by the manufacturer and shall be signed by the manufacturer and the Inspector for each pressure vessel marked with the Code U-symbol. When required, a certificate of compliance on Form U-3 shall be filled out and signed by the manufacturer for each pressure vessel marked with the Code UM-Symbol.

(*b*) Both chambers of combination units must be described on the same data sheet. When the common elements of such units are designed for a differential pressure, this limiting pressure must also be reported.

(*c*) *Partial Data Reports.* Data sheets for those parts of a pressure vessel requiring inspection under this Division, which are furnished by other than the shop of the manufacturer responsible for the completed vessel, shall be executed by the parts manufacturer and the Inspector in accordance with the requirements of this Division and shall be forwarded, in duplicate, to the manufacturer of the finished vessel. These partial data reports, together with his own inspection, shall be the final Inspector's authority to witness the application of a Code symbol to the vessel (see UG-90(c)). A sample partial data report sheet appears in the Appendix as Form U-2.

PRESSURE RELIEF DEVICES

UG-125 General [1]

(*a*) All pressure vessels within the scope of this Division of Section VIII, irrespective of size or pressure, shall be provided[2] with protective devices in accordance with the requirements of UG-125 through UG-134.

(*b*) An unfired steam boiler as defined in U-1(e) shall be equipped with protective devices required by Section I of the Code in so far as they are applicable to the service of the particular installation.

(*c*) All pressure vessels other than unfired steam boilers shall be protected by pressure-relieving devices that will prevent the pressure from rising more than 10 percent above the maximum allowable working pressure, except when the excess pressure is caused by exposure to fire or other unexpected source of heat.

(*d*) Where an additional hazard can be created by exposure of a pressure vessel to fire or other unexpected sources of external heat (for example, vessels used to store liquefied flammable gases), supplemental pressure relieving devices shall be installed to protect against excessive pressure. Such supplemental pressure relieving devices shall be capable of preventing the pressure from rising more

[1] Safety valve—An automatic pressure relieving device actuated by the static pressure upstream of the valve and characterized by full opening pop action. It is used for gas or vapor service.
Relief valve—An automatic pressure relieving device actuated by the static pressure upstream of the valve which opens further with the increase in pressure over the opening pressure. It is used primarily for liquid service.
Safety relief valve—An automatic pressure actuated relieving device suitable for use either as a safety valve or relief valve, depending on application.

[2] Safety devices need not be provided by the vessel manufacturer, but overpressure protection shall be provided prior to placing the vessel in service.

than 20 percent above the maximum allowable working pressure of the vessel. A single pressure relieving device may be used to satisfy the requirements of this paragraph and (c), provided it meets the requirements of both paragraphs.

(*e*) Pressure relieving devices shall be constructed, located, and installed so that they are readily accessible for inspection and repair and so that they cannot be readily rendered inoperative (see Appendix M), and should be selected on the basis of their intended service.

(*f*) Pressure indicating gages, if used, shall preferably be graduated to approximately double the operating pressure but in no case to less than 1.2 times the pressure at which the relieving device is set to function.

(*g*) Rupture disks may be used in lieu of safety valves on vessels containing substances that may render a safety valve inoperative, or where a loss of valuable material by leakage should be avoided, or contamination of the atmosphere by leakage of noxious gases must be avoided (see UG-127).

(*h*) Vessels that are to operate completely filled with liquid shall be equipped with liquid relief valves, unless otherwise protected against overpressure.

(*i*) The protective devices required in (a) need not be installed directly on a pressure vessel when the source of pressure is external to the vessel and is under such positive control that the pressure in the vessel cannot exceed the maximum allowable working pressure at the operating temperature except as permitted in (c) and (d) (see UG-98).

NOTE: Pressure reducing valves and similar mechanical or electrical control instruments, except for pilot operated valves as permitted in UG-126(b), are not considered as sufficiently positive in action to prevent excess pressures from being developed.

(*j*) Pressure relieving devices shall be constructed of materials suitable for the pressure, temperature, and other conditions of the service intended.

UG-126 Safety and Relief Valves

(*a*) Safety and relief valves shall be of the direct spring loaded type, except as permitted in (b).

(*b*) Pilot valve control or other indirect operation of safety valves is not permitted unless the design is such that the main unloading valve will open automatically at not over the set pressure and will discharge its full rated capacity if some essential part of the pilot or auxiliary device should fail.

(*c*) Safety and relief valves for steam or air service shall be provided with a substantial lifting device so that the disk can be lifted from its seat when the pressure in the vessel is 75 percent of that at which the valve is set to blow.

(*d*) Safety and relief valves for service other than steam and air need not be provided with a lifting device, although a lifting device is desirable if the vapors are such that their release will not create a hazard.

(*e*) If the design of a safety or relief valve is such that liquid can collect on the discharge side of the disk, the valve shall be equipped with a drain at the lowest point where liquid can collect (for installation, see UG-134).

(*f*) Seats or disks of cast iron shall not be used.

(*g*) The spring in a safety or relief valve in service for pressures up to and including 250 psi shall not be reset for any pressure more than 10 percent above or 10 percent below that for which the valve is marked. For higher pressures, the spring shall not be reset for any pressure more than 5 percent above or 5 percent below that for which the safety or relief valve is marked.

UG-127 Rupture Disks

(*a*) The cross-sectional area of the connection to a vessel shall be not less than the required relief area of the rupture disk.

(*b*) Every rupture disk shall have a specified bursting pressure at a specified temperature, shall be marked with a lot number, and shall be guaranteed by its manufacturer to burst within 5 percent (plus or minus) of its specified bursting pressure.

(*c*) The specified bursting pressure at the coincident operating temperature shall be determined by bursting two or more specimens from a lot of the same material and of the same size as those to be used. The tests shall be made in a holder of the same form and pressure area dimensions as that with which the disk is to be used.

(*d*) A rupture disk may be installed between a spring loaded safety or relief valve and the vessel provided:

(*1*) The valve is ample in capacity to meet the requirements of UG-132(a) and (b);

(*2*) The maximum pressure of the range for which the disk is designed to rupture does not exceed the maximum allowable working pressure of the vessel;

(*3*) The opening provided through the rupture disk, after breakage, is sufficient to permit a flow equal to the capacity of the attached valve and there is no chance of interference with the proper functioning of the valve; but in no case shall this area be less than the inlet area of the valve; and

(4) The space between a rupture disk and the valve should be provided with a pressure gage, try cock, free vent, or a suitable telltale indicator. This arrangement permits the detection of disk rupture or leakage.[1]

(e) A rupture disk may be installed on the outlet side[2] of a spring loaded safety or relief valve which is opened by a direct action of the pressure in the vessel provided:

(1) The valve is so constructed that it will not fail to open at its proper pressure setting regardless of any back pressure that can accumulate between the valve disk and the rupture disk;[3]

(2) The valve is ample in capacity to meet the requirements of UG-132(a) and (b);

(3) The disk is designed to rupture at not more than the maximum allowable working pressure of the vessel;

(4) The opening provided through the rupture disk, after breakage, is sufficient to permit a flow equal to the rated capacity of the attached safety or relief valve; but in no case shall this area be less than the inlet area of the safety or relief valve;

(5) Any piping beyond the rupture disk cannot be obstructed by the rupture disk or fragments;

(6) All valve parts and joints subject to stress due to the pressure from the vessel and all fittings up to the rupture disk are designed for not less than the maximum allowable working pressure of the vessel;

(7) Any small leakage or a larger flow through a break in the operating mechanism that may result in back pressure accumulation within enclosed spaces of the valve housing other than between the rupture disk and the discharge side of the safety or relief valve, so as to hinder the safety or relief valve from opening at its set pressure, will be relieved adequately and safely to atmosphere through telltale vent openings;

(8) The contents of the vessel are clean fluids, free from gumming or clogging matter, so that accumulation in the space between the valve inlet and the rupture disk (or in any other outlet that may be provided) will not clog the outlet; and

(9) The services are such that atmospheric temperatures are not exceeded.

NOTE: When a rupture disk is installed on the outlet of a safety or relief valve fitted with a lifting device, a valved vent shall be located between the valve disk and the rupture disk to permit the checking of the operative conditions of the valve. The distance between the valve and the rupture disk shall be a practical minimum.

Users are warned that replacing a ruptured disk on the outlet of a safety or relief valve may be attended by some danger if done without first reducing the pressure in the vessel, particularly when noxious or otherwise hazardous contents might be discharged.

UG-128 Liquid Relief Valves

Any liquid relief valve used shall be at least 1/2 in.-iron pipe size.

UG-129 Marking

(a) *Safety and Relief Valves.* Each safety and relief valve 1/2-in. pipe size and larger shall be plainly marked by the manufacturer with the required data in such a way that the marking will not be obliterated in service. Smaller valves may be exempted from these marking requirements. The marking may be placed on the valve or on a plate or plates securely



FIG. UG-129 OFFICIAL SYMBOL FOR STAMP TO DENOTE THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS' STANDARD

fastened to the valve. The Code symbol shall be stamped on the valve or nameplate, but the other required data may be stamped, etched, impressed, or cast on the valve or nameplate. The marking shall include the following:

(1) The name or identifying trademark of the manufacture,

(2) Manufacturer's design or type number,

(3) Size_____in.,

(The pipe size of the valve inlet)

(4) Set Pressure_____psi,

(5) Capacity_____lb of saturated steam per hour, or_____cu ft of air (60 F and 14.7 psia) per min.

NOTE: In addition, the manufacturer may indicate the capacity in other fluids (see Appendix J).

(6) ASME symbol as shown in Fig. UG-129.

(b) Safety and relief valves certified for a steam discharging capacity under the provisions of Section I of the Code and bearing the official Code symbol stamp of that Section of the Code for safety valves, may be used on pressure vessels. The rated capacity in terms of other fluids shall be determined by the method of conversion given in Appendix J. (See UG-131(h).)

(c) *Liquid Relief Valves.* Each liquid relief valve shall be marked with the following data:

(1) Name or identifying trademark of the manufacturer,

(2) Manufacturer's design or type number,

(3) Size_____in.,

(Pipe size of inlet)

(4) Set Pressure_____psi,

(5) Relieving capacity_____gal of water per min at 70 F.

(d) *Rupture Disks.* Every rupture disk shall be plainly marked by the manufacturer in such a way that the marking will not be obliterated in service. The marking may be placed on the flange of the disk or on a metal tab permanently attached thereto.[1] The marking shall include the following:

(1) The name or identifying trademark of the manufacturer,

(2) Manufacturer's design or type number and lot number,

(3) Size_____in.,

(4) Maximum bursting pressure_____psi,

(5) Minimum bursting pressure_____psi,

(6) Coincident disk temperature_____F,

(7) Capacity_____lb of saturated steam per hour, or_____cu ft of air (60 F and 14.7 psia) per min.

NOTE: In addition, the manufacturer may indicate the capacity in other fluids (see Appendix J).

UG-130 Use of Code Symbol Stamp

Each safety and relief valve to which the Code symbol is to be applied shall be fabricated by a manufacturer who is in possession of a Code symbol stamp (see Fig. UG-129) and a valid certificate of authorization obtainable under the following conditions:

(1) Permission to use the symbol referred to in UG-129(a)(6) will be granted by the Society pursuant to the provisions of this paragraph.

(2) Any manufacturer may apply to the Boiler and Pressure Vessel Committee of the Society upon forms issued by the Society for permission to use the stamp. Each applicant must agree that if permission to use the stamp is granted, it will be used according to the rules and regulations of this Division of Section VIII of the Code that any safety or relief valve to which the symbol is applied will have the certified capacity stamped upon the valve after tests as required in UG-131, and that any stamp will be promptly returned to the Society upon demand, or in case the applicant discontinues the manufacture of safety and relief valves to which the Code symbol is applied, or in case the certificate of authorization issued to such applicant has expired and no new certificate has been issued. The holder of any such stamp shall not permit any other manufacturer to use his stamp.

(3) Permission to use the stamp may be granted or withheld by the Society in its absolute discretion. If permission is given, and the proper administrative fee paid, a certificate of authorization evidencing permission to use such symbol, expiring on the triennial anniversary date thereafter, will be forwarded to the applicant. Each such certificate will be signed by the Chairman and Secretary, or other duly authorized officer or officers, of the Boiler and Pressure Vessel Committee. Six (6) months prior to the date of expiration of any such certificate, the applicant must apply for a renewal of such permission and the issuance of a new certificate.

(4) The Society reserves the absolute right to cancel or refuse to renew such permission, returning fees paid for the prorated unexpired term.

(5) The Boiler and Pressure Vessel Committee may at any time and from time to time make such regulations concerning the issuance and use of such stamps as it deems appropriate, and all such regulations shall become binding upon the holders of any valid certificates of authorization.

(6) All steel stamps for applying the symbol shall be obtained from the Society.

UG-131 Certification of Capacity of Safety and Relief Valves

(a) Before the symbol is applied to any safety or relief valve, the valve manufacturer shall have the capacity of his valves certified as prescribed in (d) or (e).

(b) Capacity certification tests shall be conducted on saturated steam, or air, or natural gas. When saturated steam is used, corrections for moisture content of the steam shall be made.

(c)(1) Capacity certification tests shall be conducted at a pressure not to exceed 110 percent of the pressure for which the safety or relief valve is

[1]Users are warned that a rupture disk will not burst at its design pressure if back pressure builds up in the space between the disk and the safety or relief valve which will occur should leakage develop in the rupture disk due to corrosion or other cause.

[2]This use of a rupture disk in series with the safety or relief valve is permitted to minimize the loss by leakage through the valve of valuable, or of noxious or otherwise hazardous, materials, and where a rupture disk alone or disk located on the inlet side of the safety valve is impracticable.

[3]Users are warned that an ordinary spring loaded safety or relief valve will not open at its set pressure if back pressure builds up in the space between the valve and rupture disk. A specially designed safety or relief valve is required, such as a diaphragm valve or a valve equipped with a bellows above the disk.

[1]The marking may be coded and identified with the marking given on the certificate supplied with each rupture disk.

set to operate. The reseating pressure shall be noted and recorded.

(2) Capacity certification of pilot operated safety and relief valves may be based on tests without the pilot valves installed, provided prior to capacity tests it has been demonstrated by test to the satisfaction of the official observer that the pilot valve will cause the main valve to fully open within 110 percent of the set pressure of the main valve and that the pilot valve in combination with the main valve will meet all the requirements of this Division.

(*d*)(1) A capacity certification test is required on a set of three valves for each combination of size, design, and pressure setting. The stamped capacity rating for each combination of design, size and test pressure shall be 90 percent of the average capacity of the three valves tested.

NOTE: The capacity of a set of three valves shall fall within a range of plus or minus 5 percent of the average capacity. Failure to meet this requirement shall be cause to refuse certification of that particular safety valve design.

(2) If a manufacturer wishes to apply the Code symbol to a design of safety or relief valves, four valves of each combination of pipe size and orifice size shall be tested. These four valves shall be set at pressures which will cover the approximate range of pressures for which the valves will be used. The capacities, as determined by these four tests, shall be plotted against the absolute flow test pressure and a curve drawn through these four points. If the four points do not establish a reasonable curve, the authorized observer shall require that additional valves be tested. From this curve, relieving capacities shall be obtained. The stamped capacity shall be 90 percent of the capacity taken from the curve.

(*e*) Instead of individual capacity certification as provided in (d), a coefficient of discharge K may be established for a specific safety valve design according to the following procedure:

(1) For each design the safety valve manufacturer shall submit for test at least three valves for each of three different sizes (a total of nine valves) together with detailed drawings showing the valve construction. Each valve of a given size shall be set at a different pressure.

(2) Tests shall be made on each safety or relief valve to determine its capacity-lift, popping and blow-down pressures, and actual capacity in terms of the fluid used in the test. Valves having an adjustable blowdown construction shall be adjusted prior to testing so that the blowdown does not exceed 5 percent of the set pressure. A coefficient K_D shall be established for each test run as follows:

$$K_D = \frac{\text{Actual flow}}{\text{Theoretical flow}} = \text{coefficient of discharge}$$

where actual flow is determined quantitatively by test, and theoretical flow is calculated by the appropriate formula which follows:

For test with dry saturated steam

$$W_T = 51.5\,AP$$

For test with air

$$W_T = 356\,\text{AP}\sqrt{\frac{M}{T}}$$

For test with natural gas

$$W_T = CAP\sqrt{\frac{M}{ZT}}$$

where

W_T = theoretical flow, pounds per hour
A = actual discharge area through the valve at developed lift, square inches
P = (set pressure × 1.10) plus atmospheric pressure, pounds per square inch absolute
M = molecular weight
T = absolute temperature at inlet (degrees Fahrenheit plus 460)
C = constant for gas or vapor based on the ratio of specific heats
$= \frac{C_p}{C_v}$ (see Fig. UA-230)
Z = compressibility factor corresponding to P and T

The average of the coefficients K_D of the nine tests required shall be multiplied by 0.90, and this product shall be taken as the coefficient K of that design.

NOTE: All experimentally determined coefficients, K_D, shall fall within a range of plus or minus 5 percent of the average K_D found. Failure to meet this requirement shall be cause to refuse certification of that particular valve design.

(3) The official relieving capacity of all sizes and pressures of a given design, for which K has been established under the provisions of (2), that are manufactured subsequently shall then be calculated by the appropriate formula in (2) multiplied by the coefficient K (see Appendix J).

(*f*) Tests shall be conducted at a place where approved equipment and personnel are available to conduct pressure relieving capacity tests. Tests shall be made in the presence of and certified by an authorized observer. The place, personnel, equipment, and the authorized observer shall be subject to approval by the Boiler and Pressure Vessel Committee. Laboratory approval is subject to review within each five year period.

(*g*) A data sheet for each safety valve tested shall be filled out and signed by the manufacturer and by the authorized observer witnessing the tests. Such data sheet will be the manufacturer's authority to stamp valves of corresponding design, size, and pressure range. When changes are made in the design, the certification test must be repeated.

(*h*) It shall be permissible to rate safety valves under PG-69.1.2 of Section I with capacity ratings at a flow pressure of 103 percent of the set pressure, for use on pressure vessels, without further test. In such instances, the capacity rating of the valve may be increased to allow for the flow pressure permitted in (c), namely, 110 percent of the set pressure, by the multiplier.

$$\frac{1.10\,p + 14.7}{1.03\,p + 14.7}$$

where p = set pressure, pounds per square inch, gage. Such valves shall be marked in accordance with UG-129. This multiplier shall not be used as a divisor to transform test ratings from a higher to a lower flow.

UG-132 Determination of Pressure Relieving Requirements

(*a*) Except as permitted in (b), the aggregate capacity of the pressure relieving devices connected to any vessel or system of vessels for the release of a liquid, air, steam or other vapor shall be sufficient to carry off the maximum quantity that can be generated or supplied to the attached equipment without permitting a rise in pressure within the vessel of more than 10 percent above the maximum allowable working pressure when the pressure relieving devices are blowing.

(*b*) Protective devices as permitted in UG-125(d), as protection against excessive pressure caused by exposure to fire or other sources of external heat, shall have a relieving capacity sufficient to prevent the pressure from rising more than 20 percent above the maximum allowable working pressure of the vessel when all pressure relieving devices are blowing.

(*c*) Vessels connected together by a system of adequate piping not containing valves which can isolate any vessel may be considered as one unit in figuring the required relieving capacity of pressure relieving safety devices to be furnished.

(*d*) Heat exchangers and similar vessels shall be protected with a relieving device of sufficient capacity to avoid overpressure in case of an internal failure.

(*e*) The official rated capacity of a pressure relieving safety device shall be that which is stamped on the device and guaranteed by the manufacturer.

(*f*) The rated pressure relieving capacity of a safety valve for other than steam or air may be determined by the method of conversion given in Appendix J.

UG-133 Pressure Setting of Safety Devices

(*a*) When safety or relief valves are provided, they shall be set to blow at a pressure not exceeding the maximum allowable working pressure of the vessel at the operating temperature, except as permitted in (b). If the capacity is supplied in more than one safety or relief valve, only one valve need be set to open at a pressure not exceeding the maximum allowable working pressure of the vessel; the additional valves may be set to open at a higher pressure, but not to exceed 105 percent of the maximum allowable working pressure of the vessel (see UG-125(c)).

(*b*) Protective devices permitted in UG-125(d) as protection against excessive pressure caused by exposure to fire or other sources of external heat shall be set to operate at a pressure not in excess of 110 percent of the maximum allowable working pressure of the vessel. If such a device is used to meet the requirements of both UG-125(c) and UG-125(d), it shall be set to operate at not over the maximum allowable working pressure.

(*c*) If the operating conditions of a valve are changed so as to require another spring rated for a different pressure, the relief setting shall be adjusted by the manufacturer or by an individual certified by the manufacturer of that safety valve; the valve shall be remarked by either of them in conformance with UG-129.

(*d*) Rupture disks when installed in place of, or in series with, a spring loaded safety valve, shall be rated to rupture at a pressure not to exceed the maximum allowable working pressure of the vessel at the operating temperature.

NOTE: It is recommended that the design pressure of the vessel be sufficiently above the intended operating pressure to provide sufficient margin between operating pressure and rupture disk bursting pressure to prevent premature failure of the rupture disk due to fatigue or creep.

(*e*) The pressure at which any device is set to operate shall include the effects of static head and constant back pressure.

(*f*) The set pressure tolerances, plus or minus, of safety or relief valves, shall not exceed 2 psi for pressures up to and including 70 psi; and 3 percent for pressures above 70 psi.

UG-134 Installation

(*a*) Safety and relief valves and rupture disks shall be connected to the vessel in the vapor space above any contained liquid, or to piping connected to the vapor space in the vessel which is to be protected.

(*b*) The opening through all pipe and fittings between a pressure vessel and its pressure relieving device shall have at least the area of the pressure relieving device inlet, and in all cases shall have sufficient area so as not to unduly restrict the flow to the pressure relieving device. The opening in the vessel wall shall be designed to provide direct and unobstructed flow between the vessel and its pressure relieving device.

(*c*) When two or more required pressure relieving devices are placed on one connection, the inlet internal cross-sectional area of this connection shall be at least equal to the combined inlet areas of the safety devices connected to it, and in all cases shall be sufficient so as not to restrict the combined flow of the attached devices.

(*d*) Liquid relief valves shall be connected below the normal liquid level.

(*e*) There shall be no intervening stop valves between the vessel and its protective device or devices, or between the protective device or devices and the point of discharge, except:

(*1*) When these stop valves are so constructed or positively controlled that the closing of the maximum number of block valves possible at one time will not reduce the pressure relieving capacity provided by the unaffected relieving devices below the required relieving capacity; or

(*2*) Under the conditions set forth in Appendix M.

(*f*) The safety devices on all vessels shall be so installed that their proper functioning will not be hindered by the nature of the vessel's contents.

(*g*) Discharge lines from pressure relieving safety devices shall be designed to facilitate drainage or shall be fitted with an open drain to prevent liquid from lodging in the discharge side of the safety device, and such lines shall lead to a safe place of discharge. The size of the discharge lines shall be such that any pressure that may exist or develop will not reduce the relieving capacity of the relieving devices below that required to properly protect the vessel. (See UG-126(e) and Appendix M.)

SUBSECTION B

REQUIREMENTS PERTAINING TO METHODS OF FABRICATION OF PRESSURE VESSELS

PART UW

REQUIREMENTS FOR PRESSURE VESSELS FABRICATED BY WELDING

GENERAL

UW-1 Scope

The rules in Part UW are applicable to pressure vessels and vessel parts that are fabricated by welding and shall be used in conjunction with the general requirements in Subsection A, and with the specific requirements in Subsection C that pertain to the class of material used.

UW-2 Service Restrictions

(*a*) When vessels are to contain lethal[1] substances, either liquid or gaseous, all butt welded joints shall be fully radiographed, and when fabricated of carbon or low-alloy steel, such vessels shall be postweld heat treated. The joints of various categories (see UW-3) shall be as follows:

(*1*) All joints of Category A shall be Type No. (1) of Table UW-12.

(*2*) All joints of Categories B and C shall be Type No. (1) or No. (2) of Table UW-12.

[1]By "lethal substances" are meant poisonous gases or liquids of such a nature that a very small amount of the gas or of the vapor of the liquid mixed or unmixed with air is dangerous to life when inhaled. For purposes of this Division, this class includes substances of this nature which are stored under pressure or may generate a pressure if stored in a closed vessel. Some such substances are hydrocyanic acid, carbonyl chloride, cyanogen, mustard gas, and xylyl bromide. For design purposes under this Division, chlorine, ammonia, natural or manufactured gas, any liquefied petroleum gas (such as propane, butane, butadiene), and vapors of any other petroleum products are not classified as lethal substances.

(*3*) All joints of Category D shall be full penetration welds extending through the entire thickness of the vessel wall or nozzle wall.

(*b*) When vessels are to operate below —20 F and impact tests in accordance with UG-84 are required for the material or weld metal, the joints of various categories (see UW-3) shall be as follows:

(*1*) All joints of Category A shall be Type No. (1) of Table UW-12.

(*2*) All joints of Category B shall be Type No. (1) or No. (2) of Table UW-12.

(*3*) All joints of Category C shall be full penetration welds extending through the entire section at the joint.

(*4*) All joints of Category D shall be full penetration welds extending through the entire thickness of the vessel wall or nozzle wall.

(*c*) Unfired steam boilers with design pressures exceeding 50 lb per sq in shall have all joints of Category A (see UW-3) in accordance with Type No. (1) of Table UW-12 and all joints in Category B in accordance with Type No. (1) or No. (2) of Table UW-12. All butt welded joints shall be fully radiographed. When fabricated of carbon or low-alloy steel such vessels shall be postweld heat treated. (See also Pars. U-1(e)(2), UCS-16(b), and UCS-25).

(*d*) Pressure vessels subject to direct firing may be constructed in accordance with all applicable rules of this Division and shall meet the following requirements.

(*1*) All welded joints in Category A (see UW-3) shall be in accordance with Type (1) of Table UW-

12, and all welded joints in Category B, when the thickness exceeds $^5/_8$ in., shall be in accordance with Type (1) or Type (2) of Table UW-12. No welded joints of Type (3) of Table UW-12 are permitted for either Category A or B joints in any thickness.

(2) When the thickness at welded joints exceeds $^5/_8$ in. for carbon (P-1) steels and for all thicknesses for low-alloy steels (other than P-1 steels) postweld heat treatment is required. For all other material and in any thickness, the requirements for postweld heat treatment shall be in conformance with the applicable subsections of this Division. See also U-1(e)(2), UCS-16(b), UCS-25 and UCS-56.

(3) The user, his agent, or the manufacturer of the vessel shall make available to the Inspector the calculations used to determine the design temperature of the vessel. The provisions of UG-20 shall apply except that pressure parts in vessel areas having joints other than types (1) and (2) of Table UW-12, subject to direct radiation and/or the products of combustion shall be designed for temperatures not less than the maximum surface metal temperatures expected under operating conditions.

UW-3 Welded Joint Category

(a) The term "Category" as used herein defines the location of a joint in a vessel, but not the type of joint. The "Categories" established by this paragraph are for use elsewhere in this Division in specifying special requirements regarding joint type and degree of inspection for certain welded pressure joints. Since these special requirements, which are based on service, material, and thickness, do not apply to every welded joint, only those joints to which special requirements apply are included in the categories. The special requirements will apply to joints of a given category only when specifically so stated. The joints included in each category are designated as joints of Categories A, B, C, and D below. Fig. UW-3 illustrates typical joint locations included in each category.

(1) *Category A.* Longitudinal welded joints within the main shell, communicating chambers,[1] transitions in diameter, or nozzles; any welded joint within a sphere, within a formed or flat head, or within the side plates[2] of a flat-sided vessel; circumferential welded joints connecting hemispherical heads to main shells, to transitions in diameters, to nozzles, or to communicating chambers.[1]

(2) *Category B.* Circumferential welded joints within the main shell, communicating chambers,[1] nozzles, or transitions in diameter including joints between the transition and a cylinder at either the large or small end; circumferential welded joints connecting formed heads other than hemispherical to main shells, to transitions in diameter, to nozzles, or to communicating chambers.[1]

(3) *Category C.* Welded joints connecting flanges, Van Stone laps, tube sheets, or flat heads to main shell, to formed heads, to transitions in diameter, to nozzles, or to communicating chambers;[1] any welded joint connecting one side plate[2] to another side plate of a flat-sided vessel.

(4) *Category D.* Welded joints connecting communicating chambers[1] or nozzles to main shells, to spheres, to transitions in diameter, to heads, or to flat-sided vessels, and those joints connecting nozzles to communicating chambers[1] (for nozzles at the small end of a transition in diameter, see Category B).

(b) When butt welded joints are required elsewhere in this Division for Category B, an angle joint connecting a transition in diameter to a cylinder shall be considered as meeting this requirement provided the angle α (see Fig. UW-3) does not exceed 30 deg. All requirements pertaining to the butt welded joint shall apply to the angle joint.

MATERIALS

UW-5 General

(a) Materials used in the construction of welded pressure vessels shall comply with the requirements for materials given in UG-5 through UG-14, and shall be proven of good weldable quality. Satisfactory qualification of the welding procedure under Section IX of the Code is considered as proof.

(b) Two materials of different specifications may be joined by welding provided the requirements of Section IX, Par. Q-11 of the Code are met.

DESIGN

UW-8 General

The rules in the following paragraphs apply specifically to the design of pressure vessels and vessel parts that are fabricated by welding and shall be used in conjunction with the general requirements for *Design* in Subsection A, and with the specific

[1]Communicating chambers are defined as appurtenances to the vessel which intersect the shell or heads of a vessel and form an integral part of the pressure containing enclosure, e.g., sumps.

[2]Side plates of a flat-sized vessel are defined as any of the flat plates forming an integral part of the pressure containing enclosure.

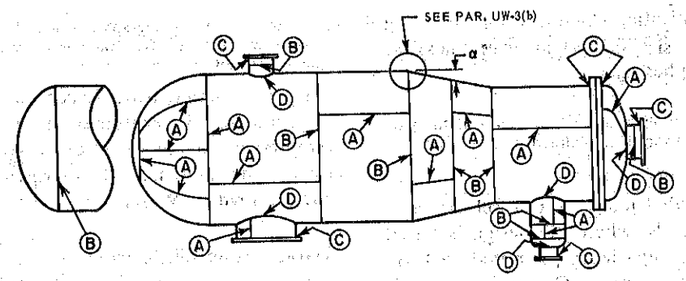


FIG. UW-3 ILLUSTRATION OF WELDED JOINT LOCATIONS TYPICAL OF CATEGORIES A, B, C, and D

requirements for *Design* in Subsection C that pertain to the class of material used.

UW-9 Design of Welded Joints

(a) *Permissible Types.* The types of welded joints permitted in arc and gas welding processes are listed in Table UW-12, together with the limiting plate thickness permitted for each type. Butt type joints only are permitted with pressure welding processes (see UW-27 (2)).

(b) *Welding Grooves.* The dimensions and shape of the edges to be joined shall be such as to permit complete fusion and complete joint penetration. Qualification of the welding procedure, as required in UW-28, is acceptable as proof that the welding groove is satisfactory.

(c) *Tapered Transitions.* A tapered transition having a length not less than *three* times the offset between the adjacent surfaces of abutting sections, as shown in Fig. UW-9, shall be provided at joints between sections that differ in thickness by more than one-fourth of the thickness of the thinner section or by more than $^1/_8$ in. whichever is less. The transition may be formed by any process that will provide a uniform taper. The weld may be partly or entirely in the tapered section or adjacent to it. This paragraph also applies when there is a reduction in thickness within a spherical shell or cylindrical shell course and to a taper at a Category A joint within a formed head. Provisions for tapers at circumferential, butt welded joints connecting formed heads to main shells are contained in UW-13.

(d) Except when radiographed 4 in. each side of each welded intersection, vessels made up of two or more courses shall have the centers of the welded longitudinal joints of adjacent courses staggered or separated by a distance of at least five times the thickness of the thicker plate.

(e) *Lap Joints.* For lapped joints, the surface overlap shall be not less than four times the thickness of the inner plate except as otherwise provided for heads in UW-13.

(f) *Welded Joints Subject to Bending Stresses.* Except where specific details are permitted in other paragraphs, fillet welds shall be added where necessary to reduce stress concentration. Corner joints, with fillet welds only, shall not be used unless the plates forming the corner are properly supported independently of such welds. (See UW-18.)

UW-10 Postweld Heat Treatment

Pressure vessels and pressure vessel parts shall be postweld heat treated as prescribed in UW-40 when postweld heat treatment is required in the applicable part of Subsection C.

UW-11 Radiographic Examination

(a) *Full Radiography.* The following butt welded joints made in accordance with Types No. (1) and No. (2) of Table UW-12 shall be examined radiographically for their full length in the manner prescribed in UW-51.

NOTE: The requirements specifying which joints must be butt welded will be found in the paragraphs referenced below.

(1) Joints in vessels used to contain lethal substances (see UW-2(a)).

(2) Joints in plates or vessel walls in which the thinner of the plate or vessel wall thickness at the welded joint exceeds $1^1/_2$ in., or exceeds the lesser thicknesses prescribed in (UCS-57, UHA-33, UCL-35, or UCL-36 for the materials covered therein.

(3) Joints in unfired steam boilers, the design pressure of which exceeds 50 psi (see UW-2(c)).

(4) Joints in nozzles, communicating chambers, etc., in a vessel or vessel section that is required to be radiographed under (1), (2), (3), or (5) hereof, except that circumferential welded butt joints in

nozzles and communicating chambers not exceeding 10-in. nominal pipe size or 1⅛-in. wall thickness need not be radiographed.

NOTE: This provision applies to the fabrication of the part itself, and not to the method of attachment to the vessel.

(5) All butt welded joints in a vessel or vessel section, including heads, where the design is based on the use of the joint efficiency permitted by UW-12(a), in which case all joints of Categories A and B (see UW-3) shall be of Type No. (1) or Type No. (2). The circumferential butt weld joining such a vessel section or head to adjacent shell sections, heads, or other vessel parts shall be fully radiographed. The latter requirements apply also in the case of seamless sections, including heads other than torispherical, when the thickness of either section is less than that required when using $E = 0.85$. When the head is torispherical this requirement applies only when the thickness of the shell is less than that required when using $E = 0.85$.

(*b*) *Spot Radiography.* Butt welded joints made in accordance with Type No. (1) or No. (2) of Table UW-12 which are not required to be fully radiographed by (a) shall be examined by spot radiographing in accordance with UW-52, except as described in (c).

NOTE: This requirement specifies spot radiography for butt welds of Type No. (1) or No. (2) that are used in a vessel, but does not preclude the use of fillet and/or corner welds permitted by other paragraphs, such as for nozzle and manhole attachments, welded stays, flat heads, etc., which need not be spot radiographed.

(*c*) *No Radiography.* Except as required in (a), no radiographic examination of welded joints is required when the vessel or vessel part is designed for external pressure only, or when the vessel design complies with UW-12(c).

UW-12 Joint Efficiencies

Table UW-12 gives the joint efficiencies, E, to be used in the formula of this Division for joints completed by an arc or gas welding process. The joint efficiencies depend on the type of joint and on the degree of examination of the joints.

(*a*) The value of E not greater than that given in column (a) of Table UW-12 shall be used in the design calculations for fully radiographed butt welds (see UW-11(a)).

(*b*) The value of E not greater than that given in column (b) of Table UW-12 shall be used in the design calculations for butt welded joints in vessels or parts of vessels that are spot-radiographically examined in accordance with the requirements of UW-11(b) and UW-52.

(*c*) The value of E not greater than that given in column (c) of Table UW-12 shall be used in the design calculations for welded joints in vessels that are neither fully radiographed nor spot-radiographically examined, provided that in all other design calculations a stress value equal to 80 percent

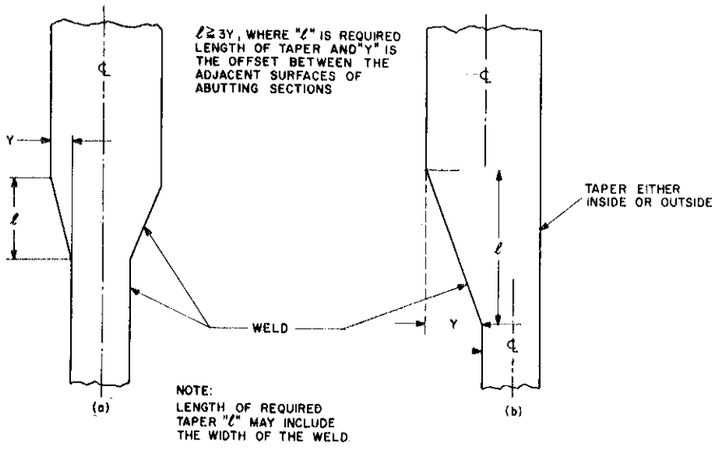


FIG. UW-9 BUTT WELDING OF PLATES OF UNEQUAL THICKNESSES

TABLE UW-12
MAXIMUM ALLOWABLE JOINT EFFICIENCIES FOR ARC AND GAS WELDED JOINTS

No.	Type of Joint Description	Limitations	Degree of Examination (a) Fully Radiographed[1]	(b) Spot Examined[2]	(c) Not Spot Examined[3]
(1)	Butt joints as attained by double-welding or by other means which will obtain the same quality of deposited weld metal on the inside and outside weld surfaces to agree with the requirements of UW-35. Welds using metal backing strips which remain in place are excluded.	None	1.00	0.85	0.70
(2)	Single-welded butt joint with backing strip other than those included under (1)	(a) None except as in (b) below (b) Butt weld with one plate offset—for circumferential joints only, see UW-13(c) and Fig. UW-13.1(k)	0.90	0.80	0.65
(3)	Single-welded butt joint without use of backing strip.	Circumferential joints only, not over $\frac{5}{8}$ in. thick and not over 24 in. outside diameter	...	...	0.60
(4)	Double full fillet lap joint	Longitudinal joints not over $\frac{3}{8}$ in. thick. Circumferential joints not over $\frac{5}{8}$ in. thick	...	...	0.55
(5)	Single full fillet lap joints with plug welds conforming to UW-17	(a) Circumferential joints[4] for attachment of heads not over 24 in. outside diameter to shells not over $\frac{1}{2}$ in. thick (b) Circumferential joints for the attachment to shells of jackets not over $\frac{5}{8}$ in. in nominal thickness where the distance from the center of the plug weld to the edge of the plate is not less than $1\frac{1}{2}$ times the diameter of the hole for the plug.	...	...	0.50
(6)	Single full fillet lap joints without plug welds	(a) For the attachment of heads convex to pressure to shells not over $\frac{5}{8}$ in. required thickness, only with use of fillet weld on inside of shell; or (b) for attachment of heads having pressure on either side, to shells not over 24 in. inside diameter and not over $\frac{1}{4}$ in. required thickness with fillet weld on outside of head flange only.	...	...	0.45

[1] See UW-12(a) and UW-51.
[2] See UW-12(b) and UW-52.
[3] The maximum allowable joint efficiencies shown in this column are the weld joint efficiencies multiplied by 0.80 (and rounded off to the nearest 0.05), to effect the basic reduction in allowable stress required by this Division for welded vessels that are not spot examined. See UW-12(c).
[4] Joints attaching hemispherical heads to shells are excluded.

of the allowable stress value prescribed for the material in Subsection C is used except for stresses S_a, S_b, S_f and S_n used in flange design and defined in UA-47(b) or for calculating the thickness of braced and stayed surfaces by formulas (1) and (2) of UG-47(a).

(*d*) A value of E not greater than 0.80 may be used in the formulas of this Division for joints completed by forge welding or by any of the pressure welding processes given in UW-27(2), provided the welding process used is permitted by the rules in the applicable parts of Subsection C for the material being welded. The quality of such welds used in vessels or parts of vessels shall be proved as follows: Test specimens shall be representative of the production welding on each vessel. They may be removed from the shell itself or from a prolongation of the shell including the longitudinal joint, or, in the case of vessels not containing a longitudinal joint, from a test plate of the same material and thickness as the vessel and welded in accordance with the same procedure. One reduced-section tension test and two side-bend tests shall be made in accordance with, and shall meet the requirements of Q-6 and Q-8, or QN-6 and QN-8, Section IX.

UW-13 Attachment Details

(*a*)(*1*) Ellipsoidal, torispherical and other types of formed heads, concave or convex to the pressure, shall have a skirt length not less than that shown in Fig. UW-13.1. Heads that are fitted inside or over a shell shall have a driving fit before welding.

(*2*) A tapered transition having a length not less than 3 times the offset between the adjacent surfaces of abutting sections as shown in Figures UW-13.1(l) and UW-13.1(m) shall be provided at joints between formed heads and shells that differ in thickness by more than one-fourth the thickness of the thinner section or by more than $^1/_8$ in., whichever is less. When a taper is required on any formed head thicker than the shell and intended for butt welded attachment (Figures UW-13.1(n) and UW-13.1(o), the skirt shall be long enough so that the required length of taper does not extend beyond the tangent line.

(*b*) Intermediate heads, without limit to thickness, of the type shown in Fig. UW-13.1(f), may be used for all types of vessels provided that the outside diameter of the head skirt is a close fit inside the overlapping ends of the adjacent length of cylinder. This construction may also be used for end heads when the thickness of the shell section of the vessel does not exceed $^5/_8$ in.

(*c*) Heads concave to pressure may be attached to shells using a butt weld with one plate offset as shown in Fig. UW-13.1(k). The offset shall be smooth and symmetrical and shall not be machined or otherwise reduced in thickness. There shall be a uniform force fit with the mating section at the root of the weld.

(*d*) The requirements for the attachment of welded unstayed flat heads to shells are given in UG-34 and in (e) and (f) hereunder.

(*e*) When shells, heads, or other pressure parts are welded to a forged or rolled plate to form a corner joint, as in Fig. UW-13.2, the joint shall meet the following requirements (see also UG-93(b)(3)):

(*1*) On the cross section through the welded joint, the line of fusion between the weld metal and the forged or rolled plate being attached shall be projected on planes both parallel to and perpendicular to the surface of the plate being attached, in order to determine the dimensions a and b respectively (see Fig. UW-13.2).

(*2*) For flange rings of bolted flanged connections, and for flat heads and unsupported tube sheets with a projection having holes for a bolted connection, the sum of a and b shall be not less than 3 times the nominal wall thickness of the abutting pressure part.

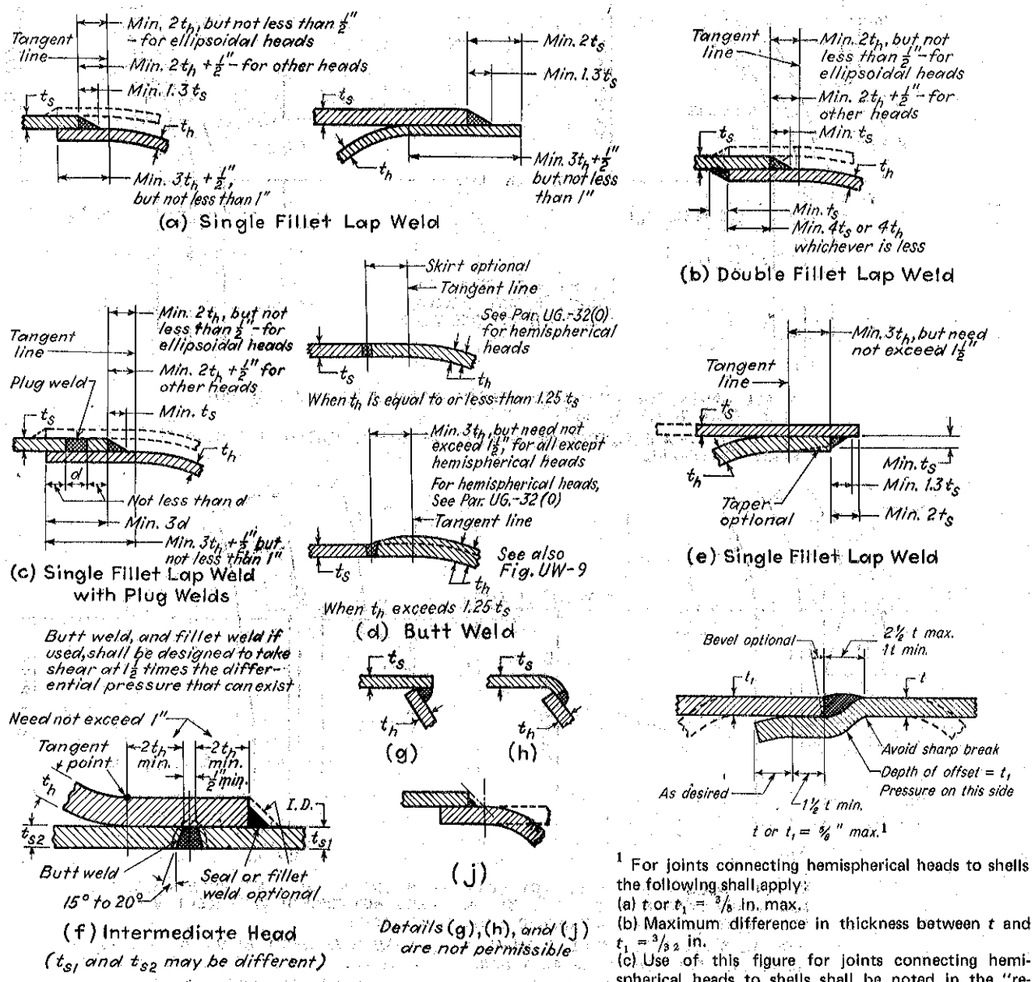
(*3*) For supported tube sheets with a projection having holes for a bolted connection, the sum of a and b shall not be less than 2 times the nominal wall thickness of the abutting pressure part. A supported tube sheet is defined as one in which not less than 80 percent of the pressure load on the tube sheet is carried by tubes, stays or braces.

(*4*) For other components, the sum a and b shall be not less than 2 times the nominal wall thickness of the abutting pressure part. Examples of such components are flat heads and supported and unsupported tube sheets without a projection having holes for a bolted connection, and the side plates of a rectangular vessel.

(*5*) Other dimensions at the joint shall be in accordance with details as shown in Fig. UW-13.2.

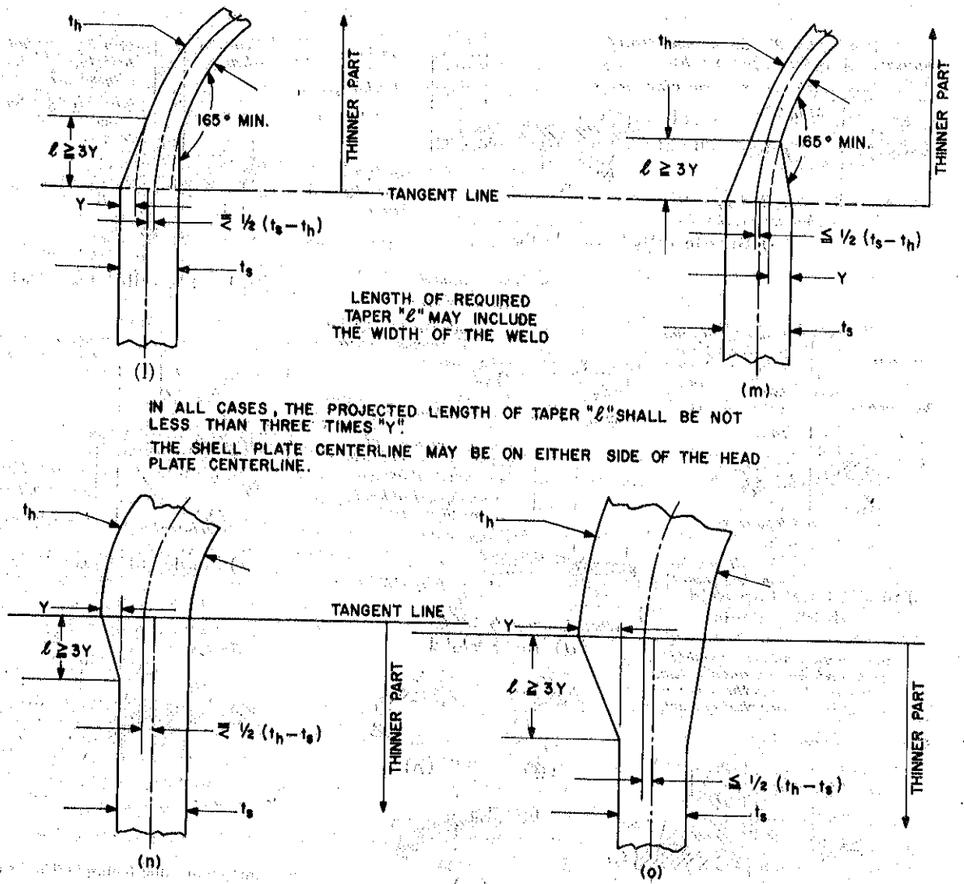
(*6*) Joint details that have a dimension through the joint less than the thickness of the shell, head or other pressure part, or that provide attachment eccentric thereto, are not permissible (see Fig. UW-13.2(o), (p) and (q)).

(*f*) Hubs for butt welding to the adjacent shell, head, or other pressure part, as in Fig. UW-13.3, shall not be machined from rolled plate. The component having the hub shall be forged in such a manner as to provide in the hub the full minimum



[1] For joints connecting hemispherical heads to shells the following shall apply:
(a) t or $t_1 = \frac{3}{8}$ in. max.
(b) Maximum difference in thickness between t and $t_1 = \frac{3}{32}$ in.
(c) Use of this figure for joints connecting hemispherical heads to shells shall be noted in the "remarks" Section of the data report form.

FIG. UW-13.1 HEADS ATTACHED TO SHELLS (see Table UW-12 for limitations)



IN ALL CASES, THE PROJECTED LENGTH OF TAPER "ℓ" SHALL BE NOT LESS THAN THREE TIMES "Y".

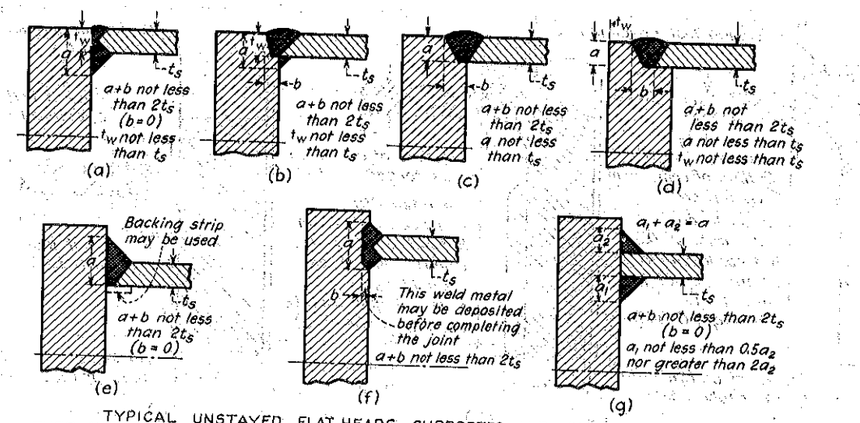
THE SHELL PLATE CENTERLINE MAY BE ON EITHER SIDE OF THE HEAD PLATE CENTERLINE.

IN ALL CASES "ℓ" SHALL BE NOT LESS THAN THREE TIMES "Y" WHEN t_h EXCEEDS 1.25 t_s, MIN LENGTH OF SKIRT IS $3t_h$ BUT NEED NOT EXCEED 1½" EXCEPT WHEN NECESSARY TO PROVIDE REQUIRED LENGTH OF TAPER.

WHEN t_h IS EQUAL TO OR LESS THAN 1.25 t_s, LENGTH OF SKIRT SHALL BE SUFFICIENT FOR ANY REQUIRED TAPER.

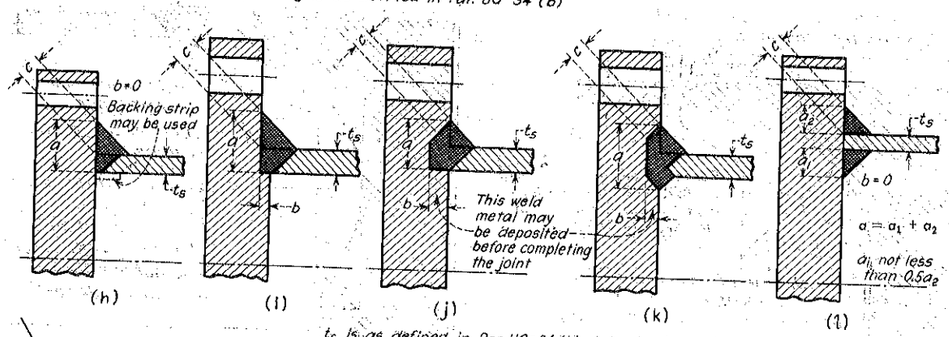
LENGTH OF REQUIRED TAPER "ℓ" MAY INCLUDE THE WIDTH OF THE WELD. THE SHELL PLATE CENTERLINE MAY BE ON EITHER SIDE OF THE HEAD PLATE CENTERLINE.

FIG. UW-13.1 (CONT'D) HEADS ATTACHED TO SHELLS (See Table UW-12 for limitations)



TYPICAL UNSTAYED FLAT HEADS, SUPPORTED AND UNSUPPORTED TUBE SHEETS WITHOUT A BOLTING FLANGE, AND SIDE PLATES OF RECTANGULAR VESSELS

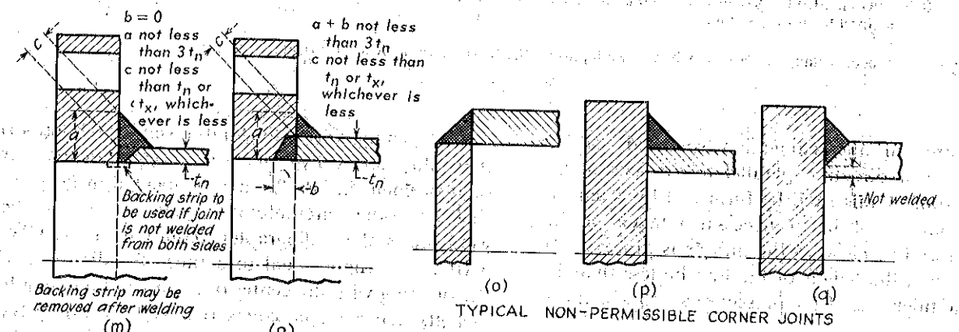
For unstayed flat heads, see also Par. UG-34
t_s is as defined in Par. UG-34 (b)



t_s is as defined in Par. UG-34 (b)

TYPICAL SUPPORTED AND UNSUPPORTED TUBE SHEETS WITH A BOLTING FLANGE

For supported tube sheets: a + b not less than $2t_s$; c not less than $0.7t_s$ or $1.4t_r$, whichever is less.
For unsupported tube sheets: a + b not less than $3t_s$; c not less than t_s or $2t_r$, whichever is less.
t_s and t_r are as defined in Par. UG-34(b)
See Par. UW-13(e)(3) for definition of supported tube sheet.



TYPICAL BOLTED FLANGE CONNECTIONS

c, t_n and t_x are as defined in Par. UA-47(b)

TYPICAL NON-PERMISSIBLE CORNER JOINTS

FIG. UW-13.2 ATTACHMENT OF PRESSURE PARTS TO PLATES TO FORM A CORNER JOINT

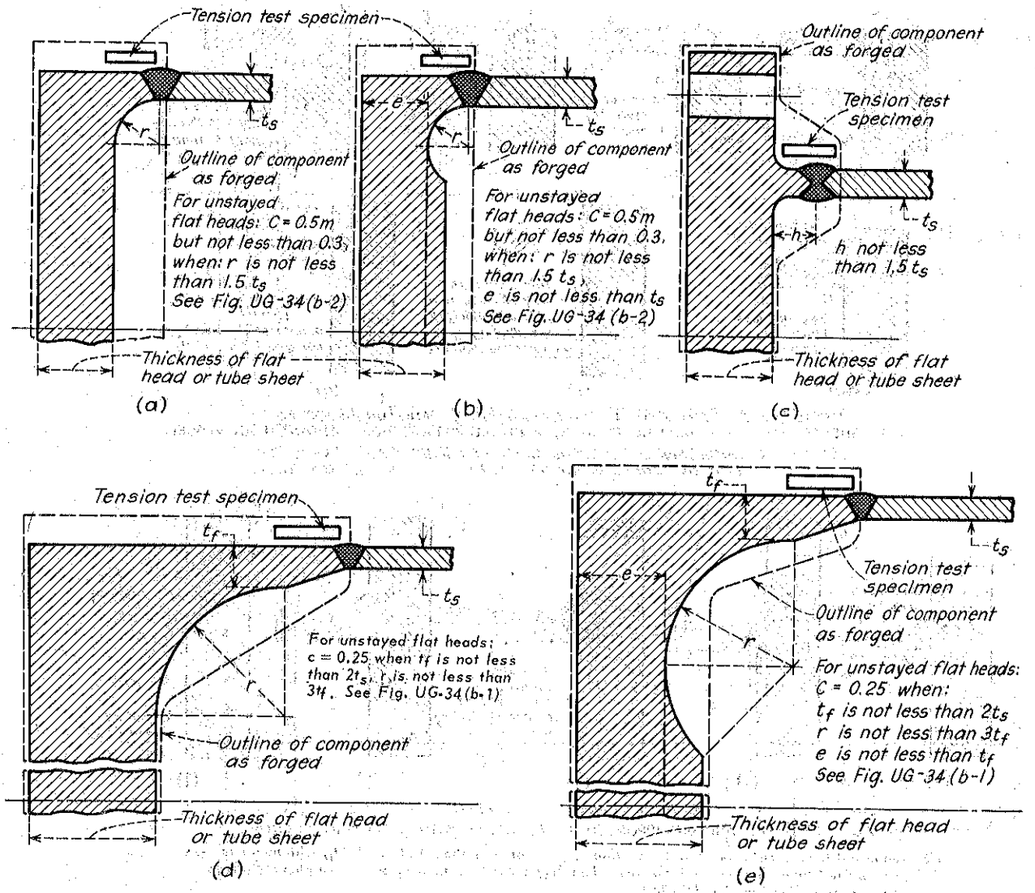


FIG. UW-13.3 TYPICAL FLAT HEADS AND SUPPORTED AND UNSUPPORTED TUBE SHEETS WITH HUBS* Not permissible if machined from rolled plate

* The tension test specimen may be located, when possible, inside the forged hub, instead of outside as shown.

tensile strength and elongation specified for the material, in a direction parallel to the axis of the vessel. Proof of this shall be furnished by a tension test specimen (subsize if necessary) taken in this direction and as close to the hub as is practical. In no case shall the height of the hub be less than 1.5 times the thickness of the pressure part to which it is welded.

UW-14 Openings in or Adjacent to Welds

(*a*) Any type of opening that meets the requirements for reinforcement given in UG-37 may be located in a welded joint.

(*b*) Openings within the limits given in UG-36(c)(3) that do not fully meet the requirements for reinforcement in UG-37 may be located in head-to-shell and other circumferential joints, provided the weld meets the radiographic requirements in UW-51(i) for a length equal to 3 times the diameter of the opening with the center of the hole at midlength. Defects that are completely removed in cutting the hole shall not be considered in judging the acceptability of the weld.

(*c*) When more than two openings not requiring added reinforcing elements in accordance with UG-36(c)(3) are in line in a welded joint, the requirements

for joint and ligament efficiency shall be met or the openings shall be reinforced in accordance with UG-37 and UG-42.

(*d*) Openings in solid plate that do not require added reinforcing elements in accordance with UG-36(c)(3), shall not be placed closer to the edge of a weld in a main joint than $1/2$ in. for plates $1\,1/2$ in. thick or less, except when the adjacent weld satisfies the requirements in (b).

UW-15 Welded Connections

(*a*) Nozzles, other connections, and their reinforcements may be attached to pressure vessels by arc or gas welding. Sufficient welding shall be provided on either side of the line through the center of the opening parallel to the longitudinal axis of the shell to develop the strength of the reinforcing parts as prescribed in UG-41 through shear or tension in the weld, whichever is applicable. The strength of groove welds shall be based in the area subjected to shear or to tension. The strength of fillet welds shall be based on the area subjected to shear (computed on the minimum leg dimension.) The inside diameter of a fillet weld shall be used in figuring its length.

(*b*) *Stress Values for Weld Metal.* The allowable stress values for groove and fillet welds and for shear in nozzle necks, in percentages of stress values for the vessel material, are as follows:

	Percent
Nozzle-wall shear	70
Groove-weld tension	74
Groove-weld shear	60
Fillet-weld shear	49

(*c*) Reinforcing plates and saddles of nozzles attached to the outside of a vessel shall be provided with at least one telltale hole (maximum size $1/4$-in. pipe tap) that may be tapped for a preliminary compressed air and soapsuds test for tightness of welds that seal off the inside of the vessel. These telltale holes may be left open or may be plugged when the vessel is in service. If the holes are plugged, the plugging material used shall not be capable of sustaining pressure between the reinforcing plate and the vessel wall.

UW-16 Minimum Requirements for Attachment Welds

(*a*) *General.* The location and minimum size of attachment welds for nozzles and other connections shall conform to the requirements in this paragraph in addition to the strength calculations required in UW-15.

(*b*) *Symbols.* The symbols used in this paragraph and in Figs. UW-16.1 and UW-16.2 are defined as follows:

t = nominal thickness of vessel shell or head less corrosion allowance, inches
t_n = nominal thickness of nozzle wall less corrosion allowance, inches
t_w = dimension of partial penetration attachment welds (fillet, single-bevel, or single-J), measured as shown in Fig. UW-16.1, inches
t_o = not less than the smaller of ¼ in. or $0.7t_{min}$ (inside corner welds may be further limited by a lesser length of projection of the nozzle wall beyond the inside face of the vessel wall)
t_{min} = the smaller of ¾ in. or the thickness less corrosion allowance of the thinner of the parts joined by a fillet, single-bevel, or single-J weld, inches
t_1 or t_2 = not less than the smaller of ¼ in. or $0.7t_{min}$

(*c*) *Necks Abutting the Vessel Wall.* Necks abutting the vessel wall shall be attached by a full penetration groove weld. When complete joint penetration cannot be verified by visual inspection or other means permitted in this Division, backing strips or equivalent shall be used with full penetration welds deposited from only one side. (See Fig. UW-16.1(a) and (b).)

Necks or tubes recessed into thick-walled vessels or headers may be welded from only one side by cutting a welding groove in the vessel wall to a depth of not less than t_n on the longitudinal axis of the opening. It is recommended that a recess $1/16$ in. deep be provided at the bottom of the groove in which to center the nozzle. The dimension, t_w, of the attachment weld shall be not less than t_n or less than $1/4$ in. (For examples see Fig. UW-16.1(y) and (z).)

(*d*) *Inserted Necks Without Added Reinforcing Elements.* Necks inserted into or through a hole cut in the vessel wall and without additional reinforcing elements shall be attached by a full penetration groove weld or by two partial penetration welds, one on each face of the vessel wall. Permissible types of welds are shown in Fig. UW-16.1(c) through (h).

When complete joint penetration cannot be verified by visual inspection or other means permitted in this

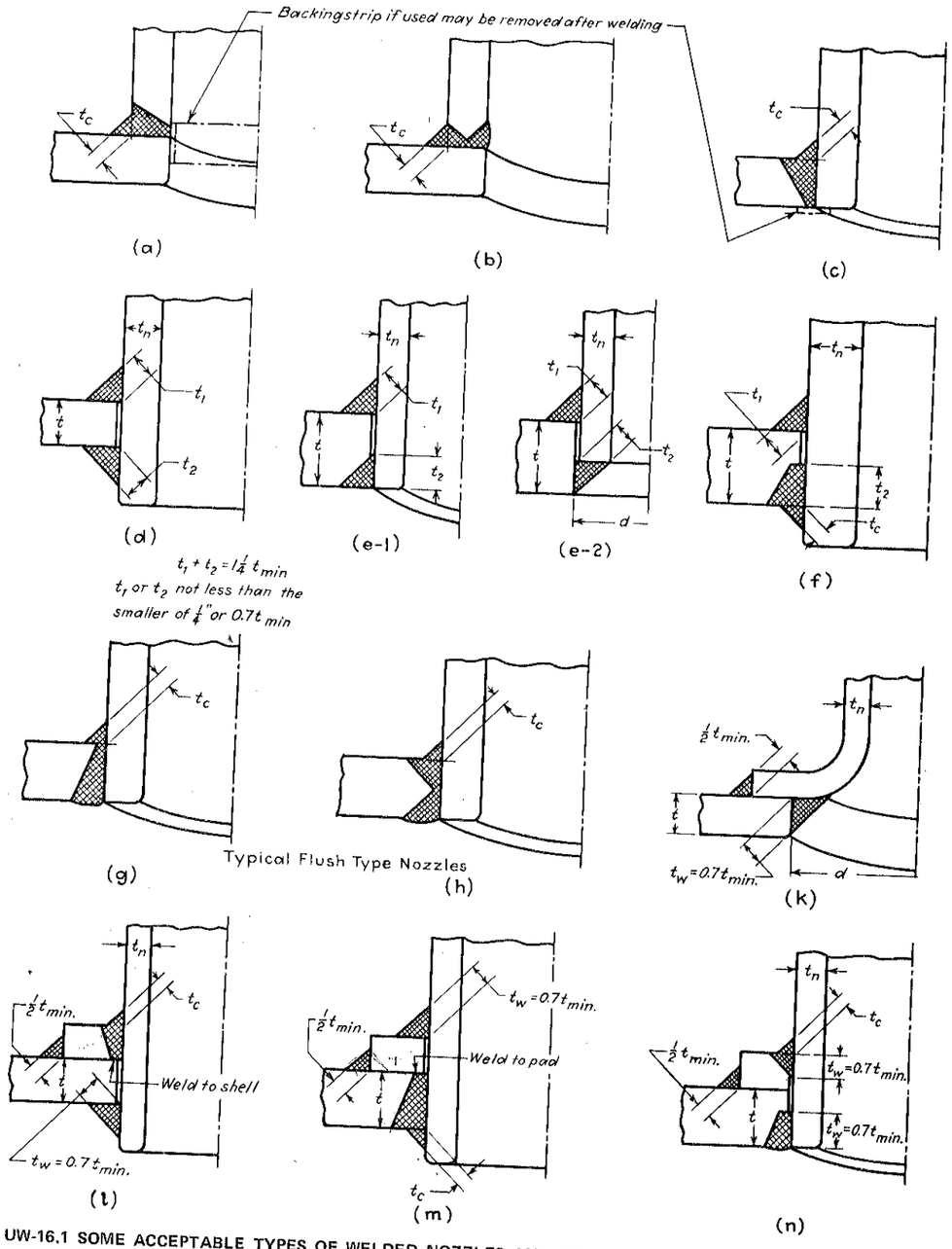


FIG. UW-16.1 SOME ACCEPTABLE TYPES OF WELDED NOZZLES AND OTHER CONNECTIONS TO SHELLS, DRUMS, AND HEADERS

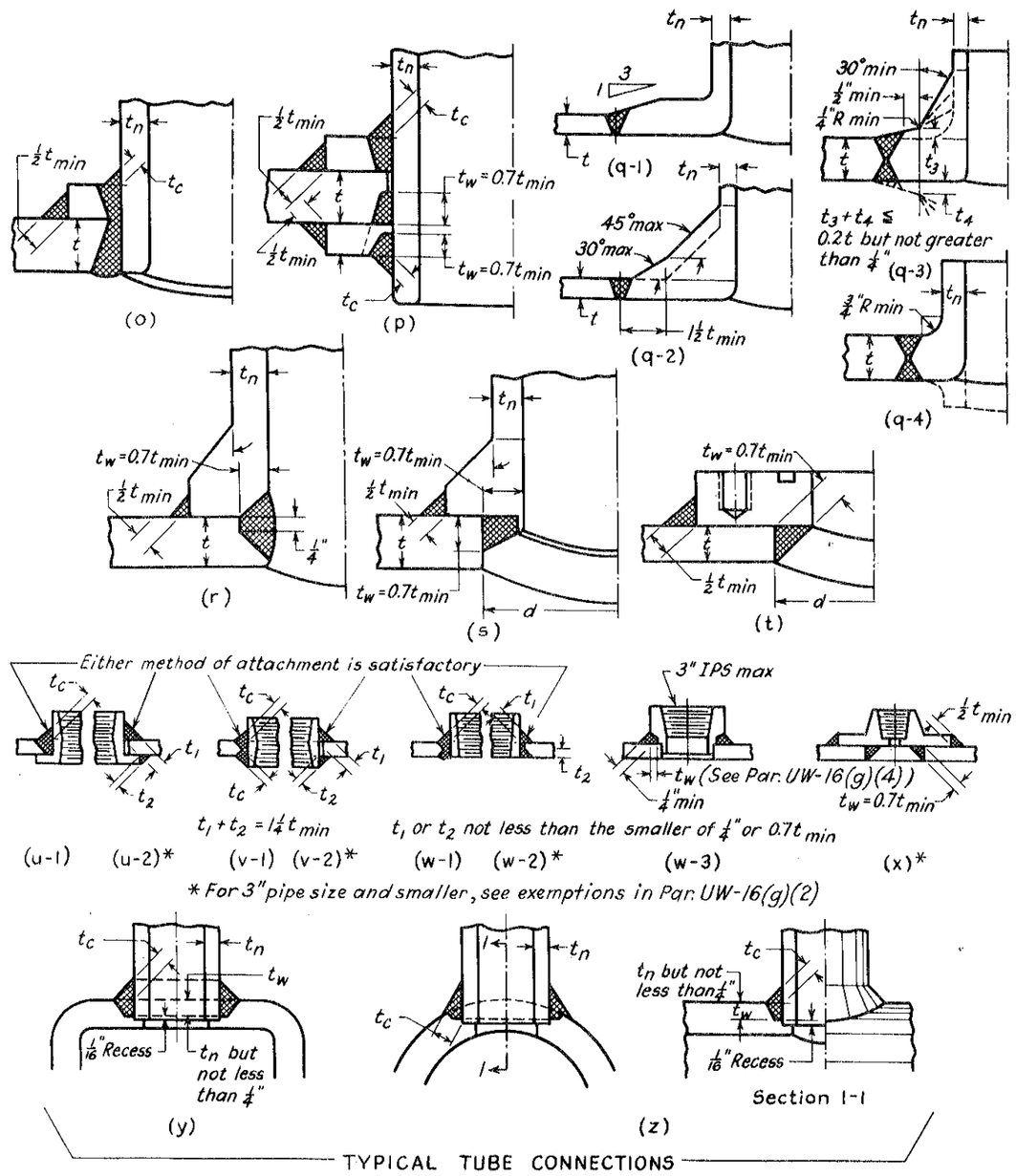


FIG. UW-16.1 (CONT'D) SOME ACCEPTABLE TYPES OF WELDED NOZZLES AND OTHER CONNECTIONS TO SHELLS, DRUMS, AND HEADERS

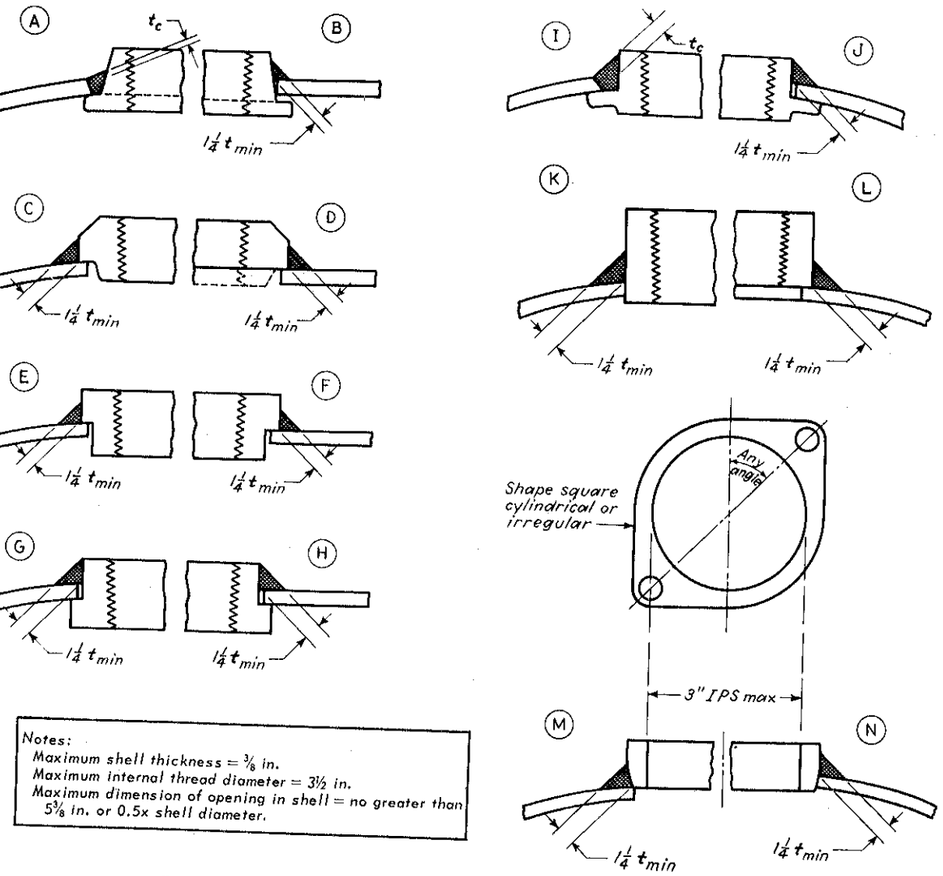


FIG. UW-16.2 SOME ACCEPTABLE TYPES OF SMALL FITTINGS

Division, backing strips or equivalent shall be used with full penetration welds deposited from only one side. The two partial penetration welds may be any desired combination of fillet, single-bevel, and single-J welds. The dimension of t_w of each weld shall be not less than the smaller of ¼ in. or 0.7 t_{min} and their sum shall be not less than 1¼ t_{min}. (See Fig. UW-16.1).

(*e*) *Inserted Necks With Added Reinforcement.* Inserted type necks having added reinforcement in the form of one or more separate reinforcing plates shall be attached by welds at the outer edge of the reinforcement plate and at the nozzle-neck periphery. The weld at the outer edge of the reinforcement shall be a fillet weld with a minimum throat dimension of ½ t_{min}. The welds attaching the neck to the vessel wall and to the reinforcement shall consist of one of the following combinations:

(*1*) A single-bevel or single-J weld in the shell plate, and a single-bevel or single-J weld in each reinforcement plate. The dimension, t_w, of each weld shall be not less than 0.7 t_{min} (Fig. UW-16.1(n)).

(*2*) A full penetration groove weld in the shell plate, and a fillet, single-bevel, or single-J weld with a weld dimension, t_w, not less than 0.7 t_{min} in each reinforcement plate (Fig. UW-16.1(m)).

(*3*) A full penetration groove weld in each reinforcement plate, and a fillet, single-bevel, or single-J weld with a weld dimension, t_w, not less than 0.7 t_{min} in the shell plate (Fig. UW-16.1(1)).

(*f*) *Nozzles With Integral Reinforcement.* Nozzles

and other connections having integral reinforcement in the form of extended necks or saddle type pads shall be attached by a full penetration weld or by means of a fillet weld along the outer edge and a fillet, single-bevel, or single-J weld along the inner edge. The throat dimension of the outer weld shall be not less than ½ t_{min}. The dimension, t_w, of the inner weld shall be not less than 0.7 t_{min} (see Fig. UW-16.1(k), (r), (s), and (t)).

(*g*) *Fittings With Internal Threads.* The attachment of internally threaded fittings shall meet the following requirements:

(*1*) Except as provided for in (2), (3), and (4), internally threaded fittings shall be attached by a full penetration groove weld or by two fillet or partial penetration welds one on each face of the vessel wall. The minimum weld dimensions shall be as shown in Fig. UW-16.1(u), (v), (w), and (x).

(*2*) Fittings shown in Fig. UW-16.1 (u-2), (v-2), (w-2), and (x) not exceeding 3-in. pipe size may be attached by welds that are exempt from size requirements other than those specified in UW-15(a).

(*3*) (a) Internally threaded fittings and bolting pads not exceeding 3-in. pipe size, as shown in Fig. UW-16.2, may be attached to vessels having a wall thickness not greater than ⅜ in. by a fillet weld, deposited from the outside only. The welds shall comply with the dimensions shown in Fig. UW-16.2. These openings do not require reinforcement other than that inherent in the construction as permitted in UG-36(c)(3).

(b) If the opening exceeds 5⅜ in. in any direction, or is greater than one-half the vessel diameter, the part of the vessel affected shall be subjected to a proof test as required in UG-36(a)(2), or the opening shall be reinforced in accordance with UG-37 and the nozzle or other connection attached, using a suitable detail in Fig. UW-16.1, if welded.

(*4*) Internally threaded fittings not exceeding 3-in. pipe size may be attached by a fillet groove weld from the outside only as shown in Fig. UW-16.1 (w-3). The groove weld t_w shall not be less than the thickness of schedule 160 pipe (ANSI B36.10-1970).

UW-17 Plug Welds

(*a*) Plug welds may be used in lap joints, in reinforcements around openings and in nonpressure structural attachments. They shall be properly spaced to carry their proportion of the load, but shall not be considered to take more than 30 percent of the total load to be transmitted.

(*b*) Plug weld holes shall have a diameter not less than t + ¼ in. and not more than $2t$ + ¼ in., where t is the thickness in inches of the plate or attached part in which the hole is made.

(*c*) Plug weld holes shall be completely filled with weld metal when the thickness of the plate, or attached part, in which the weld is made is 5/16 in. or less; for thicker plates or attached parts the holes shall be filled to a depth of at least half the plate thickness or 5/16 of the hole diameter, whichever is larger, but in no case less than 5/16 in.

(*d*) The allowable working load on a plug weld in either shear or tension shall be computed by the following formula:

$$P = 0.63\ S(d - 1/4)^2$$

where

P = total allowable working load on the plug weld, pounds
d = the bottom diameter of the hole in which the weld is made, inches
S = maximum allowable stress value for the material in which the weld is made, pounds per square inch (see applicable table of stress values in Subsection C)

UW-18 Fillet Welds

(*a*) Fillet welds may be employed as strength welds for pressure parts within the limitations given in Table UW-12. Particular care shall be taken in the layout of joints in which fillet welds are to be used in order to assure complete fusion at the root of the fillet.

(*b*) Corner or tee joints may be made with fillet welds provided the plates are properly supported independently of such welds, except that independent supports are not required for joints used for the purposes enumerated in UG-55.

(*c*) Figs. UW-13.1 and UW-13.2 show several construction details that are not permissible.

(*d*) The allowable load on fillet welds shall equal the product of the weld area (based on minimum leg dimension), the allowable stress value in tension of the material being welded, and a joint efficiency of 55 percent.

UW-19 Welded Stayed Construction

(*a*) Welded-in staybolts shall meet the following requirements:

(*1*) The arrangement shall conform to one of those illustrated in Fig. UW-19.1;

(*2*) The required thickness of the plate shall not exceed $1^1/_2$ in., but if greater than $^3/_4$ in., the staybolt pitch shall not exceed 20 in.;

(*3*) The provisions of UG-47 and UG-49 shall be followed; and

(*4*) The required area of the staybolt shall be determined in accordance with the requirements in UG-50.

(*b*) Welded stays, substantially as shown in Fig. UW-19.2, may be used to stay jacketed unfired pressure vessels provided:

(*1*) The pressure does not exceed 300 psi;

(*2*) The required thickness of the plate does not exceed $^1/_2$ in;

(*3*) The size of the fillet welds is not less than the plate thickness;

(*4*) The inside welds are properly inspected before the closing plates are attached;

(*5*) The allowable load on the fillet welds is computed in accordance with UW-18(d);

(*6*) The maximum diameter or width of the hole in the plate does not exceed $1^1/_4$ in.;

(*7*) The welders are qualified under the rules of Section IX of the Code;

(*8*) The maximum spacing of stays is determined by the formula in UG-47(a), using;

$C = 2.1$ if either plate is not over $^7/_{16}$ in. thick,

$C = 2.2$ if both plates are over $^7/_{16}$ in. thick.

(*c*) Welded stayed construction, consisting of a dimpled or embossed plate welded to another like plate or to a plain plate may be used, provided:

(*1*) The pressure does not exceed 300 psi;

(*2*) The welded attachment is made by fillet welds around holes or slots as shown in Fig. UW-19.2 or if the thickness of the plate having the hole or slot is $^3/_{16}$ in. or less, and the hole is 1 in. or less in diameter the holes may be completely filled with weld metal. The allowable load on the weld shall equal the product of the thickness of the plate having the hole or slot, the circumference or perimeter of the hole or slot, the allowable stress value in tension of the material being welded and a joint efficiency of 55 percent;

(*3*) The maximum allowable working pressure of the dimpled or embossed components is established in accordance with the requirements of UG-101;

(*4*) The plain plate, if used, shall meet the requirements for braced and stayed surfaces.

(*d*) The welds need not be radiographed, nor need they be postweld heat treated unless the vessel or vessel part in which they occur is required to be postweld heat treated.

FABRICATION

UW-26 General

(*a*) The rules in the following paragraphs apply specifically to the fabrication of pressure vessels and vessel parts that are fabricated by welding and shall be used in conjunction with the general requirements for *Fabrication* in Subsection A, and with the specific requirements for *Fabrication* in Subsection C that pertain to the class of material used.

(*b*) Each manufacturer or contractor shall be responsible for the quality of the welding done by his organization and shall conduct tests not only of the welding procedure to determine its suitability to insure welds which will meet the required tests, but also of the welders and welding operators to determine their ability to apply the procedure properly.

(*c*) No production work shall be undertaken until both the welding procedure and the welders or welding operators have been qualified.

UW-27 Welding Processes

The welding processes that may be used in the construction of vessels under this Part of this Division are restricted as follows:

(*1*) Arc or gas welding processes are restricted to shielded metal arc, submerged arc, gas metal arc, gas tungsten arc, plasma arc, atomic hydrogen metal arc, oxyhydrogen, and oxyacetylene. No mechanical pressure or blows shall be applied except as permitted for peening in UW-39.

(*2*) Pressure welding processes are restricted to flash, induction, resistance, pressure thermit, and pressure gas.

UW-28 Qualification of Welding Procedure

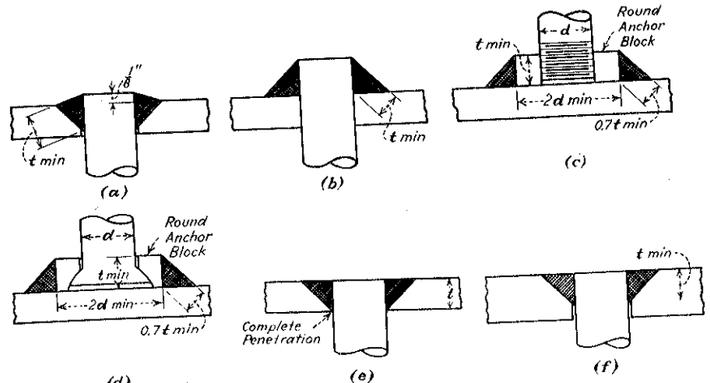
(*a*) Each procedure of welding that is to be followed in construction shall be recorded in detail by the manufacturer.

(*b*) Each such welding procedure shall be qualified in accordance with the provisions of Section IX of the Code insofar as they apply. Only qualified procedure specifications shall be followed in construction.

(*c*) Each manufacturer shall conduct the required tests to qualify all welding procedures to be used by his organization.

UW-29 Tests of Welders and Welding Operators

(*a*) All welders assigned to manual welding shall have passed the tests prescribed for welder



NOTE = t equals nominal thickness of the thinner stayed plate

FIG. UW-19.1 TYPICAL FORMS OF WELDED STAYBOLTS

qualification in Section IX of the Code. All operators assigned to machine welding equipment shall have passed the examination prescribed in Q-21 or QN-21 of Section IX. Such tests shall be conducted by the manufacturer or contractor.

(*b*) Each welder and welding operator shall be assigned an identifying number, letter, or symbol by the manufacturer which shall be used to identify the work of that welder or welding operator.

(*c*) The manufacturer shall maintain a record of the welders and welding operators employed by him showing the date and result of tests and the identification mark assigned to each. These records shall be certified to by the manufacturer and be accessible to the Inspector.

(*d*) The test conducted by one manufacturer shall not qualify a welder or welding operator to do work for any other manufacturer.

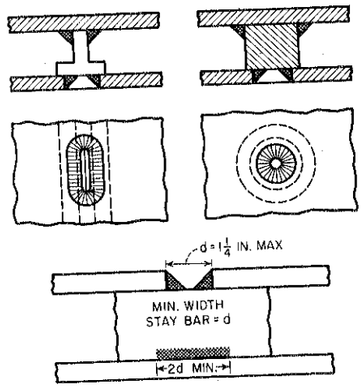


FIG. UW-19.2 USE OF PLUG AND SLOT WELDS FOR STAYING PLATES

UW-30 Lowest Permissible Temperatures for Welding

It is recommended that no welding of any kind be done when the temperature of the base metal is lower than 0 F. At temperatures between 32 F and 0 F, the surface of all areas within 3 in. of the point where a weld is to be started should be heated to a temperature at least warm to the hand (estimated to be above 60 F) before welding is started. It is recommended also that no welding be done when surfaces are wet or covered with ice, when snow is falling on the surfaces to be welded, or during periods of high wind, unless the welders or welding operators and the work are properly protected.

UW-31 Cutting, Fitting, and Alignment

(*a*) When plates are shaped by oxygen or arc cutting, the edges to be welded shall be uniform and smooth and shall be freed of all loose scale and slag accumulations before welding (see UG-76 and UCS-5).

(*b*) Plates that are being welded shall be fitted, aligned, and retained in position during the welding operation.

(*c*) Bars, jacks, clamps, tackwelds, or other appropriate means may be used to hold the edges of parts in alignment. Tackwelds used to secure alignment shall either be removed completely when they have served their purpose, or their stopping and starting ends shall be properly prepared by grinding or other suitable means so that they may be satisfactorily incorporated into the final weld. Tackwelds whether removed or left in place shall be made using qualified procedures and welders in

accordance with Section IX and the tackwelds which remain in place shall be examined visually for defects and if found to be defective, shall be removed.

(*d*) The edges of butt joints shall be held during welding so that the tolerances of UW-33 are not exceeded in the completed joint. When fitted girth joints have deviations exceeding the permitted tolerances, the head or shell ring, whichever is out-of-true, shall be reformed until the errors are within the limits specified. Where fillet welds are used, the lapped plates shall fit closely and be kept in contact during welding.

UW-32 Cleaning of Surfaces to Be Welded

(*a*) The surfaces to be welded shall be clean and free from foreign material such as grease, oil, lubricants, and marking paints for a distance of at least $1/2$ in. from the welding edge for ferrous materials and at least 2 in. for nonferrous materials. Detrimental oxide shall be removed from the weld metal contact area. When weld metal is to be deposited over a previously welded surface, all slag shall be removed by a roughing tool, chisel, air chipping hammer, or other suitable means so as to prevent inclusion of impurities in the weld metal.

(*b*) Cast surfaces to be welded shall be machined, chipped, or ground to remove foundry scale and to expose sound metal.

UW-33 Alignment Tolerance

(*a*) Alignment of sections at edges to be butt welded shall be such that the maximum offset is not greater than the applicable amount as listed in the following Table, where t is the nominal thickness of the thinner section at the joint.

	Direction of Joints In Cylindrical Shells	
Section Thickness, in.	Longitudinal	Circumferential
Up to $1/2$, incl.	$1/4\ t$	$1/4\ t$
Over $1/2$ to $3/4$, incl.	$1/8$ in.	$1/4\ t$
Over $3/4$ to $1\ 1/2$, incl.	$1/8$ in.	$3/16$ in.
Over $1\ 1/2$ to 2, incl.	$1/8$ in.	$1/8\ t$
Over 2	Lesser of $1/16\ t$ or $3/8$ in.	Lesser of $1/8\ t$ or $3/4$ in.

(*b*) Joints in spherical vessels and within heads and joints between cylindrical shells and hemispherical heads shall meet the requirements in (a) above for longitudinal joints in cylindrical shells.

(*c*) Any offset within the allowable tolerance provided above shall be faired at a 3 to 1 taper over the width of the finished weld, or if necessary, by adding additional weld metal beyond what would otherwise be the edge of the weld.

UW-35 Finished Longitudinal and Circumferential Joints

(*a*) Butt joints shall have complete joint penetration and complete fusion for the full length of the weld and shall be free from undercuts, overlaps, or abrupt ridges or valleys.[1] To assure that the weld grooves are completely filled so that the surface of the weld metal at any point does not fall below the surface of the adjoining plate, weld metal may be built up as reinforcement on each side of the plate. The thickness of the reinforcement on each side of the plate shall not exceed the following thicknesses:

Plate Thickness, in.	Maximum Thickness of Reinforcement, in.
Up to $1/2$, incl.	$3/32$
Over $1/2$ to 1, incl.	$1/8$
Over 1	$3/16$

The reinforcement need not be removed except to the extent that it exceeds the permissible thickness or when required by UW-51.

(*b*) When a single-welded butt joint is made by using a backing strip which is left in place (Type No. (2) of Table UW-12), the requirement for reinforcement applies only to the side opposite the backing strip.

UW-36 Fillet Welds

In making fillet welds, the weld metal shall be deposited in such a way that adequate penetration into the base metal at the root of the weld is secured.

UW-37 Miscellaneous Welding Requirements

(*a*) The reverse side of double-welded joints shall be prepared by chipping, grinding, or melting out, so as to secure sound metal at the base of weld metal first deposited, before applying weld metal from the reverse side.

(*b*) The requirements in (a) are not intended to apply to any process of welding by which proper fusion and penetration are otherwise obtained and

[1] If the reinforcement is built up so as to form a ridge with a valley or depression in the weld at the edge next to the plate, the result is a notch that causes concentration of stress and reduces the strength of the joint.

by which the base of the weld remains free from impurities.

(*c*) If the welding is stopped for any reason, extra care shall be taken in restarting to get the required penetration and fusion. For submerged arc welding, chipping out a groove in the crater is recommended.

(*d*) Where single-welded joints are used, particular care shall be taken in aligning and separating the components to be joined so that there will be complete penetration and fusion at the bottom of the joint for its full length.

(*e*) In welding plug welds, a fillet around the bottom of the hole shall be deposited first.

(*f*) Each welder and welding operator shall stamp the identifying number, letter, or symbol, assigned by the manufacturer, adjacent to and at intervals of not more than 3 ft along the welds which he makes in steel plates $1/4$ in. and over in thickness and in nonferrous plates $1/2$ in. and over in thickness; or a record shall be kept by the manufacturer of welders and welding operators employed on each joint which shall be available to the Inspector. For identifying welds on vessels in which the wall thickness is less than $1/4$ in. for steel material and less than $1/2$ in. for nonferrous material, suitable stencil or other surface markings shall be used; or a record shall be kept by the manufacturer of welders and welding operators employed on each joint which shall be available to the Inspector.

UW-38 Repair of Weld Defects

Visible defects, such as cracks, pinholes, and incomplete fusion, and defects detected by the hydrostatic test or by the examinations prescribed in UW-51 and UW-52 shall be removed by mechanical means, or by oxygen grooving, after which the joint shall be rewelded. (See UW-40(d) and Thermal Cutting in Appendix NF.)

UW-39 Peening

The weld metal may be peened when it is deemed necessary or helpful to control distortion, to relieve residual stresses, or to improve the quality of the weld.

UW-40 Procedures for Postweld Heat Treatment

(*a*) The operation of postweld heat treatment shall be performed in accordance with the requirements given in the applicable Part in Subsection C using one of the following procedures:

(*1*) Heating the vessel as a whole in an enclosed furnace. This procedure is perferable and should be used whenever practicable;

(*2*) Heating the vessel in more than one heat in a furnace, provided the overlap of the heated sections of the vessel is at least 5 ft. When this procedure is used the portion outside of the furnace shall be shielded so that the temperature gradient is not harmful;

(*3*) Heating of shell sections and/or portions of vessels to postweld heat treat longitudinal joints or complicated welded details before joining to make the completed vessel. When the vessel is required to be postweld heat treated, and it is not practicable to postweld heat treat the completed vessel as a whole or in two or more heats as provided in (2), any circumferential joints not previously postweld heat treated may be thereafter locally postweld heat treated by heating such joints by any appropriate means that will assure the required uniformity. The width of the heated band on each side of the greatest width of finished weld shall be not less than 2 times the shell thickness. The portion outside the heating device shall be protected so that the temperature gradient is not harmful. This procedure may also be used to postweld heat treat portions of new vessels after repairs;

(*4*) Heating the vessel internally by any appropriate means and with adequate indicating and recording temperature devices to aid in the control and maintenance of a uniform distribution of temperature in the vessel wall. Previous to this operation, the vessel should be fully enclosed with insulating material, or the permanent insulation may be installed provided it is suitable for the required temperature. In this procedure the internal pressure should be kept as low as practicable, but shall not exceed 50 percent of the maximum allowable working pressure at the highest metal temperature expected during the postweld heat treatment period;

(*5*) Heating a circumferential band containing nozzles or other welded attachments that require postweld heat treatment in such a manner that the entire band shall be brought up uniformly to the required temperature and held for the specified time. The circumferential band shall extend around the entire vessel, shall include the nozzle or welded attachment, and shall extend at least 6 times the plate thickness beyond the welding which connects the nozzle or other attachment to the vessel. The portion of the vessel outside of the circumferential band shall be protected so that the temperature gradient is not harmful;

(*6*) Heating the circumferential joints of pipe

or tubing by any appropriate means over a band having a width on each side of the centerline of not less than 3 times the greatest width of the finished weld. The portion outside of the heated band shall be protected so that the temperature gradient is not harmful.

(*b*) The temperatures and rates of heating and cooling to be used in postweld heat treatment of vessels constructed of materials for which postweld heat treatment may be required are given in UCS-56 and UHA-32.

(*c*) The minimum temperature for postweld heat treatment given above shall be the minimum temperature of the plate material of the shell or head of any vessel. Where more than one pressure vessel or pressure vessel part are postweld heat treated in one furnace charge, thermocouples shall be placed on vessels at the bottom, center, and top of the charge, or in other zones of possible temperature variation so that the temperature indicated shall be true temperature for all vessels or parts in those zones.[1]

(*d*) Postweld heat treatment, when required, shall be done before the hydrostatic test and after any repairs to welding. A preliminary hydrostatic test to reveal leaks prior to postweld heat treatment is permissible.

(*e*) Vessels of different thickness may be postweld heat treated in the same furnace charge according to the postweld heat treatment requirements for the thickest vessel in the charge.

UW-41 Sectioning of Welded Joints

Welded joints may be examined by sectioning when agreed to by user and manufacturer, but this examination shall not be considered a substitute for spot radiographic examination. This type of examination has no effect on the joint factors in Table UW-12. The method of closing the hole by welding is subject to approval by the Inspector. Some acceptable methods are given in Appendix K.

INSPECTION AND TESTS

UW-46 General

The rules in the following paragraphs apply specifically to the inspection and testing of pressure vessels and vessel parts that are fabricated by welding and shall be used in conjunction with the general requirements for *Inspection and Tests* in Subsection A, and with the specific requirements for *Inspection and Tests* in Subsection C that pertain to the class of material used. (For tests on reinforcing plates see UW-15(c).

UW-47 Check of Welding Procedure

The Inspector shall assure himself that the welding procedure employed in the construction of a vessel has been qualified under the provisions of Section IX of the Code. The manufacturer shall submit evidence to the Inspector that the requirements have been met.

UW-48 Check of Welder and Welding Operator Qualifications

(*a*) The manufacturer shall certify that the welding on a vessel has been done only by welders and welding operators who have been qualified under the requirements of Section IX and the Inspector shall assure himself that only qualified welders and welding operators have been used.

(*b*) The manufacturer shall make available to the Inspector a certified copy of the record of the qualification tests of each welder and welding operator. The Inspector shall have the right at any time to call for and witness tests of the welding procedure or of the ability of any welder and welding operator.

UW-49 Check of Postweld Heat Treatment Practice

The Inspector shall satisfy himself that all postweld heat treatment has been correctly performed and that the temperature readings conform to the requirements.

UW-50 Nondestructive Examination of Welds on Pneumatically Tested Vessels

On welded pressure vessels to be pneumatically tested in accordance with UG-100, the full length of the following welds shall be examined[2] for the purpose of detecting possible cracks:

(*a*) All welds around openings;

(*b*) All attachment welds, including welds attaching nonpressure parts to pressure parts, having a throat thickness greater than 1/4 in.

[1]Furnace gas temperature measurement alone is not considered sufficiently accurate.

[2]Examination shall be by magnetic particle or liquid penetrant methods when the material is ferromagnetic, or by the liquid penetrant method when the material is nonmagnetic.

UW-51 Technique for Radiographic Examination of Welded Joints

(*a*) All welded joints to be radiographed shall be prepared as follows:

The weld ripples or weld surface irregularities, on both the inside and outside, shall be removed by any suitable mechanical process to such a degree that the resulting radiographic contrast due to any irregularities cannot mask or be confused with the image of any objectionable defect. Also the weld surface shall merge smoothly into the plate surface. The finished surface of the reinforcement of all butt-welded joints may be flush with the plate or may have a reasonably uniform crown not to exceed the following thickness:

Plate Thickness, in.	Thickness of Reinforcement in.
Up to 1/2 in.	1/16
Over 1/2 in. to 1	3/32
Over 1 to 2	1/8
Over 2	5/32

(*b*) The weld shall be radiographed with a technique which will have sufficient sensitivity to indicate the features of the penetrameter as described in UW-51(c)(8), using a penetrameter of the specified thickness for the thickness of the weld being examined. The size and shape of the penetrameter shall be substantially as shown on Fig. UW-51. These dimensions apply to the penetrameter itself and not ot its projected image on the radiograph. The image will be enlarged to some degree on the film. It is recommended that penetrameters be protected by being embedded in plastic.

The maximum thickness of the penetrameter shall be as shown in Table UW-51.

Standard penetrameters shall be limited to the thickness in Table UW-51 and identified by number in symbols at least 3/32 in. high.

(*c*) As a check on the radiographic technique employed, penetrameters, as herein described, shall be used in the following manner to determine whether the requirements are being met.

(*1*) The radiographic quality shall be evaluated by the image of a properly located penetrameter.

(*2*) A standard source side penetrameter of the thickness shown in Table UW-51 shall be placed on the side nearest the radiation source. Where it is physically impossible to do this, a film side penetrameter shall be placed on the film side of the joint, and its thickness shall conform to Table UW-51, and a lead letter "F" at least 1/2 in. high shall be placed adjacent to the penetrameter.

(*3*) One penetrameter shall be used for each exposure, to be placed so that the plane of the penetrameter is normal to the radiation beam. Each penetrameter shall represent an area of essentially uniform radiographic density as judged by density

TABLE UW-51
STANDARD PENETRAMETER SIZES

Weld Thickness Range,* in.	Thickness of Penetrameter on Source Side, in.	Designation on Penetrameter	Thickness of Penetrameter on Film Side, in.	Designation on Penetrameter
Up to 1/4 incl.	0.005	5	0.005	5
Over 1/4 thru 3/8	0.0075	7	0.0075	7
Over 3/8 thru 1/2	0.010	10	0.010	10
Over 1/2 thru 5/8	0.0125	12	0.010	10
Over 5/8 thru 3/4	0.015	15	0.012	12
Over 3/4 thru 7/8	0.0175	17	0.015	15
Over 7/8 thru 1	0.020	20	0.017	17
Over 1 thru 1 1/4	0.025	25	0.020	20
Over 1 1/4 thru 1 1/2	0.030	30	0.025	25
Over 1 1/2 thru 2	0.035	35	0.030	30
Over 2 thru 2 1/2	0.040	40	0.030	30
Over 2 1/2 thru 3	0.045	45	0.035	35
Over 3 thru 4	0.050	50	0.040	40
Over 4 thru 6	0.060	60	0.050	50
Over 6 thru 8	0.080	80	0.060	60
Over 8 thru 10	0.100	100	0.080	80
Over 10 thru 12	0.120	120	0.100	100
Over 12 thru 16	0.160	160	0.120	120
Over 16 thru 20	0.200	200	0.160	160

* Including any weld reinforcement and/or backing strip thickness, if not removed. In the case of double wall tube radiography, the thickness of the penetrameter shall be based on the thickness of the weld next to the film.

comparison strips or a densitometer. If the film density through the weld varies more than minus 15 or plus 30 percent from the density through the penetrameter, then an additional penetrameter will be required for the exceptional area or areas. If the requirements of (c)(8) are met by two penetrameters, one a penetrameter appearing in the lightest area of a film, and the other in the darkest, the intervening film shall be considered as having acceptable density. It is not necessary that these additional penetrameters be normal to the radiation at their locations. The H. & D.[1] density through acceptable weld metal shall be 1.3 minimum for single-film viewing, and 1.8 minimum for composite viewing of double film exposures.

(*4*) The material of the penetrameter shall be radiographically similar to that of the filler metal under examination. For example, any steel, preferably stainless, may be used for steel; and aluminum for aluminum, etc. If the filler metal is not radiographically similar to the base material, or the geometric configuration makes placement adjacent to the weld impractical, then the penetrameter may be placed over the filler metal.

(*5*) The penetrameter shall be placed adjacent to the weld seam except as provided for in (4). If the weld reinforcement, and/or backing strip, is not removed, a shim of a radiographically similar material to the filler metal shall be placed under the penetrameter. The shim thickness shall be selected so that the total thickness being radiographed under the penetrameter is the same as the total weld thickness (including backing strip if used and not removed).

(*6*) In each penetrameter there shall be three holes, one of which shall be of diameter equal to twice the nominal penetrameter thickness (2T) but not less than $1/16$ in. The diameter of the two remaining holes shall be selected by the manufacturer; they will ordinarily be equal to three (3T) and four times (4T) the penetrameter thickness but they need not be smaller than $1/16$ in.; but smaller holes are permitted.

These holes shall be true and normal to the surface and not chamfered. For weld thickness less than $1/2$ in., the penetrameter shall also contain a slit $1/4$ in. long by 0.010 in. wide. The long dimension of this slit is to be placed parallel to the longitudinal direction of the weld.

(*7*) The holes, or in the range where the slit is required, then the slit shall be delineated on the radiograph as defined in UW-51(c)(8).

(*8*) The images of the identifying numbers, of the penetrameter outline, and of the 2T hole are all essential indexes of image quality on the radiograph, and they shall appear clearly on the radiograph; except that for penetrameters 5, 7 and 10 the slit shall appear clearly and the hole need not appear.

(*d*) When the source is placed on the axis of the joint and the complete circumference is radiographed with a single exposure, at least three uniformly spaced penetrameters shall be employed.

(*e*) All radiographs shall be free from excessive mechanical, chemical, or other processing defects that could interfere with proper interpretation of the radiograph.

(*f*) Identification markers, the images of which will appear on the film, shall be placed adjacent to the weld on the part, not on the film, and their locations shall be marked on the surface near the weld, in such a manner that a defect appearing on a radiograph may be accurately located; and in such a manner that it is evident on the film that complete coverage of the weld has been obtained.

(*g*) The job number, the vessel, the seam, and the manufacturer's identification symbol or name shall be plainly indicated on each film.

(*h*) The radiographs shall be submitted to the Inspector with such information regarding the radiographic technique as he may request.

(*i*) Sections of weld that are shown by radiography to have any of the following types of imperfections shall be judged unacceptable and shall be repaired as provided in UW-38 and the repair radiographed to UW-51.

(*1*) Any type of crack, or zone of incomplete fusion or penetration;

(*2*) Any elongated slag inclusion which has length greater than

$1/4$ in. for T up to $3/4$ in.

$1/3$ T for T from $3/4$ in. to $2\,1/4$ in.

$3/4$ in. for T over $2\,1/4$ in.

where T is the thickness of the weld;

(*3*) Any group of slag inclusions in line that have an aggregate length greater than T in a length of $12T$, except when the distance between the successive imperfections exceeds $6L$ where L is the length of the longest imperfection in the group;

(*4*) Porosity in excess of that specified by the acceptance standards given in Appendix IV.

(*j*) A complete set of radiographs for each job shall be retained by the manufacturer and kept on file for a period of at least five years.

[1]Hurter-Driffield method of defining quantitative blackening of the film.

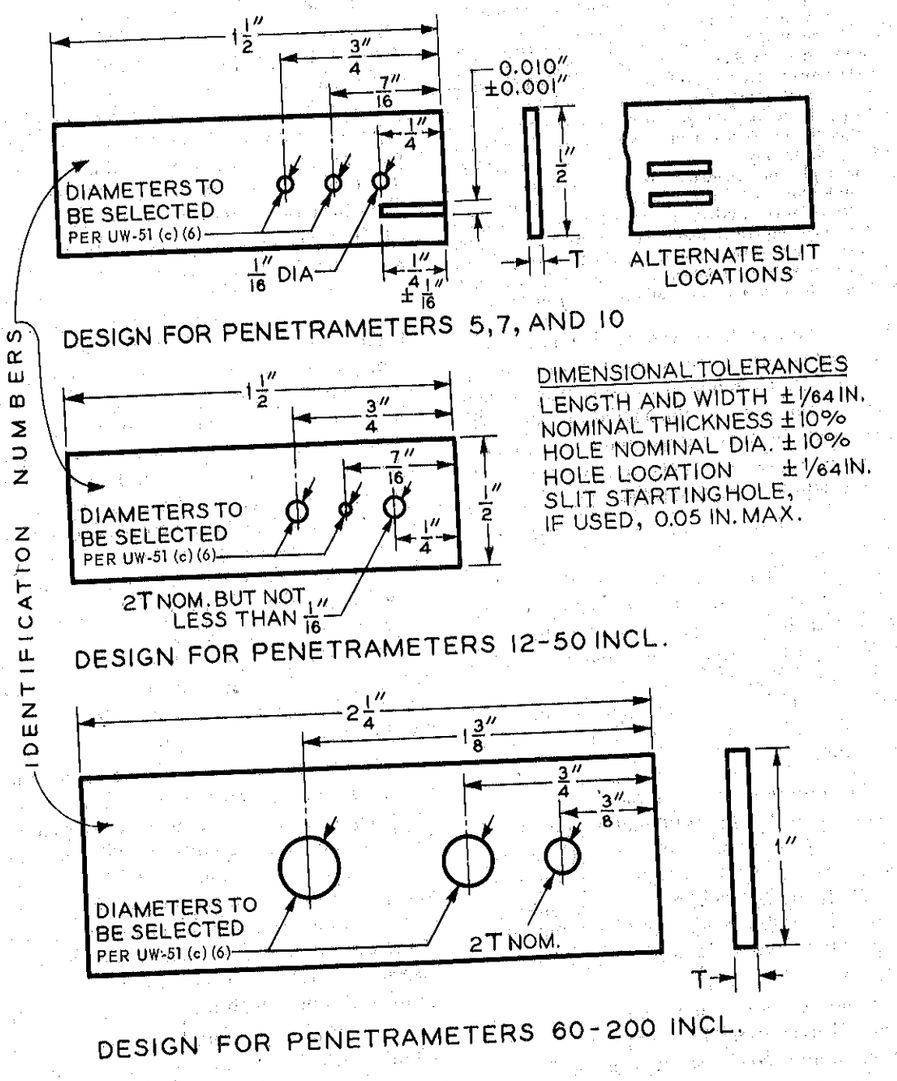


FIG. UW-51 PENETRAMETER (IMAGE QUALITY INDICATOR)

UW-52 Spot Examination of Welded Joints

NOTE: Spot radiographing of a welded joint is recognized as an effective inspection tool. The spot radiography rules are also considered to be an aid to quality control. Spot radiographs made directly after a welder or an operator has completed a unit of weld proves that the work is or is not being done in accordance with a satisfactory procedure. If the work is unsatisfactory, corrective steps can then be taken to improve the welding in the subsequent units, which unquestionably will improve the weld quality.

Spot radiography in accordance with these rules will not insure a fabrication product of predetermined quality level throughout. It must be realized that an accepted vessel under these spot radiography rules may still contain defects which might be disclosed on further examination. If all radiographically disclosed unacceptable weld defects must be eliminated from a vessel, then 100 percent radiography must be employed.

(*a*) Vessels and parts of vessels that have butt-welded joints that are not radiographed for their full length and which are required to be spot examined by other paragraphs of this Division shall be examined locally by spot radiographing as provided herein, except for those vessels or parts of vessels designed for external pressure only.

(*b*) *Minimum Extent of Spot Radiographic Examination.*

(*1*) One spot shall be examined in the first 50 ft of welding in each vessel and one spot shall be examined for each additional 50 ft of welding or fraction thereof, except that when identical vessels, individually of less than 50 ft seam length, are being fabricated under the rules of this paragraph, 50 ft increments of welding may be represented by one spot examination.

(*2*) Such additional spots as may be required shall be selected so that an examination is made of the welding of each welding operator or welder. Under conditions where two or more welders or welding operators make weld layers in a joint, or on the two sides of a double welded butt joint, one spot examination may represent the work of both welders or welding operators.

(*3*) Each spot examination shall be made as soon as practicable after the completion of the increment of weld that is to be examined. The location of the spot shall be chosen by the Inspector except that when the Inspector has been duly notified in advance and cannot be present or otherwise make the selection, the fabricator may exercise his own judgment in selecting the spots.

(*c*) *Standards for Spot Radiographic Examination.* Spot examination by radiography shall be made in accordance with the technique prescribed in UW-51. The minimum length of spot radiograph shall be 6 in. Spot radiographs may be retained or be discarded by the manufacturer after acceptance of the vessel by the Inspector. The acceptability of welds examined by spot radiography shall be judged by the following standards:

(*1*) Welds in which the radiograph shows any type of crack, or zone of incomplete fusion or penetration shall be unacceptable.

(*2*) Welds in which the radiographs show slag inclusions or cavities shall be unacceptable if the length of any such imperfection is greater than $^2/_3\ T$ where T is the thickness of the thinner plate welded. If several imperfections within the above limitations exist in line, the welds shall be judged acceptable if the sum of the longest dimensions of all such imperfections is not more than T in a length of $6T$ (or proportionately for radiographs shorter than $6T$) and if the longest imperfections considered are separated by at least $3L$ of acceptable weld metal, where L is the length of the longest imperfection. The maximum length of acceptable imperfections shall be $^3/_4$ in. Any such imperfections shorter than $^1/_4$ in. shall be acceptable for any plate thickness.

(*3*) Porosity is not a factor in the acceptability of welds not required to be fully radiographed.

(*d*) *Evaluation and Retests*

(*1*) When a spot, radiographed as required in (b)(1) or (b)(2), is acceptable in accordance with (c)(1) and (c)(2), the entire weld length represented by this radiograph is acceptable.

(*2*) When a spot, radiographed as required in (b)(1) or (b)(2), has been examined and the radiograph discloses welding which does not comply with the minimum quality requirements of (c)(1) and (c)(2), two additional spots shall be radiographically examined in the same weld unit at locations away from the original spot. The locations of these additional spots shall be determined by the Inspector or fabricator as provided for the original spot examination in (b)(3).

(a) If the two additional spots examined show welding which meets the minimum quality requirements of (c)(1) and (c)(2), the entire weld unit represented by the three radiographs is acceptable. The defective welding disclosed by the first of the three radiographs may be removed and the area repaired by welding, or it may be allowed to remain in the weld joint, at the discretion of the Inspector.

(b) If either of the two additional spots examined shows welding which does not comply with the minimum quality requirements of (c)(1) and (c)(2), the entire unit of weld represented shall be rejected. The entire rejected weld shall be removed and the joint shall be rewelded or, at the fabricator's option, the entire unit of weld represented shall be completely radiographed and defective welding only need be corrected.

(c) Repair welding shall be performed using a qualified procedure and in a manner acceptable to the Inspector. The rewelded joint, or the weld repaired areas shall be spot radiographically examined at one location in accordance with the foregoing requirements of UW-52.

STAMPING AND REPORTS

UW-60 General

The provisions for stamping and reports, UG-115 through UG-120, shall apply without supplement to welded pressure vessels.

PRESSURE RELIEF DEVICES

UW-65 General

The provisions for pressure relief devices, UG-125 through UG-134, shall apply without supplement to welded pressure vessels.

PART UR

REQUIREMENTS FOR PRESSURE VESSELS FABRICATED BY RIVETING

GENERAL

UR-1 Scope

The rules in Part UR are applicable to pressure vessels and vessel parts that are fabricated by riveting or by closely fitted bolting and shall be used in conjunction with the general requirements in Subsection A, and with the specific requirements in Subsection C that pertain to the class of material used.

MATERIALS

UR-5 General

Materials entering into the construction of riveted pressure vessels shall comply with the requirements for materials given in UG-5 through UG-13.

UR-6 Rivets and Bolts

(*a*) Material for rivets and bolts shall comply with the requirements in Subsection C for the class of material used.

(*b*) Rivets should be of material closely similar to the plate material being assembled.

(*c*) Bolts and nuts may be of any of the materials permitted by this Division but precautions should be taken to avoid excessive galvanic corrosion (see Appendix NF).

[1]Closely fitted bolting is included under riveting.

DESIGN

UR-10 General

(*a*) The rules in the following paragraphs apply specifically to the design of pressure vessels and vessel parts that are fabricated by riveting and shall be used in conjunction with the general requirements for *Design* in Subsection A, and with the specific requirements for *Design* in Subsection C that pertain to the class of material used.

(*b*) *Minimum Thickness of Plate.* The minimum thickness, after forming, of any plate in a riveted vessel which is subject to pressure, shall be $^3/_{16}$ in., exclusive of corrosion allowance, except as otherwise provided in UCS-16(b), UNF-16(b) and UHA-20(b).

UR-11 Strength of Rivets

The maximum allowable stress in tension and in shear for rivets, and bolts used instead of rivets, shall be 80 percent of the maximum allowable stress value prescribed in Subsection C for the material at the operating metal temperature. The maximum allowable stress in bearing shall be twice that permitted for shear.

UR-12 Crushing Strength of Plates

The maximum allowable stress for resistance to crushing of plates shall be 160 percent of the maximum allowable stress value prescribed in Subsection C for the material at the operating temperature.

UR-13 Corrosion Allowance

(*a*) Provision shall be made for corrosion in accordance with the requirements in UG-25.

(*b*) The plate thickness in excess of that computed for a seamless vessel, taking into account the applicable loadings in UG-22, may be taken as allowance for corrosion in vessels that have longitudinal joints of double-strap butt-joint construction. Additional corrosion allowance shall be provided when needed, particularly on the inner buttstraps.

(*c*) The use of swell-neck rivets with oversize heads is recommended when anticipated corrosion conditions are such that the loss of metal from standard heads of rivets may impair the strength or tightness of the vessel during its expected life.

UR-14 Thickness of Buttstraps

(*a*) The minimum thickness of a buttstrap for a double-strap riveted joint shall be as given in Table UR-14. Intermediate values may be determined by interpolation. For a shell-plate thickness exceeding 1 1/4 in., the thickness of the buttstrap shall be not less than two-thirds of the thickness of the shell plate.

(*b*) The minimum thickness of a buttstrap for a single-strap joint shall be twice that given in Table UR-14, except that on a circumferential joint a buttstrap need not be thicker than the shell plate.

UR-15 Joint Efficiency

(*a*) The efficiency of a riveted joint is the ratio which the working strength of the joint bears to the working strength of the solid plate away from the joint. When the plates of a lap joint are not the same in thickness, the joint efficiency shall be based on the thickness of the thinner plate.

(*b*) The efficiency of a riveted joint is determined by calculating the working strength of a unit length of the joint, considering each possible mode of failure separately, using the allowable stresses specified in UR-11 and UR-12 for net tension, shear, and crushing strength, respectively, or any combination thereof and dividing the lowest result

TABLE UR-14
MINIMUM THICKNESS OF BUTTSTRAPS

Thickness of Shell Plate, in. (without corrosion allowance)	Minimum Thickness[1] of Butt-straps, in.
3/16	3/16
1/4	1/4
9/32	1/4
5/16	1/4
11/32	1/4
3/8	5/16
13/32	5/16
7/16	3/8
15/32	3/8
1/2	7/16
17/32	7/16
9/16	7/16
5/8	1/2
3/4	1/2
7/8	5/8
1	11/16
1 1/8	3/4
1 1/4	7/8

[1]The same corrosion allowance is to be added to the thickness and edges of inside buttstraps as is used for the shell plate.

by the working strength of an equivalent width of the solid plate away from the joint. In calculating joint efficiency, the plate thickness to be used shall be net, after corrosion allowance has been deducted from all plates subject to corrosion. In the computations, the diameter of the rivet shall be assumed as the nominal diameter of the finished holes.

UR-16 Longitudinal Joints

The longitudinal joints of a shell which exceeds 1/2 in. in thickness shall be of a double-strap butt type construction. This rule need not apply to the portion of a shell which is fully staybolted to an inner plate.

UR-17 Circumferential Joints

(*a*) The strength of a circumferential joint in a pressure vessel, the heads of which are not stayed by tubes or through-braces, shall be at least one-half of that required for the longitudinal joint.

(*b*) When the heads in a vessel are stayed by tubes or through-stays which support at least one-half of the load acting on the head, the minimum strength of the circumferential joints in the shell shall be at least one-third of that required for the intersecting longitudinal joint.

UR-18 Lap Joints

(*a*) Longitudinal shell joints and radial head joints of the lap or single-strap butt type, and circumferential joints of the single-riveted lap type, shall not be used for an actual plate thickness exceeding 1/2 in., except as otherwise permitted in (b) and (c), nor for metal temperatures which during normal operation may exceed the limiting temperature prescribed in Subsection C for the material used (see UCS-18 and UNF-18).

(*b*) When a vessel is used for a purpose that makes it necessary to provide in its construction for extraordinary wear, corrosion, or other deterioration in service, and plates of greater thickness are used than would otherwise be required, the longitudinal joints of shells exceeding 1/2 in. in thickness may be lap riveted or single-strapped butt type, provided:

(*1*) The operating pressure does not exceed 50 psi; and

(*2*) The original plate thickness is at least 1.8 times that required for strength; and

(*3*) Telltale holes are drilled as provided in UG-25.

(*c*) The thickness limitations in (a) do not apply to the portion of a shell which is fully staybolted to an inner plate.

UR-19 Bolted Joints

(*a*) Permanent joints in plates made by closely fitted bolting, instead of by riveting, shall be computed in the same manner as for riveted joints (see UR-35).

(*b*) The crushing strength of bolts and plates shall be taken into consideration when designing bolted connections for bolts having high shear strength at elevated temperatures.

UR-20 Transverse Pitch (Back Pitch) of Rows of Rivets

(*a*) The distance between the centerlines of any adjacent rows of rivets in a longitudinal joint, or the back pitch measured at right angles to the direction of the joint, shall have the following minimum values:

(*1*) If p/d is 4 or less, the minimum value shall be $1\frac{3}{4}\ d$;

(*2*) If p/d is over 4, the minimum value shall be $1\frac{3}{4}\ d+0.1\ (p-4d)$;

where

p = pitch of rivets in outer row when a rivet in the inner row comes midway between two rivets in the outer row, inches, or

p = pitch of rivets in the outer row less pitch of rivets in the inner row when two rivets in the inner row come between two rivets in the outer row, inches (it is here assumed that the joints are of the usual construction in which the rivets are symmetrically spaced)

d = nominal diameter of the rivet holes, inches

(*b*) The back pitch *or* rivets in a circumferential joint may be less than that called for in (a), provided the ligaments between rivets in a circumferential direction, and those in a diagonal direction, as determined by the rules in UG-53, have sufficient strength to withstand the maximum combined stress due to the applicable loadings enumerated in UG-22 without exceeding the allowable stress values given in Subsection C.

UR-21 Preparation of Plate Edges

(*a*) The calking edges of plates, buttstraps, and heads shall be beveled to an angle not sharper than 70 deg to the plane of the plate, and as near thereto as practicable.

(*b*) Every portion of the unfinished surfaces of the calking edges of plates, buttstraps, and heads shall be planed, milled, chipped, or ground to a depth of not less than one-fourth of the thickness of the material, but in no case less than 1/8 in.

UR-22 Edge Distance

On longitudinal joints, the distance from the centers of rivet holes to the edges of the plates, except rivet holes in the ends of buttstraps, shall be not less than 1 1/2 times and not more than 1 3/4 times the diameter of the rivet holes; this distance to be measured from the center of the rivet holes to the calking edge of the plate before mechanical calking (see UR-40). The corresponding distance for circumferential seams shall be not less than 1 1/4 times the diameter of the rivet holes.

UR-23 Openings

(*a*) Openings for nozzles and other connections shall be far enough away from any main riveted joint so that the joint and the opening reinforcement plates do not interfere with one another.

(*b*) Welded connections which require postweld heat treatment and which are attached to vessels having seams of riveted construction shall be fabricated and postweld heat treated prior to the

UR-12 Crushing Strength of Plates

The maximum allowable stress for resistance to crushing of plates shall be 160 percent of the maximum allowable stress value prescribed in Subsection C for the material at the operating temperature.

UR-13 Corrosion Allowance

(*a*) Provision shall be made for corrosion in accordance with the requirements in UG-25.

(*b*) The plate thickness in excess of that computed for a seamless vessel, taking into account the applicable loadings in UG-22, may be taken as allowance for corrosion in vessels that have longitudinal joints of double-strap butt-joint construction. Additional corrosion allowance shall be provided when needed, particularly on the inner buttstraps.

(*c*) The use of swell-neck rivets with oversize heads is recommended when anticipated corrosion conditions are such that the loss of metal from standard heads of rivets may impair the strength or tightness of the vessel during its expected life.

UR-14 Thickness of Buttstraps

(*a*) The minimum thickness of a buttstrap for a double-strap riveted joint shall be as given in Table UR-14. Intermediate values may be determined by interpolation. For a shell-plate thickness exceeding $1^1/_4$ in., the thickness of the buttstrap shall be not less than two-thirds of the thickness of the shell plate.

(*b*) The minimum thickness of a buttstrap for a single-strap joint shall be twice that given in Table UR-14, except that on a circumferential joint a buttstrap need not be thicker than the shell plate.

TABLE UR-14
MINIMUM THICKNESS OF BUTTSTRAPS

Thickness of Shell Plate, in. (without corrosion allowance)	Minimum Thickness[1] of Butt-straps, in.
$^3/_{16}$	$^3/_{16}$
$^1/_4$	$^1/_4$
$^9/_{32}$	$^1/_4$
$^5/_{16}$	$^1/_4$
$^{11}/_{32}$	$^1/_4$
$^3/_8$	$^5/_{16}$
$^{13}/_{32}$	$^5/_{16}$
$^7/_{16}$	$^3/_8$
$^{15}/_{32}$	$^3/_8$
$^1/_2$	$^7/_{16}$
$^{17}/_{32}$	$^7/_{16}$
$^9/_{16}$	$^7/_{16}$
$^5/_8$	$^1/_2$
$^3/_4$	$^1/_2$
$^7/_8$	$^5/_8$
1	$^{11}/_{16}$
$1^1/_8$	$^3/_4$
$1^1/_4$	$^7/_8$

[1]The same corrosion allowance is to be added to the thickness and edges of inside buttstraps as is used for the shell plate.

UR-15 Joint Efficiency

(*a*) The efficiency of a riveted joint is the ratio which the working strength of the joint bears to the working strength of the solid plate away from the joint. When the plates of a lap joint are not the same in thickness, the joint efficiency shall be based on the thickness of the thinner plate.

(*b*) The efficiency of a riveted joint is determined by calculating the working strength of a unit length of the joint, considering each possible mode of failure separately, using the allowable stresses specified in UR-11 and UR-12 for net tension, shear, and crushing strength, respectively, or any combination thereof and dividing the lowest result by the working strength of an equivalent width of the solid plate away from the joint. In calculating joint efficiency, the plate thickness to be used shall be net, after corrosion allowance has been deducted from all plates subject to corrosion. In the computations, the diameter of the rivet shall be assumed as the nominal diameter of the finished holes.

UR-16 Longitudinal Joints

The longitudinal joints of a shell which exceeds $^1/_2$ in. in thickness shall be of a double-strap butt type construction. This rule need not apply to the portion of a shell which is fully staybolted to an inner plate.

UR-17 Circumferential Joints

(*a*) The strength of a circumferential joint in a pressure vessel, the heads of which are not stayed by tubes or through-braces, shall be at least one-half of that required for the longitudinal joint.

(*b*) When the heads in a vessel are stayed by tubes or through-stays which support at least one-half of the load acting on the head, the minimum strength of the circumferential joints in the shell shall be at least one-third of that required for the intersecting longitudinal joint.

UR-18 Lap Joints

(*a*) Longitudinal shell joints and radial head joints of the lap or single-strap butt type, and circumferential joints of the single-riveted lap type, shall not be used for an actual plate thickness exceeding $^1/_2$ in., except as otherwise permitted in (b) and (c), nor for metal temperatures which during normal operation may exceed the limiting temperature prescribed in Subsection C for the material used (see UCS-18 and UNF-18).

(*b*) When a vessel is used for a purpose that makes it necessary to provide in its construction for extraordinary wear, corrosion, or other deterioration in service, and plates of greater thickness are used than would otherwise be required, the longitudinal joints of shells exceeding $^1/_2$ in. in thickness may be lap riveted or single-strapped butt type, provided:

(*1*) The operating pressure does not exceed 50 psi; and

(*2*) The original plate thickness is at least 1.8 times that required for strength; and

(*3*) Telltale holes are drilled as provided in UG-25.

(*c*) The thickness limitations in (a) do not apply to the portion of a shell which is fully staybolted to an inner plate.

UR-19 Bolted Joints

(*a*) Permanent joints in plates made by closely fitted bolting, instead of by riveting, shall be computed in the same manner as for riveted joints (see UR-35).

(*b*) The crushing strength of bolts and plates shall be taken into consideration when designing bolted connections for bolts having high shear strength at elevated temperatures.

UR-20 Transverse Pitch (Back Pitch) of Rows of Rivets

(*a*) The distance between the centerlines of any adjacent rows of rivets in a longitudinal joint, or the back pitch measured at right angles to the direction of the joint, shall have the following minimum values:

(*1*) If p/d is 4 or less, the minimum value shall be $1^3/_4\ d$;

(*2*) If p/d is over 4, the minimum value shall be $1^3/_4\ d+0.1\ (p-4d)$;

where

p = pitch of rivets in outer row when a rivet in the inner row comes midway between two rivets in the outer row, inches, or

p = pitch of rivets in the outer row less pitch of rivets in the inner row when two rivets in the inner row come between two rivets in the outer row, inches (it is here assumed that the joints are of the usual construction in which the rivets are symmetrically spaced)

d = nominal diameter of the rivet holes, inches

(*b*) The back pitch *or* rivets in a circumferential joint may be less than that called for in (a), provided the ligaments between rivets in a circumferential direction, and those in a diagonal direction, as determined by the rules in UG-53, have sufficient strength to withstand the maximum combined stress due to the applicable loadings enumerated in UG-22 without exceeding the allowable stress values given in Subsection C.

UR-21 Preparation of Plate Edges

(*a*) The calking edges of plates, buttstraps, and heads shall be beveled to an angle not sharper than 70 deg to the plane of the plate, and as near thereto as practicable.

(*b*) Every portion of the unfinished surfaces of the calking edges of plates, buttstraps, and heads shall be planed, milled, chipped, or ground to a depth of not less than one-fourth of the thickness of the material, but in no case less than $^1/_8$ in.

UR-22 Edge Distance

On longitudinal joints, the distance from the centers of rivet holes to the edges of the plates, except rivet holes in the ends of buttstraps, shall be not less than $1^1/_2$ times and not more than $1^3/_4$ times the diameter of the rivet holes; this distance to be measured from the center of the rivet holes to the calking edge of the plate before mechanical calking (see UR-40). The corresponding distance for circumferential seams shall be not less than $1^1/_4$ times the diameter of the rivet holes.

UR-23 Openings

(*a*) Openings for nozzles and other connections shall be far enough away from any main riveted joint so that the joint and the opening reinforcement plates do not interfere with one another.

(*b*) Welded connections which require postweld heat treatment and which are attached to vessels having seams of riveted construction shall be fabricated and postweld heat treated prior to the

making up or attachment of the courses by riveting. If they do not require postweld heat treatment and are attached after riveting, the welds shall be located at a distance from the riveted seam at least equal to the outside diameter of the attachment weld plus four times the thickness of the shell plate.

(*c*) Openings for pipe connections to vessels having riveted joints may be made by inserting pipe couplings or similar devices, not exceeding 3-in. pipe size, in the shell or heads and securing them by welding, without necessitating the application of the restrictive stamping provisions of UG-116, provided the welding is performed by welders or welding operators who have been qualified under the provisions of Section IX of the Code for the welding position and type of joint used.

UR-24 Nozzles

(*a*) Nozzles may be integral or attached to the vessel by any of the methods provided for in UG-43.

(*b*) For nozzle fittings having a bolting flange and an integral flange for riveting, the thickness of the flange attached to the pressure vessel shall not be less than the thickness of the neck of the fitting.

UR-25 Reinforcement of Openings

(*a*) The area of reinforcement shall be calculated by the rules in UG-36 through UG-43.

(*b*) The thickness of each independent riveted reinforcing flange or ring shall not be less than given in Table UR-25.

(*c*) The strength of rivets in tension in a flanged frame or ring riveted to the outside of a vessel shall be at least equal to that required to resist the load due to the maximum allowable working pressure computed as follows:

(*1*) For outside calking the load shall be equal to the area bounded by the outside calking multiplied by the maximum allowable working pressure;

(*2*) For inside calking (and with no outside calking) the load shall be equal to the area bounded by the inside calking multiplied by the maximum allowable working pressure.

(*d*) The rivets attaching nozzles shall be so spaced as to avoid the possibility of the shell plate or the nozzle flange failing by tearing around through the rivet holes. This feature shall be checked by applying the rules given in UG-53.

UR-26 Lugs and Brackets

Shearing and crushing stresses in rivets used for attaching lugs or brackets shall not exceed 40 percent of the maximum allowable stresses permitted in UR-11 and UR-12.

FABRICATION

UR-30 General

The rules in the following paragraphs apply specifically to the fabrication of pressure vessels and vessel parts that are fabricated by riveting and shall be used in conjunction with the general requirements for *Fabrication* in Subsection A, and with the specific requirements for *Fabrication* in Subsection C that pertain to the class of material used.

UR-31 Buttstraps

(*a*) Buttstraps shall be formed to the curvature of the shell with which they are to be used (see UG-79).

(*b*) When the buttstrap of a longitudinal joint does not extend the full length of a shell section, the abutting edges of the shell plate may be welded provided the length of the weld between the end of the buttstrap and the edge of the head or adjoining shell plate is not greater than $2^1/_2$ in. When so constructed, the restrictive stamping provisions of UG-116 shall not apply provided the welding is performed by welders who have been qualified under the provisions of Section IX for the welding position and type of joint used.

TABLE UR-25
MINIMUM THICKNESS OF INDEPENDENT RIVETED REINFORCING RINGS OR FLANGES

Thickness of Shell Plate, in.	Thickness of Reinforcing Ring or Flange, in.
$^1/_8$	$^1/_8$
$^3/_{16}$	$^3/_{16}$
$^1/_4$ to $^{11}/_{32}$	$^1/_4$
$^3/_8$ to $^{13}/_{32}$	$^5/_{16}$
$^7/_{16}$ to $^{15}/_{32}$	$^3/_8$
$^1/_2$ to $^9/_{16}$	$^7/_{16}$
$^5/_8$ to $^3/_4$	$^1/_2$
$^7/_8$	$^5/_8$
1	$^{11}/_{16}$
$1^1/_8$ to 2	$^3/_4$
Over 2	1

UR-32 Rivet and Staybolt Holes

(*a*) All holes for rivets or staybolts in plates, heads and attachments to the vessel wall shall be drilled to size after assembly except as follows:

(*1*) Rivet holes may be subdrilled before assembly and reamed to size after the parts have been firmly bolted in position with tack bolts. The finished holes shall be true, clean, and concentric;

(*2*) In plates or heads not more than $^5/_{16}$ in. in thickness, holes for rivets may be subpunched at least $^1/_8$ in. less than finished diameter; and, in plates or heads more than $^5/_{16}$ in. but not more than $^5/_8$ in. in thickness, holes for rivets may be subpunched at least $^1/_4$ in. less than the finished diameter. Rivet holes subpunched before assembly shall be reamed to size after the parts have been firmly bolted in position with tack bolts.

(*b*) Rivet holes for swell-neck or countersunk rivets as used for corrosive contents shall be countersunk on the inside of the vessel.

UR-33 Tolerance on Rivet Holes

(*a*) *Hot Driven Rivets.* The diameter of the rivet hole when drilled or reamed shall not exceed the diameter of the rivet when cold by more than $^1/_{16}$ in. For rivets up to $^7/_{16}$ in. diameter it is preferable to limit the diameter of the hole to $^1/_{32}$ in. greater than the rivet diameter when cold.

(*b*) *Cold Driven Rivets.* The diameter of the hole when drilled or reamed shall not exceed the diameter of the rivet by more than $^1/_{32}$ in.

UR-34 Chamfering Rivet Holes

(*a*) All rivet holes shall be chamfered to remove burrs and chips after drilling or reaming.

(*b*) In vessels for use at metal temperatures at which the allowable stress value is less than its allowable stress value at 100 F, or for use at working pressures above 150 psi, the edges of rivet holes for rivets 1 in. or over in diameter shall be chamfered approximately $^3/_{32}$ in. to avoid a sharp edge under the head. The edges of rivet holes for rivets under 1 in. in diameter shall be chamfered approximately $^1/_{32}$ in.

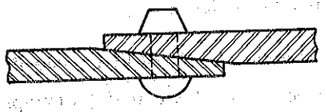


FIG. UR-38 TAPERED CIRCUMFERENTIAL JOINT: TAPERED CIRCUMFERENTIAL JOINT CONNECTION MAY BE USED FOR SEAMLESS AND WELDED RINGS AND FOR HEADS TO SEAMLESS, WELDED, OR RIVETED RINGS

UR-35 Holes for Bolted Joints

Bolt holes for permanent joints or for attaching permanent fixtures shall be carefully reamed to not more than 0.02 in. larger than the bolt as finished, or bolts may be machined to a light-drive fit in reamed holes. Bolt holes may be countersunk to an angle of not less than 30 deg to the axis of the hole when the bolt heads are so formed.

UR-36 Postweld Heat Treatment

Any heat treatment required for parts of riveted vessels shall be completed before riveting.

UR-37 Assembly of Joints

(*a*) All parts assembled for riveting shall have contact surfaces free from scale, chips, or other foreign material.

(*b*) Before riveting, parts shall be securely bolted together at intervals in order to bring surfaces into close contact and to prevent creeping during riveting.

(*c*) Holes shall be made fair by reaming only; drifting of holes is not permitted.

UR-38 Assembly of Circumferential Joints

(*a*) The inside circumference of an outside course or head shall not exceed the outside circumference of an inside course or head by more than one-fourth of one percent (1/400) of the diameter of the shell, the circumference to be measured before the longitudinal joint is riveted.

(*b*) Circumferential joints shall preferably be made with a shrink fit, especially for seamless rings. If rings or heads are machined to obtain a proper fit, rounded fillets shall be provided at the inner edge of the cut.

(*c*) Circumferential joints may be machined to a slight taper to facilitate fitting as shown in Fig. UR-38. Such tapered joints shall be assembled with a light-drive or shrink fit. The combined thickness of the plates at the rivets shall not be less than three-fourths of the sum of the plate thicknesses.

UR-39 Riveting

(*a*) All mill scale shall be removed from rivets before they are inserted in the holes. All rivets $^5/_8$ in. nominal diameter and larger shall be driven hot. All rivets shall be driven to completely fill the rivet holes and to form a full head as specified in the design without showing any depression from the dies in the plate or fitting. Some acceptable forms

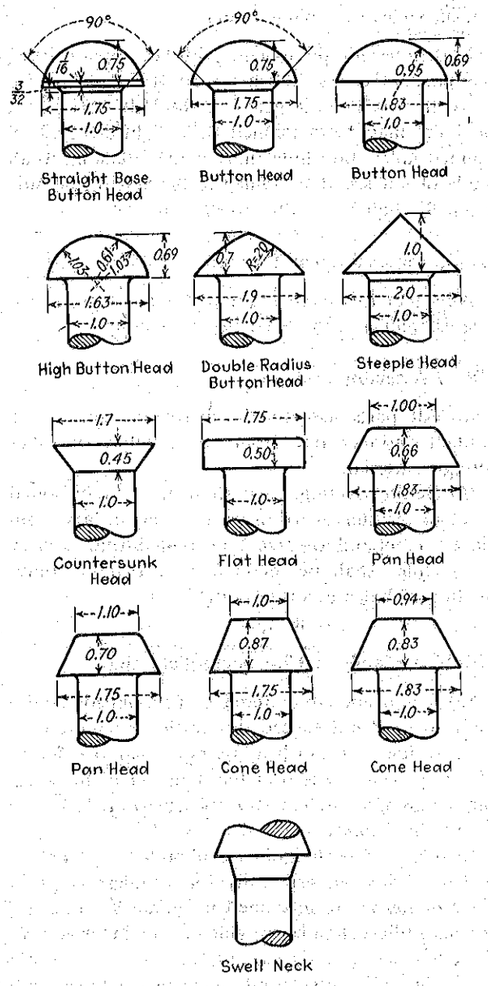


FIG. UR-39 ACCEPTABLE FORMS OF RIVET HEADS AFTER DRIVING

of rivet heads are shown in Fig. UR-39. No driven rivet head shall have an eccentricity of more than 10 percent of the nominal diameter of the rivet. All rivets shall preferably be driven with a pressure riveting device. Pressure shall be applied to hot-driven rivets sufficiently long to permit shrinkage in cooling while under pressure. All rivets not driven with a pressure riveting device shall be driven with a pneumatic riveting hammer. Rivets over $^{7}/_{8}$ in. in nominal diameter shall preferably be driven with pneumatic riveting hammers used on both ends of the rivet simultaneously.

(*b*) Rivets which do not meet the requirements given above shall be removed and replaced by new rivets.

UR-40 Joint Tightness

(*a*) Joints may be made tight by mechanical calking before or during the preliminary hydrostatic test. The calking shall be done with a tool of such form that there is no danger of scoring or damaging the plate underneath the calking edge, or of splitting the calked plate. No foreign material shall be used between the calked plates for the purpose of making a joint tight.

(*b*) Welding may be used to seal the calking edges of riveted plate joints, nozzles and their reinforcements, the edges of stiffening rings at the contact surface, and the edges of all rivets and bolt heads, either inside or outside, provided the carbon content of steel plates does not exceed 0.35 percent. The seal welding shall be done after the vessel has successfully passed a preliminary hydrostatic test at the pressure required for the final hydrostatic test.

(*c*) Seal welding shall be applied either in a single or a double layer so as to have a throat dimension not less than $^{3}/_{16}$ in. nor more than $^{5}/_{16}$ in.

INSPECTION AND TESTS

UR-50 General

The rules in the following paragraphs apply specifically to the inspection and testing of pressure vessels and vessel parts that are fabricated by riveting and shall be used in conjunction with the general requirements for *Inspection and Tests* in Subsection A, and with the specific requirements for *Inspection and Tests* in Subsection C that pertain to the class of material used.

UR-51 Inspection During Fabrication

The Inspector shall assure himself that the rivet holes are properly reamed and that each vessel is subjected to the prescribed hydrostatic or pneumatic test and is tight under such test.

UR-52 Curvature and Fit of Plates and Buttstraps

The Inspector shall see that buttstraps and the ends of shell plates forming the longitudinal joints are formed to the proper curvature and that the buttstraps are properly fitted, particularly at the girth joint intersections.

UR-53 Inspection of Rivets and Bolts

Before rivets and bolts are used, the Inspector shall satisfy himself that they are free from injurious defects and that rivets are of sufficient length to completely fill the rivet holes and give a full rivet head.

UR-54 Rivet Holes

The Inspector shall see that all rivet holes are in accordance with this Division, that all holes after reaming are fair, and that all burrs and chips are removed. When drilling the holes is required, the Inspector shall satisfy himself that they have been drilled. Before holes are reamed, the Inspector shall see that burrs are removed between the plates, that the plates are laid up tightly together, and are held by sufficient bolts before riveting is started. If swell-neck or countersunk rivets are to be used, the Inspector shall see that the rivet holes are properly countersunk.

UR-55 Rivets

(*a*) The Inspector shall test the tightness with which the rivets fill the holes by tapping the heads with a rivet-testing hammer while holding a finger against one side of the rivet head next to the plate.

(*b*) Loose, cracked, and burned rivets shall be replaced.

STAMPING AND REPORTS

UR-60 General

The provisions for stamping and reports given in UG-115 through UG-120 shall apply without supplement to riveted pressure vessels.

PRESSURE RELIEF DEVICES

UR-65 General

The provisions for pressure relief devices given in UG-125 through UG-134 shall apply without supplement to riveted pressure vessels.

PART UF

REQUIREMENTS FOR PRESSURE VESSELS FABRICATED BY FORGING

GENERAL

UF-1 Scope

The rules in Part UF are applicable to forged pressure vessels without longitudinal joints, including their component parts that are fabricated of carbon and low-alloy steels or of high-alloy steels within the limitations of Part UHA. These rules shall be used in conjunction with the applicable requirements in Subsection A, and with the specific requirements in Subsection C that pertain to the respective classes of all materials used.

MATERIALS

UF-5 General

(*a*) Materials used in the construction of forged pressure vessels shall comply with the requirements for materials given in UG-5 through UG-14, except as specifically limited or extended in (b) and (c), and in UF-6.

(*b*) The ladle analysis of forgings to be fabricated by welding shall not exceed carbon 0.35 percent. When the welding, however, involves only minor nonpressure attachments as limited in UF-32, seal welding of threaded connections, as permitted in UF-43, or repairs as limited by UF-37, the carbon content shall not exceed 0.50 percent by ladle analysis. When by ladle analysis the carbon analysis exceeds 0.50 percent no welding is permitted.

(*c*) Materials, other than austenitic steels, subjected to liquid quench and temper heat treatment shall be fabricated without welding or brazing except as otherwise provided in this Division.

UF-6 Forgings

Vessels, main sections of vessels, and other pressure parts shall conform to one of the following:

(*1*) Forging specifications SA-105, SA-181, SA-182, SA-266, SA-336, SA-350, or SA-372.

(*2*) One of the specifications listed in Table UCS-23 or Table UHA-23 for plates, seamless pipe, or seamless tube when such material is further processed by a forging operation.

DESIGN

UF-12 General

The rules in the following paragraphs apply specifically to vessels or main sections of vessels that are forged from ingots, slabs, billets, plate, pipe, or tubes, and shall be used to supplement the requirements for design which are applicable, as given in UG-16 through UG-55, and those given in UCS-16 through UCS-67, and UHA-20 through UHA-34. Sections of vessels may be joined by any method permitted in the several parts of this Division except as limited in UF-5(b) and UF-5(c).

Vessels constructed of SA-372 Classes III, IV or V materials must be of streamlined design, and stress raisers such as abrupt changes in section shall be minimized. Openings in vessels constructed of liquid quenched and tempered materials, other than austenitic steel, shall be reinforced in accordance with UG-37; UG-36(c)(3) shall not apply.

UF-13 Head Design

(*a*) The minimum required thickness of forged heads shall be computed using the formulas of UG-32. When heads are made separate from the body forging they may be attached by any method permitted in the several parts of this Division except as limited in UF-5(b) and UF-5(c).

(*b*) The juncture of a forged conical head with the body shall be a knuckle, the inside radius of which shall be not less than 6 percent of the internal diameter of the vessel. The thickness at the knuckle shall be not less than that of the cylinder and shall be faired into that of the head at the base of the cone.

(*c*) Except for the $3t$ requirements in UG-32(j) the design of the head shall comply with the applicable provisions of UG-32, UG-33, UG-34, and UA-6.

UF-25 Corrosion Allowance

(*a*) Provision shall be made for corrosion in accordance with the requirements in UG-25.

FABRICATION

UF-26 General

The rules in the following paragraphs apply specifically to forged vessels, main sections of vessels and other vessel parts, and shall be used to supplement the applicable requirements for fabrication given in UG-75 through UG-84 and UCS-79. For high-alloy steel forged vessels, the applicable paragraphs of Part UHA shall also apply.

UF-27 Tolerances on Body Forgings

(*a*) The inner surface of the body shall be true-to-round to the degree that the maximum difference between any two diameters at 90 deg to each other, determined for any critical cross section, does not exceed 1 percent of the mean diameter at that section. Chip marks and minor depressions in the inner surface may be filled by welding to meet these tolerances when the welding is done as permitted in UF-32.

(*b*) If out-of-roundness exceeds the limit in (a) and the condition cannot be corrected, the forging shall be rejected except that if the out-of-roundness does not exceed 3 percent, the forging may be certified for a lower pressure in the formula:

$$\text{Reduced pressure } P' = P\left[\frac{1.25}{\frac{S_b}{S}+1}\right]$$

$$\text{and in which } S_b = \frac{1.5\,P\,R_1 t(D_1-D_2)}{t^3+3\frac{P}{E}R_1R_a^2}$$

P = maximum allowable working pressure for forging meeting the requirements of (a), pounds per square inch

t = the average (mean) thickness, inches

D_1 and D_2 = respectively the inside diameters, maximum and minimum, as measured for the critical section, and for one additional section in each direction therefrom at a distance not exceeding $0.2D_2$. The average of the three readings for D_1 and D_2 respectively shall be inserted in the formula

S_b = bending stress, pounds per square inch at metal service temperature

E = modulus of elasticity. For ferritic steels $=29\times10^6$; for austenitic steels $=28\times10^6$; to be corrected for metal service temperature (see Fig. UF-27)

S = design stress value, pounds per square inch, at metal service temperature

$R_1 = \frac{1}{4}\ (D_1+D_2)$ = average inside radius at critical section, inches

$R_a = \frac{1}{4}\ (D_1+D_2)+t/2$ = average radius to middle of shell wall at critical section, inches

NOTE 1: Use $P'=P$ when S_b is less than $0.25S$.
NOTE 2: In all measurements, correct for corrosion allowance if specified.

UF-28 Methods of Forming Forged Heads

Forged heads shall be made either by closing in extensions of the body of such shape and dimensions as may be required to produce the final form desired, or by separate forgings (see UF-13(a)).

UF-29 Tolerance on Forged Heads

Forged heads shall be as true as it is practicable to make them to the shape shown on the design drawings. Any deviations therefrom shall merge smoothly into the general shape of the head and shall not evidence a decrease of strength for the sections as required by the formulas for design.

UF-30 Localized Thin Areas

Forgings are permitted to have small areas thinner than required if the adjacent areas surrounding each has sufficient thickness to provide the necessary reinforcement according to the rules for reinforcement in UG-40.

UF-31 Heat Treatment

(*a*) *Normalized or Annealed Material*

(*1*) After all forging is completed, each vessel or forged part fabricated without welding shall be heat treated in accordance with the applicable material specification. When defects are repaired by welding, subsequent heat treatment may be necessary in accordance with UF-37(b).

(*2*) Vessels fabricated by welding of forged parts requiring heat treatment shall be heat treated in accordance with the applicable material specification as follows:

(a) After all welding is completed, or

(b) Prior to welding, followed by postweld heat treatment of the finished weld in accordance with UW-40.

(c) When the welding involves only minor nonpressure attachments to vessels having carbon content exceeding 0.35 percent but not exceeding 0.50 percent by ladle analysis, requirements of UF-32(b) shall govern.

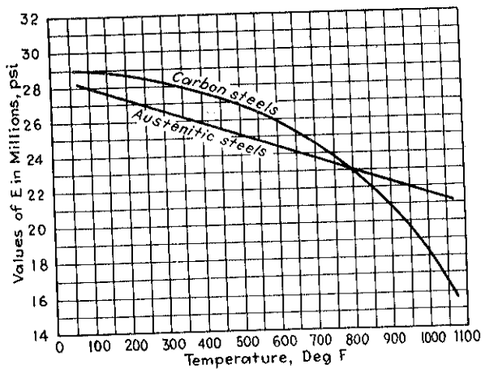


FIG. UF-27 MODULUS OF ELASTICITY—DESIGN VALUES

(*b*) *Liquid Quenched Material*

(*1*) Vessels fabricated by forging material to be liquid quenched and tempered shall be subjected to this heat treatment in accordance with the applicable material specifications after the completion of all forging, welding of nonpressure attachments as permitted by UF-32 and repair welding as limited by UF-37. Seal welding of threaded connections as permitted in UF-43 may be performed either before or after this heat treatment. (Quenching medium must be oil for vessels fabricated from SA-372 material.)

(a) After final heat treatment, such vessels shall be examined for the presence of cracks on the outside surface of the shell portion and on the inside surface where practicable. This examination shall be made by liquid penetrant when the material is nonmagnetic and by liquid penetrant or magnetic particle examination when the material is ferromagnetic.

(b) After final heat treatment, liquid quenched and tempered vessels, except those made of austenitic steels, shall be subjected to Brinell hardness tests at 5 ft intervals with a minimum of four readings at each of not less than three different sections representing approximately the center and each end of the heat treated shell. The average of the individual Brinell hardness numbers at each section shall be not less than 10 percent below nor more than 25 percent above the number obtained by dividing 500 into the specified minimum tensile strength of the material, and the highest average hardness number shall not exceed the lowest average value on an individual vessel by more than 40.

NOTE: Other hardness testing methods may be used and converted to Brinell numbers by means of the Table in ASTM E-140-58.

Reheat treatment is permitted.

(c) In the case of austenitic steels, the heat treatment procedures followed shall be in accordance with UHA-32.

(c) *Non-Heat Treated Material.* Postweld heat treatment of vessels fabricated by welding of forged parts not requiring heat treatment shall meet with the requirements of UCS-56.

UF-32 Welding for Fabrication

(a) Vessels which are constructed of material other than austenitic steel and which have been liquid quenched and tempered shall be fabricated without welding or brazing, except as otherwise provided in the Division.

(b) All welding used in connection with the fabrication of forged vessels or components shall comply with the applicable requirements of Parts UW, UCS, and UHA, and UF-5(b) except as modified in UF-32(c). Procedure qualification in accordance with Section IX shall be performed with the heat treatment condition of the base metal and weld metal as in UF-31 as contemplated for the actual work.

(c) When the carbon content of the material exceeds 0.35 percent by ladle analysis, the vessel or part shall be fabricated without welding of any kind, except for repairs (see UF-37(b)), for seal welding of threaded connections as permitted in UF-43, and for minor nonpressure attachments. Minor nonpressure attachments shall be joined by fillet welds of not over ¼ in. throat dimensions. Such welding shall be allowed under the following conditions:

(1) The suitability of the electrode and procedure shall be established by making a groove weld specimen as shown in Fig. Q-3 of Section IX in material of the same analysis and of thickness in conformance with Table Q-13. The specimen before welding shall be in the same condition of heat treatment as the work it represents and after welding the specimen shall be subjected to heat treatment equivalent to that contemplated for the work. Tensile and bend tests, as shown in Figs. Q-6 and Q-7 (Figs. Q-7.1 and Q-7.2 respectively), shall be made. These tests shall meet the requirements of Q-6 and Q-8 of section IX. The radius of the mandrel used in the guided bend test shall be as follows:

Specimen Thickness	Radius of Mandrel (B)*	Radius of Die (D)*
⅜ in.	1½ in.	1 11/16 in.
t	3⅓ t	4⅓ t + 1/16 in.

* Corresponds to dimensions B and D in Fig. Q-8 in Section IX, and other dimensions to be in proportion.

Any cutting and gouging processes used in the repair work shall be included as part of the procedure qualification.

(2) Welders shall be qualified for fillet welding specified by making and testing a specimen in accordance with Fig. Q-9(a) and Q-9 of Section IX. Welders shall be qualified for repair welding by making a test plate in accordance with Fig. Q-3 from which the bend tests outlined in Table Q-24 shall be made. The electrode used in making these tests shall be of the same classification number as that specified in the procedure. The material for these tests can be carbon steel plate or pipe provided the test specimens are preheated, welded and postheated in accordance with the procedure specification for the type of electrode involved.

(3) The finished weld shall be postweld heat treated or given a further heat treatment as required by the applicable material specification. The types of welding permitted in UF-32(c) shall be performed prior to final heat treatment except for seal welding of threaded openings which may be performed either before or after final heat treatment.

(4) The finished welds shall be examined after postweld heat treatment by liquid penetrant when the material is nonmagnetic and by liquid penetrant or magnetic particle examination using the prod method when the material is ferromagnetic.

UF-37 Repair of Defects in Material

(a) Surface imperfections such as chip marks, blemishes, or other irregularities shall be removed by grinding or machining and the surface exposed shall be blended smoothly into the adjacent area where sufficient wall thickness permits thin areas in compliance with the requirements of UF-30.

(b) Thinning to remove defects beyond those permitted in UF-30 may be repaired by welding, only after approval by the Inspector. Defects shall be removed to sound metal as shown by acid etch or any other suitable method of examination. The welding shall be as outlined below:

(1) Material having carbon content of 0.35 percent or less (by ladle analysis).

(a) The welding procedure and welders shall be qualified in accordance with Section IX.

(b) Postweld heat treatment after welding shall be governed as follows:

(1) All welding shall be postweld heat treated if UCS-56 requires postweld heat treatment, for all thicknesses of material of the analysis being used.

(2) Fillet welds need not be postweld heat treated unless required by (1) or unless the fillet welds exceed the limits given in UCS-56.

(3) Repair welding shall be postweld heat treated when required by UF-37(6)(1) or if it exceeds 6 sq in. at any spot or if the maximum depth exceeds ¼ in.

(c) Repair welding shall be radiographed if the maximum depth exceeds ⅜ in. Repair welds ⅜ in. and under in depth which exceed 6 sq in. at any spot and those made in materials requiring postweld heat treatment shall be examined by radiographing, magnetic particle or liquid penetrant examination, or any alternative method suitable for determining cracks.

(d) For liquid quenched and tempered steels, other than austenitic steels, welding repairs shall be in accordance with UF-37(b)(3).

(2) Material having carbon content over 0.35 percent (by ladle analysis).

(a) Welding repairs shall conform with UF-32(c) except that if the maximum weld depth exceeds ¼ in., radiography, in addition to magnetic particle or liquid penetrant examination, shall be used.

(b) For liquid quenched and tempered steels, other than austenitic steel, welding repair shall be in accordance with UF-37(b)(3).

(3) Welding repairs of materials which are to be or have been liquid quenched and tempered, regardless of depth or area of repairs shall have the repaired area radiographed and examined by magnetic particle or liquid penetrant examination.

UF-38 Repair of Weld Defects

The repair of welds of forging having carbon content not exceeding 0.35 percent by ladle analysis shall follow the requirements of UW-38.

UF-43 Attachment of Threaded Nozzles to Integrally Forged Necks and Thickened Heads on Vessels

Threaded openings, over 3-in. pipe size, but not exceeding the smaller of one-half of the vessel diameter or 8-in. pipe size, may be used in the heads of vessels having integrally forged heads and necks that are so shaped and thickened as to provide a center opening, which shall meet the rules governing openings and reinforcements contained elsewhere in the code. Length of thread shall be calculated for the opening design, but shall not be less than shown in Table UG-43. Threaded connections employing straight threads shall provide for mechanical seating of the assembly by a shoulder or similar means. When seal welding is employed in the installation of a threaded nozzle, the work shall be performed and inspected in the shop of the vessel manufacturer. Seal welding shall comply with UF-32.

INSPECTION AND TESTS

UF-45 General

The rules in the following paragraphs apply specifically to the inspection and testing of forged vessels and their component parts. These rules shall be used to supplement the applicable requirements for inspection and tests given in UG-90 through UG-102. All forged vessels shall be examined as manufacture proceeds, to assure freedom from loose scale, gouges or grooves, and cracks or seams that are visible. After fabrication has passed the machining stage, the vessel body shall be measured at suitable intervals along its length to get a record of variations in wall thickness, and the nozzles for connecting piping and other important details shall be checked for conformity to the design dimensions.

UF-46 Approval by Inspector

Surfaces which are not to be machined shall be carefully inspected for visible defects such as seams, laps, or folds. On surfaces to be machined the inspection shall be made after machining. Regions from which defective material has been removed shall be inspected after removal and again after any necessary repair.

UF-47 Parts Forging

(a) When welding is used in the fabrication of parts forgings completed elsewhere, the parts forging manufacturer shall furnish a partial data report Form U-2.

(b) All parts forgings completed elsewhere shall be marked with the manufacturer's name and the forging identification, including material designation. Should identifying marks be obliterated in the fabrication process, and for small parts, other means of identification shall be used. The forging manufacturer shall furnish reports of chemical and

mechanical properties of the material and certification that each forging conforms to all requirements of Part UF.

(*c*) Parts forgings furnished as material for which parts data reports are not required need not be inspected at the plant of the forging manufacturer, but the manufacturer shall furnish a report of the extent and location of any repairs together with certification that they were made in accordance with all other requirements of UF-37 and UF-38. If desired, welding repairs of such forgings may be made, inspected, and tested at the shop of the pressure vessel manufacturer.

UF-52 Check of Heat Treatment and Postweld Heat Treatment

The Inspector shall check the provisions made for heat treatment to assure himself that the heat treatment is carried out in accordance with provisions of UF-31 and UF-32. He shall also assure himself that postweld heat treatment is done after repair welding when required under the rules of UF-37.

UF-53 Test Specimens

When test specimens are to be taken under the applicable specification, the Inspector shall be allowed to witness the selection, place the identifying stamping on them, and witness the testing of these specimens.

UF-54 Tests and Retests

Tests and retests shall be made in accordance with the requirements of the material specification.

STAMPING AND REPORTS

UF-115 General

The rules of UG-115 through UG-120 shall apply to forged vessels as far as practicable. Vessels constructed of liquid quenched and tempered material, other than austenitic steels, shall be stamped on the thickened head, unless a nameplate is used.

All data reports shall show the heat number or numbers and ladle analysis of the metal in the ingot from which the vessel was forged, the test results obtained for the forging, and the dimensions of the forged vessel.

PRESSURE RELIEF DEVICES

UF-125 General

The provisions for pressure relief devices of UG-125 through UG-134 shall apply without supplement.

PART UB

REQUIREMENTS FOR PRESSURE VESSELS FABRICATED BY BRAZING

GENERAL

UB-1 Scope

(*a*) The rules in Part UB are applicable to pressure vessels and parts thereof that are fabricated by brazing and shall be used in conjunction with the general requirements in Subsection A, and with the specific requirements in Subsection C that pertain to the class of material used.

(*b*) *Definition.* The term brazing as used in Part UB is defined as a metal joining process wherein coalescence is produced by heating to suitable temperatures above 800 F and by using a nonferrous filler metal, having a melting point below that of the base metals. The filler metal is distributed between the closely fitted surfaces of the joint by capillary attraction.

(*c*) Specific brazing processes which are permitted for use under this Division are classified by method of heating as follows:

Torch brazing
Furnace brazing
Induction brazing
Electrical resistance brazing
Dip brazing—salt and flux bath

UB-2 Elevated Temperature

Operating temperature is dependent on the brazing filler metal as well as on the base metals being joined. The maximum allowable operating temperatures for the brazing filler metals are shown in Table UB-2.

MATERIALS

UB-5 General

(*a*) Materials used in the construction of pressure vessels and parts thereof by brazing shall conform to the specifications in Section II of the Code, and shall be limited to those materials for which allowable stress values have been assigned in Subsection C. The materials being brazed shall be of proved brazing quality with the brazing filler metal employed. Satisfactory qualification of the brazing procedure under Section IX of the Code is considered proof of acceptable material for brazed construction for operating temperatures not exceeding 200 F. For operating temperatures above 200 F to the limits shown in Table UB-2, the requirements in UB-12 shall also be met.

(*b*) Combinations of dissimilar metals may be joined by brazing provided they meet the qualification requirements of Section IX, and the additional requirements of UB-12 when applicable.

UB-6 Brazing Filler Metals

Brazing filler metals used in the construction of pressure vessels and parts thereof by brazing shall conform to Specification SB-260. The selection of the brazing filler metal for a specific application shall depend upon its suitability for the base metals being joined. Satisfactory qualification of the brazing procedure under Section IX of the Code is considered proof of the suitability of the filler metal for operating temperatures not exceeding 200 F. For operating temperatures above 200 F to the limits of Table UB-2, Par. UB-12 shall also be met.

UB-7 Fluxes and Atmosphere

Suitable fluxes or atmosphere or combinations of fluxes and atmospheres shall be used to prevent oxidation of the brazing filler metal and the surfaces to be joined. Satisfactory qualification of the brazing procedure under Section IX of the Code is considered proof of the suitability of the flux and/or atmosphere.

DESIGN

UB-9 General

The rules in the following paragraphs apply specifically to pressure vessels and parts thereof that are fabricated by brazing and shall be used in conjunction with the general requirements for *Design* in Subsection A, and the specific requirements for *Design* in Subsection C that pertain to the class of material used.

UB-10 Strength of Brazed Joints

It is the responsibility of the designer to determine from suitable tests or from past experience that the specific brazing filler metal selected can produce a joint which will have adequate strength over the operating temperature range. The strength of the brazed joint shall not be less than the strength of the base metal, or the weaker of two base metals in the case of dissimilar metal joints, for all temperature within the operating range.

UB-11 Room Temperature

Satisfactory qualification of the brazing procedure in accordance with Section IX, Part C of the Code is considered satisfactory proof of the adequacy of the base materials, the brazing filler metal, the flux and/or atmosphere, and other variables of the procedure for service not exceeding 200 F.

UB-12 Temperatures Above 200 F

For service temperatures above 200 F to the limits shown in Column 1 of the Table UB-2, procedure qualification tests in addition to those required in UB-10 and UB-11 and Section IX are required and shall be considered a part of the qualification procedure. For such service temperatures, the following tests are required at no more than 100 F increments to and including the design temperature:

(*1*) A tensile test of the joint, the resulting tensile strength and yield strength of which shall not be less than the minimum tensile strength or yield strength of the weaker of the base materials at the test temperature.

(*2*) If the design stress of one of the base materials is based on creep or rupture properties at the design temperature, creep or rupture tests shall be performed to determine that the creep or rupture strength of the joint is no less than that of the weaker of the two base metals. (See Appendices P and Q.)

The substantiating test data shall be recorded and

TABLE UB-2
MAXIMUM OPERATING TEMPERATURES FOR BRAZING FILLER METAL

SB-260 Filler Metal Classification	Column 1 Maximum Allowable Operating Temperature °F Based on Complete Design Data[1]	Column 2 Maximum Allowable Operating Temperature °F Based on Brazing Qualification[2]
B Cu P (Group)	300	200
B Ag (Group)	400	200
B Cu Zn (Group)	400	200
B Cu	400	200
B AlSi	400	200

[1]See UB-5 and UB-12.
[2]See UB-5 and UB-11.

the record of any tests shall be made available to the authorized Inspector.

UB-13 Corrosion

(*a*) Provision shall be made for corrosion in accordance with the requirements in UG-25.

(*b*) Corrosion of the brazing filler metal and galvanic action between the brazing filler metal and the base metals shall be considered in selecting the brazing filler metal.

(*c*) The plate thickness in excess of that computed for a seamless vessel taking into account the applicable loadings in UG-22 may be taken as allowance for corrosion in vessels that have longitudinal joints of double-strap butt-joint construction. Additional corrosion allowance shall be provided when needed, particularly on the inner buttstraps.

(*d*) The rules in this Part are not intended to apply to brazing used for the attachment of linings of corrosion resistant material that are not counted on to carry load.

UB-14 Joint Efficiency Factors

(*a*) The joint efficiency factor to be used in the design of pressure vessels and parts thereof shall be 1.0 for joints in which visual examination assures that the brazing filler metal has penetrated the entire joint (see Fig. UB-14(a)).

(*b*) The joint efficiency factor to be used in the design of pressure vessels and parts thereof shall be 0.5 for joints in which visual examination will not provide proof that the brazing filler metal has penetrated the entire joint. (See Fig. UB-14(b), Par. UB-15(b) and (c).

UB-15 Application of Brazing Filler Metal

(*a*) The design shall provide for the application of the brazing filler metal as part of the design of the joint. Where practicable, the brazing filler metal shall be applied in such a manner that it will flow into the joint or be distributed across the joint and produce visible evidence that it has penetrated the joint.

(*b*) *Manual Application.* The manual application of the brazing filler metal by face feeding to a joint should be from the one side only. Visual observation of the other side of the joint will then show if the required penetration of the joint by the filler metal has been obtained. If the side opposite to the filler metal application cannot be visually examined, as is the case with socket type joints in pipe and tubing (blind joint), a joint efficiency factor of 0.5 shall be used in design of this joint as provided in UB-14(b).

(*c*) *Preplaced Brazing Filler Metal.* The brazing filler metal may be preplaced in the form of slugs, powder, rings, strip, cladding, spraying or other means. After brazing, the brazing filler metal should be visible on both sides of the joint. If the brazing filler metal is preplaced within a blind joint in such a manner that it penetrates the major portion of the joint during brazing and appears at the visible side of the joint, a joint efficiency factor of 1.0 may be used in the design of the joint. If the brazing filler metal is preplaced on the outside or near the outside of a blind joint, and the other side cannot be inspected to ascertain complete penetration, then a joint efficiency factor of 0.5 shall be used in the design of the joint as provided in UB-14(b). Fig. UB-14 illustrates a few examples of this rule.

UB-16 Permissible Types of Joints

(*a*) Some permissible types of brazed joints are shown in Fig. UB-16. For any type of joint, the strength of the brazed section shall exceed that of the base metal portion of the test specimen in the qualification tension tests provided for in QB-5 of Section IX of the Code. Lap joints shall have a

sufficient overlap to provide a higher strength in the brazed joint than in the base metal.

(*b*) The nominal thickness of base material used with lap joints tested using the test fixture shown in Fig. QB-8(a) shall not exceed $1/2$ in. There is no thickness limitation when specimens are tested without the test fixture shown in Fig. QB-8(a).

TABLE UB-17
RECOMMENDED JOINT CLEARANCES AT BRAZING TEMPERATURE

Brazing Filler Metal	Clearance, In.
B Al Si Group	0.006–0.010 for laps less than $1/4$ in. 0.010–0.025 for laps greater than $1/4$ in.
B Cu P Group	0.001–0.005
B Ag Group	0.002–0.005
B Cu Zn Group	0.002–0.005
B Cu Group	0.000–0.002

UB-17 Joint Clearance

The joint clearance shall be kept sufficiently small so that the filler metal will be distributed by capillary attraction. Since the strength of a brazed joint tends to decrease as the joint clearance used is increased, the clearances for the assembly of joints in pressure vessels or parts thereof shall be within the tolerances set up by the joint design and as used for the corresponding qualification specimens made in accordance with Section IX and UB-12 where applicable.

NOTE: For guidance, see Table UB-17 which gives recommended joint clearances at brazing temperature for various types of brazing filler metal. Brazing alloys will exhibit maximum unit strength if clearances are maintained within these limits.

UB-18 Joint Brazing Procedure

A joint brazing procedure shall be developed for each different type of joint of a brazed assembly. A recommended form for recording the brazing procedure is shown in Appendix II of Section IX of the Code. If more than one joint occurs in a brazed assembly, the brazing sequence shall be specified on the drawing or in instructions accompanying the drawing. If welding and brazing are to be done on the same assembly, the welding shall precede the brazing unless it is determined that the heat of welding will not adversely affect the braze previously made.

UB-19 Openings

(*a*) Openings for nozzles and other connections shall be far enough away from any main brazed joint so that the joint and the opening reinforcement plates do not interfere with one another.

(*b*) Openings for pipe connections in vessels having brazed joints may be made by inserting pipe couplings, not exceeding 3-in. pipe size, or similar devices in the shell or heads and securing them by welding, without necessitating the application of the restrictive stamping provisions of UG-116, provided the welding is performed by welders who have been qualified under the provisions of Section IX of the Code for the welding position and type of joint used. Such attachments shall conform to the rules for welded connections in UW-15 and UW-16.

UB-20 Nozzles

(*a*) Nozzles may be integral or attached to the vessel by any of the methods provided for in UG-43.

(*b*) For nozzle fittings having a bolting flange and an integral flange for brazing, the thickness of the flange attached to the pressure vessel shall not be less than the thickness of the neck of the fitting.

UB-21 Brazed Connections

Connections, such as saddle type fittings and fittings inserted into openings formed by outward flanging of the vessel wall, in sizes not exceeding 3-in. pipe size, may be attached to unfired pressure vessels by lap joints of brazed construction. Sufficient brazing shall be provided on either side of the line through the center of the opening parallel to the longitudinal axis of the shell to develop the strength of the reinforcement as prescribed in UG-41 through shear in the brazing.

UB-22 Low Temperature Operation

Impact tests shall be made of the brazed joints in pressure vessels and parts thereof fabricated from materials for which impact tests are required in Subsection C. The tests shall be made in accordance with UG-84 except that terms referring to welding shall be interpreted as referring to brazing.

FABRICATION

UB-30 General

(*a*) The rules in the following paragraphs apply specifically to the fabrication of pressure vessels and parts thereof that are fabricated by brazing and shall be used in conjunction with the general requirements for *Fabrication* in Subsection A, and

with the specific requirements for *Fabrication* in Subsection C that pertain to the class of material used.

(*b*) Each manufacturer or contractor shall be responsible for the quality of the brazing done by his organization and shall conduct tests not only of the brazing procedure to determine its suitability to insure brazes which will meet the required tests, but also of the brazers and brazing operators to determine their ability to apply the procedure properly.

(*c*) No production work shall be undertaken until both the brazing procedure and the brazers or brazing operators have been qualified.

UB-31 Qualification of Procedure

(*a*) Each brazing Procedure as required in UB-18 shall be qualified in accordance with Section IX of the Code. Only qualified procedure specifications shall be followed in construction.

(*b*) Each manufacturer shall conduct the required tests to qualify all brazing procedures to be used by his organization.

UB-32 Qualification of Brazers and Brazing Operators

(*a*) All brazers assigned to manual brazing shall have passed the tests prescribed for brazers in Section IX of the Code. All brazing operators assigned to brazing by automatic means or by furnace, induction, resistance, or dip brazing shall pass the tests as prescribed in Section IX of the Code. Such tests shall be conducted by the manufacturer or contractor.

(*b*) Each brazer and brazing operator, so qualified, shall be assigned an identifying number, letter, or symbol by the manufacturer which shall be used to identify the work of that brazer or brazing operator.

(*c*) The manufacturer shall maintain a record of the brazers and brazing operators employed by him showing the date and results of tests and the identifying mark assigned to each. These records shall be certified to by the manufacturer and shall be accessible to the Inspector.

(*d*) The tests conducted by one manufacturer shall not qualify the brazer or brazing operator to do work for any other manufacturer.

UB-33 Buttstraps

(*a*) Buttstraps shall be formed to the curvature of the shell with which they are to be used.

(*b*) When the buttstraps of a longitudinal joint do not extend the full length of a shell section, the abutting edges of the shell plate may be welded provided the length of the weld between the end of the buttstraps and the edge of the head or adjoining shell plate is not greater than four times the shell plate thickness. When so constructed, the restrictive stamping provisions of UG-116 shall not apply provided the welding is performed by welders who have been qualified under the provisions of Section IX for the welding position and type of joint used. The welds shall be completed before brazing is begun.

UB-34 Cleaning of Surfaces to Be Brazed

The surfaces to be brazed shall be clean and free from grease, paint, oxides, scale and foreign matter of any kind. Any chemical or mechanical cleaning method may be used that will provide a surface suitable for brazing.

UB-35 Clearance Between Surfaces to Be Brazed

The clearances between surfaces to be brazed shall be maintained within the tolerances provided for by the joint design and used in the qualifying procedure. If greater tolerances are to be used in production, the joint must be requalified for those greater tolerances. The control of tolerances required may be obtained by using rivets, spot welding, crimping, or other means which will not interfere with the quality of the braze. If such means are employed in production, they must also be employed in qualification of procedure, brazer, and operator.

UB-36 Post Brazing Operations

Brazed joints shall be thoroughly cleaned of flux residue by any suitable means after brazing and prior to inspection.[1] Other postbrazing operations such as thermal treatments shall be performed in accordance with the qualified procedure.

UB-37 Repair of Defective Brazing

Brazed joints which have been found to be defective may be rebrazed, where feasible, after through cleaning, and by employing the same brazing procedure used for the original braze. See UB-44. If a different brazing procedure is employed, i.e., torch

[1]Flux residues can be extremely corrosive as well as interfering with visual inspection.

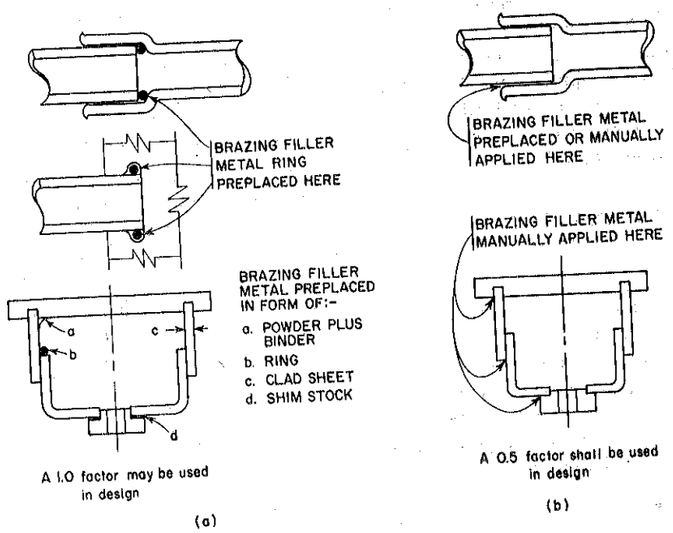


FIG. UB-14 EXAMPLES OF FILLER METAL APPLICATION

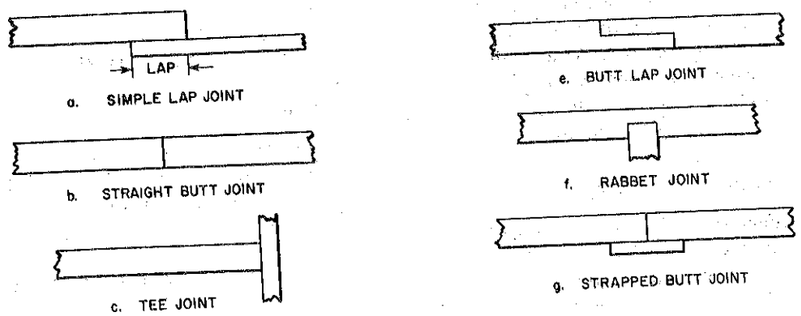


FIG. UB-16 SOME ACCEPTABLE TYPES OF BRAZE JOINTS (Other equivalent geometries yielding substantially equal results also are acceptable)

repair of furnace brazed parts, a repair brazing procedure shall be established and qualified.

When a repair brazing procedure is established it shall provide control of the application of brazing filler metal to meet the conditions set forth in UB-14(a). Where these requirements cannot be met, the limitations of UB-14(b) will apply.

INSPECTION AND TESTS

UB-40 General

The rules in the following paragraphs apply specifically to the inspection and testing of pressure vessels and parts thereof that are fabricated by brazing and shall be used in conjunction with the general requirements for *Inspection and Tests* in Subsection A and with the specific requirements for *Inspection and Tests* in Subsection C that pertain to the class of material used.

UB-41 Design

The Inspector shall verify the design test data for all joints that are to operate above 200 F in service and satisfy himself that adequate design data are available to meet the requirements of UB-12.

UB-42 Procedure

The Inspector shall examine the procedure for each type of joint being produced and shall determine that the procedure has been qualified in accordance with the requirements of Section IX and shall satisfy himself that each joint has been fabricated in accordance with the procedure. Where there is evidence of consistent poor quality, the Inspector shall have the right at any time to call for and witness tests for the brazing procedure.

UB-43 Brazer and Brazing Operator

(*a*) The manufacturer shall certify that the brazing on a vessel or part thereof has been done by brazers or brazing operators who are qualified under the requirements of Section IX and the Inspector shall assure himself that only qualified brazers or brazing operators have been used.

(*b*) The manufacturer shall make available to the Inspector a certified copy of the record of the qualification tests of each brazer and brazing operator. The Inspector shall have the right at any time to call for and witness tests of the ability of a brazer or brazing operator.

UB-44 Visual Examination

(*a*) Where possible, the Inspector shall visually inspect both sides of each brazed joint after flux residue removal. Where it is not possible to inspect one side of a brazed joint (blind joint), the Inspector shall check the design to determine that the proper joint factor has been employed, unless he can assure himself that the brazing filler metal has been preplaced in such a manner that it satisfies UB-15(b) and (c).

(*b*) There shall be evidence that the brazing filler metal has penetrated the joint. In a butt braze there shall be no concavity. The braze may be repaired or rebrazed.

(*c*) The presence of a crack in the brazing filler metal shall be cause for rejection. Dye penetrant inspection may be used if desired. The braze may be repaired or rebrazed. See UB-37.

(*d*) The presence of a crack in the base metal adjacent to a braze shall be cause for rejection even if the crack is filled with brazing alloy. Such cracking shall not be repaired.

(*e*) Visible pinholes or open defects in the braze shall be cause for rejection. The joint may be rebrazed.

(*f*) Rough fillets, particularly those with a convex appearance, are cause for rejection. Such joints may be repaired or rebrazed.

STAMPING AND REPORTS

UB-50 General

The provisions for stamping and reports given in UG-115 through UG-120 shall apply without supplement to brazed pressure vessels and parts thereof.

PRESSURE RELIEF DEVICES

UB-55 General

The provisions for pressure relieving devices given in UG-125 through UG-134 shall apply without supplement to brazed pressure vessels.

SUBSECTION C

REQUIREMENTS PERTAINING TO CLASSES OF MATERIALS

PART UCS

REQUIREMENTS FOR PRESSURE VESSELS CONSTRUCTED OF CARBON AND LOW-ALLOY STEELS[1]

GENERAL

UCS-1 Scope

The rules in Part UCS are applicable to pressure vessels and vessel parts that are constructed of carbon and low-alloy steels and shall be used in conjunction with the general requirements in Subsection A, and with the specific requirements in Subsection B that pertain to the method of fabrication used.

MATERIALS

UCS-5 General

(*a*) All carbon and low-alloy steel material subject to stress due to pressure shall conform to one of the specifications given in Section II of the Code and shall be limited to those listed in Table UCS-23 except as otherwise provided in UG-10 and UG-11.

(*b*) Carbon or low-alloy steel having a carbon content of more than 0.35 percent by ladle analysis shall not be used in welded construction or be shaped by oxygen cutting (except as provided elsewhere in this Division).

(*c*) Small parts used under the provisions of UG-11(a)(2) in welded construction shall be of good weldable quality.

[1]Low-alloy steels—those alloy steels listed in Tables UCS-23 and UCS-27.

UCS-6 Steel Plates

(*a*) Approved specifications for carbon and low-alloy steel plates are given in Table UCS-23 together with a tabulation of allowable stress together with a tabulation of allowable stress values at different temperatures (see UG-6).

(*b*) Steel plates conforming to specifications

SA-7 Steel for Bridges and Buildings,
SA-36 Structural Steel,
SA-113 (Grade C) Structural Steel for Locomotives and Cars,
SA-283 (Grades A, B, C, and D) Low and Intermediate Tensile Strength Carbon Steel Plates of Structural Quality,

may be used for pressure parts in pressure vessels provided all of the following requirements are met:

(*1*) The vessels are not used to contain lethal substances, either liquid or gaseous;

(*2*) The material is not used in the construction of unfired steam boilers (see U-1(e));

(*3*) The design temperature at which the material is used is between —20 F and 650 F;

(*4*) The thickness of plates on which strength welding is applied does not exceed $^5/_8$ in.;

(*5*) The steel is manufactured by the electric furnace or open hearth process or by the basic oxygen process provided this process is permitted in the material specification.

(*c*) Steel plate conforming to specification SA-433 may be used for pressure parts in unfired pressure

vessels provided all the following requirements are met:

(*1*) The maximum allowable stress values between —20 F and 550 F shall be one-fourth of the minimum specified tensile strength shown in Table UCS-23;

(*2*) The maximum thickness of welds shall be 2 in.;

(*3*) Overlay or joining by welding of these materials with stainless steels or other high alloys is prohibited. These materials shall be welded only with carbon steel filler materials.

UCS-7 Steel Forgings

Approved specifications for forgings of carbon and low-alloy steel are given in Table UCS-23 together with tabulation of allowable stress values at different temperatures (see UG-7).

UCS-8 Steel Castings

(*a*) Approved specifications for castings of carbon and low-alloy steel are given in Table UCS-23 together with a tabulation of allowable stress values at different temperatures. These stress values are to be multiplied by the casting quality factors of UG-24. Castings that are to be welded shall be of weldable grade.

(*b*) Cast steel flanges and fittings complying with ANSI B16.5-1968 shall be used within the ratings assigned in these Standards.

UCS-9 Steel Pipe and Tubes

(*a*) Approved specifications for pipe and tubes of carbon and low-alloy steel and wrought iron are given in Table UCS-23 together with allowable stress values of the materials from which the pipe or tubes are manufactured. Net allowable stress values after making provision for the efficiency of the longitudinal joints in pipe or tubes of welded manufacture are given in Table UCS-27.

(*b*) Pressure vessels may be built of pipe fittings within pressure-temperature ratings conforming to ANSI B16.5-1968.

UCS-10 Bolt and Rivet Materials

(*a*) *Bolts.* Approved specifications for bolt materials of carbon and low-alloy steel are given in Table UCS-23 together with allowable stress values at different temperatures (see UG-12).

(*b*) *Rivets.* Rivets shall conform to Specifications SA-31, SA-84, or SA-202 Grade A, except that where special types of corrosion are expected, it may be desirable to use rivets of material conforming more closely to the chemical composition of the plate (see UR-6(b)).

UCS-11 Nuts and Washers

(*a*) Materials for nuts and washers shall conform to Specification SA-194 or to the requirements for nuts in the specification for the bolting material with which they are to be used.

(*b*) Nuts shall be threaded to Class 2B or finer tolerances according to ANSI B1.1-1960. Materials for nuts and washers shall be selected as follows:

(*1*) Carbon steel nuts and carbon steel washers may be used with carbon steel bolts or studs;

(*2*) Carbon or alloy steel nuts and carbon or alloy steel washers of approximately the same hardness as the nuts may be used with alloy steel bolts or studs for metal temperatures not exceeding 900 F;

(*3*) Alloy steel nuts shall be used with alloy steel studs or bolts for metal temperatures exceeding 900 F. Washers, if used, shall be of alloy steel equivalent to the nut material.

(*c*) Nuts shall be semifinished, chamfered and trimmed. For use with flanges, conforming to the standards listed in UG-44, nuts shall conform at least to the dimensions given in ANSI B18.2-1965 for Heavy Series Nuts. For use with connections designed in accordance with the rules in Appendix II, nuts may be of the ANSI American National Standard Heavy Series, or they may be of other dimensions provided their strength is equal to that of the bolting, giving due consideration to bolt hole clearance, bearing area, thread form and class to fit, thread shear, and radial thrust from threads (see U-2(c)).

UCS-12 Rods and Bars

(*a*) Approved specifications for bar materials of carbon steel are given in Table UCS-23, together with a tabulation of allowable stress values at different temperatures.

(*b*) Bolt and rivet materials as described in UCS-10 may be used as bar materials.

(*c*) Parts made from bars, on which welding is done, shall be of material for which a P-number for procedure qualification is given in Section IX, Table Q-11.1 of the Code (see UW-5).

DESIGN

UCS-16 General

(*a*) The rules in the following paragraphs apply specifically to the design of pressure vessels and vessel parts that are constructed of carbon and low-alloy steel and shall be used in conjunction with the general requirements for *Design* in Subsection A, and with the specific requirements for *Design* in Subsection B that pertain to the method of fabrication used.

(*b*) *Minimum Thickness of Plate.* The thickness, after forming and without allowance for corrosion, of any plate subject to pressure shall be not less than $^3/_{32}$ in. for welded or brazed construction, and not less than $^3/_{16}$ in. for riveted construction, except that the thickness of unfired steam boilers shall be not less than $^1/_4$ in. (see U-1(e), UG-25(a), and UCS-25).

UCS-18 Lap Joints in Riveted Vessels

Lap and single buttstrap type joints of the types covered in UR-18(a) and (b) shall not be used in carbon and low-alloy steel at design metal temperatures exceeding 450 F.

UCS-19 Welded Joints

When radiographic examination is required for butt-welded joints by UCS-57, joints of Categories A and B (see UW-3) shall be of Type No. (1) or No. (2) of Table UW-12.

UCS-23 Maximum Allowable Stress Values

Table UCS-23 gives the maximum allowable stress values at the temperature indicated for materials conforming to the specifications listed therein.[1] Values may be interpolated for intermediate temperatures. (See UG-23.)

UCS-25 Corrosion Allowance

Vessels with a required minimum thickness of less than $^1/_4$ in. that are to be used in compressed air service, steam service, or water service shall be provided with a corrosion allowance on the metal surface in contact with such substance of not less than $^1/_6$ of the calculated plate thickness. This requirement does not apply to vessels designed in accordance with UW-12(c). No applied linings except as provided by Part UCL shall be acceptable in lieu of the above requirement.

UCS-27 Shells Made from Pipe

(*a*) Shells of pressure vessels may be made from seamless pipe or tubing listed in Table UCS-23 provided the material of the pipe is manufactured by the open-hearth, basic oxygen, or electric-furnace process.

(*b*) Shells of pressure vessels may be made from welded pipe or tubing listed in Table UCS-27 in nominal diameters up to 30 in. provided the material is manufactured by the open-hearth, basic oxygen, or electric-furnace process (see UG-16(d)). The applicable stress values given in Table UCS-27 shall be used instead of the factor *SE* in the formulas of UG-27. No increase in the stress values given in Table UCS-27 shall be allowed for the performance of postweld heat treatment or radiographing.

UCS-28 Thickness of Shells Under External Pressure

(*a*) Cylindrical and spherical shells under external pressure shall be designed by the rules in UG-28, using Fig. UCS-28.1 or Fig. UCS-28.2.

(*b*) Examples illustrating the use of the charts in Figs. UCS-28.1 and UCS-28.2 are given in Appendix L.

(*c*) Corrugated shells subject to external pressure may be used in unfired pressure vessels in accordance with P-243 of Section I of the Code.

UCS-29 Stiffening Rings for Shells Under External Pressure

Rules covering the design of stiffening rings are given in UG-29. An example illustrating the use of these rules is given in Appendix L.

UCS-30 Attachment of Stiffening Rings to Shell

Rules covering the attachment of stiffening rings are given in UG-30.

UCS-33 Formed Heads, Pressure on Convex Side

Ellipsoidal, torispherical, hemispherical, and conical heads having pressure on the convex side (minus heads) shall be designed by the rules of UG-33, using Fig. UCS-28.1 or Fig. UCS-28.2. Examples illustrating the application of this paragraph are given in Appendix L.

[1] See Appendix P for the basis on which the allowable stress values have been established for steels.

TABLE UCS-23
MAXIMUM ALLOWABLE STRESS VALUES IN TENSION FOR CARBON AND LOW-ALLOY STEEL, IN KIPS/SQ IN. (MULTIPLY BY 1000 TO OBTAIN PSI)
(See UW-12(c) for vessels constructed under Part UW that include welded joints that are neither fully radiographed nor spot radiographically examined)

Nominal Composition	P Number	Product Form	Specification Number	Grade	Notes	Specified Minimum Yield	Specified Minimum Tensile
CARBON STEELS							
¼ Pb	1	Plate	SA-433	L-45	(25)	24.0	45.0
¼ Pb	1	Plate	SA-433	L-50	(25)	27.0	50.0
¼ Pb	1	Plate	SA-433	L-55	(25)	30.0	55.0
¼ Pb C-Si	1	Plate	SA-433	LK-55	(25)	30.0	55.0
¼ Pb C-Si	1	Plate	SA-433	LK-60	(25)	32.0	60.0
¼ Pb C-Si	1	Plate	SA-433	LK-65	(25)	35.0	65.0
¼ Pb C-Si	1	Plate	SA-433	LK-70	(25)	38.0	70.0
...	...	Plate	SA-593	...	(13)	...	...
C-Mn-Si	1	Plate	SA-537	A > 1¼"	(14)	46.0	65.0
C-Mn-Si	1	Plate	SA-537	A ≤ 1¼"	(14)	50.0	70.0
C-Mn-Si	12B Sub 2	Plate	SA-537	B > 1¼"	(14)(31)	56.0	75.0
C-Mn-Si	12B Sub 2	Plate	SA-537	B ≤ 1¼"	(14)(31)	60.0	80.0
...	1	Plate	SA-283	A	(1)(3)	24.0	45.0
...	1	Plate	SA-285	A	(4)	24.0	
...	1	Plate	SA-414	A	(4)	24.0	
...	...	Bar	SA-31	A	(4)	23.0	45.0
...	...	Bar	SA-306	45	(4)	22.5	
...	1	Smls. Tb.	SA-556	A2	(27)	26.0	47.0
	1	Smls. Tb	SA-192	...	(27)	...	...
...	1	Smls. Tb.	SA-179	...	(4)(6)(27)	...	...
...	1	Plate	SA-113	C	(1)(3)	26.0	48.0
...	1	Smls. Pp.	SA-53	A	(4)(6)(27)	30.0	48.0
...	1	Smls. Pp.	SA-106	A	(27)	30.0	48.0
...	1	Plate	SA-283	B	(1)(3)	27.0	50.0
...	1	Plate	SA-285	B	(4)	27.0	
...	1	Plate	SA-414	B	(4)	27.0	50.0
...	...	Bar	SA-306	50	(4)	25.0	
...	...	Bolt	SA-307	B	(11)	...	55.0
...	1	Plate	SA-283	C	(1)(3)	30.0	55.0
...	1	Smls. Pp.	SA-333	1	...		
...	1	Smls. Tb.	SA-334	1	...	30.0	55.0
C-Si	1	Plate	SA-442	55	...	30.0	55.0
...	1	Plate	SA-285	C	(4)	30.0	
...	1	Plate	SA-414	C	(4)	30.0	55.0
...	...	Bar	SA-306	55	(4)	27.5	
C-Si	1	Plate	SA-515	55	(27)		
C-Si	1	Plate	SA-516	55	(27)	30.0	55.0
...	1	Plate	SA-36	...	(1)(3)(19)	36.0	58.0
...	...	Bar	SA-31	B	(4)	29.0	58.0
...	1	Forg.	SA-372	I	(20)(24)	35.0	60.0

TABLE UCS-23 (CONT'D)
MAXIMUM ALLOWABLE STRESS VALUES IN TENSION FOR CARBON AND LOW-ALLOY STEEL, IN KIPS/SQ IN. (MULTIPLY BY 1000 TO OBTAIN PSI)
(See UW-12(c) for vessels constructed under Part UW that include welded joints that are neither fully radiographed nor spot radiographically examined)

For Metal Temperatures Not Exceeding Deg F												Specification Number	Grade
-20 to 650	700	750	800	850	900	950	1000	1050	1100	1150	1200		
												CARBON STEELS (Cont'd)	
...	...	...	...	...	...	...	...	...	...	...	...	SA-433	L-45
...	...	...	...	...	...	...	...	...	...	...	...	SA-433	L-50
...	...	...	...	...	...	...	...	...	...	...	...	SA-433	L-55
...	...	...	...	...	...	...	...	...	...	...	...	SA-433	LK-55
...	...	...	...	...	...	...	...	...	...	...	...	SA-433	LK-60
...	...	...	...	...	...	...	...	...	...	...	...	SA-433	LK-65
...	...	...	...	...	...	...	...	...	...	...	...	SA-433	LK-70
												SA-593	...
...	...	...	...	...	...	...	...	...	...	...	...	SA-537	A > 1¼"
...	...	...	...	...	...	...	...	...	...	...	...	SA-537	A ≤ 1¼"
...	...	...	...	...	...	...	...	...	...	...	...	SA-537	B > 1¼"
...	...	...	...	...	...	...	...	...	...	...	...	SA-537	B ≤ 1¼"
10.3	...	...	...	...	...	...	...	...	...	...	...	SA-283	A
												SA-285	A
11.2	11.0	10.2	9.0	7.7	6.5	...	...	...	...	...	...	SA-414	A
												SA-31	A
												SA-306	45
11.7	11.4	10.5	9.2	7.8	6.5	4.5	2.5	...	...	...	...	SA-556	A2
												SA-192	...
11.7	11.4	10.5	9.2	7.8	6.5	...	...	...	...	...	...	SA-179	...
11.0	...	...	...	...	...	...	...	...	...	...	...	SA-113	C
12.0	11.6	10.7	9.3	7.9	6.5	...	...	...	...	...	...	SA-53	A
12.0	11.6	10.7	9.3	7.9	6.5	4.5	2.5	...	...	...	...	SA-106	A
11.5	...	...	...	...	...	...	...	...	...	...	...	SA-283	B
12.5	12.1	11.1	9.6	8.0	6.5	...	...	...	...	...	...	SA-285	B
												SA-414	B
												SA-306	50
...	...	...	...	...	...	...	...	...	...	...	...	SA-307	B
12.6	...	...	...	...	...	...	...	...	...	...	...	SA-283	C
13.7	...	...	...	...	...	...	...	...	...	...	...	SA-333	1
												SA-334	1
13.7	13.2	12.0	10.2	8.3	...	...	...	...	...	...	...	SA-442	55
13.7	13.2	12.0	10.2	8.3	6.5	...	...	...	...	...	...	SA-285	C
												SA-414	C
												SA-306	55
13.7	13.2	12.0	10.2	8.3	6.5	4.5	2.5	...	...	...	...	SA-516	55
												SA-516	55
12.6	...	...	...	...	...	...	...	...	...	...	...	SA-36	...
14.5	13.9	12.6	10.5	8.5	6.5	...	...	...	...	...	...	SA-31	B
...	...	...	...	...	...	...	...	...	...	...	...	SA-372	I

TABLE UCS-23 (CONT'D)
MAXIMUM ALLOWABLE STRESS VALUES IN TENSION FOR CARBON AND LOW-ALLOY STEEL, IN KIPS/SQ IN. (MULTIPLY BY 1000 TO OBTAIN PSI)
(See UW-12(c) for vessels constructed under Part UW that include welded joints that are neither fully radiographed nor spot radiographically examined)

Nominal Composition	P Number	Product Form	Specification Number	Grade	Notes	Specified Minimum Yield	Specified Minimum Tensile
CARBON STEELS (Cont'd)							
...	1	Forg.	SA-350	LF1	...	30.0	60.0
...	1	Smls. Pp.	SA-333	6	...	35.0	
...	1	Smls. Tb.	SA-334	6	...	35.0	
...	1	Plate	SA-283	D	(1)(3)	33.0	60.0
C-Si	1	Plate	SA-442	60	...	32.0	60.0
...	1	Smls. Pp.	SA-53	B	(4)(6)(27)	35.0	60.0
...	...	Bar	SA-306	60	(4)	30.0	
C-Si	1	Plate	SA-515	60	(27)	32.0	60.0
C-Si	1	Plate	SA-516	60	(27)	32.0	
...	1	Smls. Pp.	SA-106	B	(27)	35.0	
...	1	Smls. Tb.	SA-210	A-1	(27)	37.0	
...	1	Smls. Tb.	SA-556	B2	(27)	37.0	
...	1	Forg.	SA-105	I	(4)(27)	30.0	
...	1	Forg.	SA-181	I	(4)(27)	30.0	
...	1	Forg.	SA-266	I	(27)	30.0	
...	1	Cast.	SA-216	WCA	(27)	30.0	
C-Si	1	Plate	SA-515	65	(27)	35.0	65.0
C-Si	1	Plate	SA-516	65	(27)	35.0	
...	...	Bar	SA-306	65	(4)	32.5	
...	...	Cast.	SA-352	LCB	...	35.0	65.0
...	1	Forg.	SA-350	LF2	...	36.0	70.0
...	1	Smls. Pp.	SA-106	C	(27)	40.0	70.0
...	1	Smls. Tb.	SA-556	C2	(27)		
...	1	Smls. Tb.	SA-210	C	(27)	40.0	70.0
C-Si	1	Plate	SA-515	70	(27)	38.0	70.0
C-Si	1	Plate	SA-516	70	(27)	38.0	
...	1	Forg.	SA-105	II	(4)(27)	36.0	
...	1	Forg.	SA-181	II	(4)(27)	36.0	
...	1	Forg.	SA-266	II	(27)	35.0	
...	1	Cast.	SA-216	WCB	(27)	36.0	
...	1	Cast.	SA-216	WCC	(27)	40.0	
...	...	Bar	SA-306	70	(4)	35.0	
...	1	Plate	SA-455	B	(26)	36.5	73.0
...	...	Forg.	SA-372	II	(20)(22)(24)	45.0	75.0
...	1	Plate	SA-455	A	(29)	37.5	75.0
C-Mn-Si	...	Forg.	SA-266	III	(27)	37.5	75.0
...	1	Plate	SA-299	...	...	40.0/42.0	
...	...	Forg.	SA-372	III	(20)(22)(24)	55.0	90.0
...	...	Bolt.	SA-325	...	(9)(10)	77.0	105.0

TABLE UCS-23 (CONT'D)
MAXIMUM ALLOWABLE STRESS VALUES IN TENSION FOR CARBON AND LOW-ALLOY STEEL, IN KIPS/SQ IN. (MULTIPLY BY 1000 TO OBTAIN PSI)
(See UW-12(c) for vessels constructed under Part UW that include welded joints that are neither fully radiographed nor spot radiographically examined)

For Metal Temperatures Not Exceeding Deg F												Specification Number	Grade
–20 to 650	700	750	800	850	900	950	1000	1050	1100	1150	1200		
												CARBON STEELS (Cont'd)	
15.0	...	...	...	...	...	...	...	...	...	...	...	SA-350	LF1
												SA-333	6
												SA-334	6
12.6	...	...	...	...	...	...	...	...	...	...	...	SA-283	D
15.0	14.3	12.9	10.8	8.6	...	...	...	...	...	...	...	SA-442	60
												SA-53	B
15.0	14.3	12.9	10.8	8.6	6.5	...	...	...	...	...	...	SA-306	60
												SA-515	60
												SA-516	60
												SA-106	B
												SA-210	A-1
15.0	14.3	12.9	10.8	8.6	6.5	4.5	2.5	...	...	...	...	SA-556	B2
												SA-105	I
												SA-181	I
												SA-266	I
												SA-216	WCA
												SA-515	65
16.2	15.5	13.8	11.4	8.9	6.5	4.5	2.5	...	...	...	...	SA-516	65
												SA-306	65
16.2	...	...	...	...	...	...	...	...	...	...	...	SA-352	LCB
17.5	...	...	...	...	...	...	...	...	...	...	...	SA-350	LF2
												SA-106	C
17.5	16.6	14.7	12.0	...	...	...	...	...	...	...	...	SA-556	C2
17.5	16.6	14.7	12.0	7.8	5.0	3.0	1.5	...	...	...	...	SA-210	C
												SA-515	70
												SA-516	70
												SA-105	II
												SA-181	II
17.5	16.6	14.7	12.0	9.2	6.5	4.2	2.5	...	...	...	...	SA-266	II
												SA-216	WCB
												SA-216	WCC
												SA-306	70
18.2	...	...	...	...	...	...	...	...	...	...	...	SA-455	B
...	...	...	...	...	...	...	...	...	...	...	...	SA-372	II
18.7	...	...	...	...	...	...	...	...	...	...	...	SA-455	A
												SA-266	III
18.7	17.7	15.6	12.6	9.5	6.5	4.5	2.5	...	...	...	...	SA-299	...
...	...	...	...	...	...	...	...	...	...	...	...	SA-372	III
19.2	...	...	...	...	...	...	...	...	...	...	...	SA-325	...

TABLE UCS-23 (CONT'D)
MAXIMUM ALLOWABLE STRESS VALUES IN TENSION FOR CARBON AND LOW-ALLOY STEEL, IN KIPS/SQ IN. (MULTIPLY BY 1000 TO OBTAIN PSI)
(See UW-12(c) for vessels constructed under Part UW that include welded joints that are neither fully radiographed nor spot radiographically examined)

Nominal Composition	P Number	Product Form	Specification Number	Grade	Notes	Specified Minimum Yield	Specified Minimum Tensile
LOW ALLOY STEELS							
¼ Mo	...	Forg.	SA-372	IV	(20)(22)(24)	65.0	105.0
C-½ Mo	3	Smls. Tb.	SA-209	T1b	(28)	28.0	53.0
C-½ Mo	3	Smls. Tb.	SA-209	T1	(28)	30.0	55.0
C-½ Mo	3	Smls. Pp.	SA-335	P1	(28)		
C-½ Mo	3	Smls. Pp.	SA-369	FP1	(28)		
C-½ Mo	3	Smls. Tb.	SA-209	T1a	(28)	32.0	60.0
C-½ Mo	3	Plate	SA-204	A	(28)	37.0	65.0
C-½ Mo	3	Cast.	SA-217	WC1	(8)	35.0	
C-½ Mo	3	Cast.	SA-352	LC1	...	35.0	65.0
C-½ Mo	3	Plate	SA-204	B	(28)	40.0	70.0
	3	Forg.	SA-182	F1	(28)		
	3	Forg.	SA-336	F1	(28)		
C-½ Mo	3	Plate	SA-204	C	(28)	43.0	75.0
Mn-½ Mo	3	Plate	SA-302	A	...	45.0	75.0
Mn-½ Mo, Mn-½ Mo-Ni	3	Plate	SA-302	B,C,D	...	50.0	80.0
C-Mn-Mo	12B SG1	Plate	SA-533	A, Cl1	...		
C-Mn-Mo, 0.4-0.7 Ni	12B SG1	Plate	SA-533	B, Cl1	...	50.0	80.0
C-Mn-Mo, 0.7-1.0 Ni	12B SG1	Plate	SA-533	C, Cl1	...		
Mn-V	10A	Plate	SA-225	A	(12)	40.0	70.0
Mn-V	10A	Plate	SA-225	B	(12)	43.0	75.0
1 Mn-0.10 V	10A	Cast.	SA-487	IN	(14)	55.0	85.0
Cr-Mn-Si	4	Plate	SA-202	A	...	45.0	75.0
Cr-Mn-Si	4	Plate	SA-202	B	...	47.0	85.0
Cr-Cu-Ni-Al	4	Plate	SA-410	...	...	30.0	60.0
Cr-Cu-Ni-Al	4	Smls. Pp.	SA-333	4	...	35.0	
Cr-Cu-Ni-Al	4	Forg.	SA-350	LF4	...	30.0	
¾ Cr-½ Ni-0.4 Cu	4	Smls. Tb.	SA-423	1	...	37.0	
¾ Ni-0.6 Cu-0.1 Mo	4	Smls. Tb.	SA-423	2	...	37.0	
½ Cr-½ Ni-1/5 Mo	...	Forg.	SA-372	V (C&D)	(21)(22)(24)	70.0	120.0
1 Cr-1/5 Mo	...	Forg.	SA-372	V (A,B&E)	(21)(22)(24)		
Ni-Cr-½ Mo	4	Cast.	SA-217	WC4	(8)	40.0	70.0
Ni-Cr-1 Mo	4	Cast.	SA-217	WC5	(8)	40.0	70.0
½ Ni-½ Cr	10F	Cast.	SA-487	4N	(14)	60.0	90.0
Cr-Mo and Ni-Cr-Mo	...	Bolt.	SA-320	L7, L43	(9)(15)	105.0	125.0
...	...	Bolt.	SA-354	BB	(9)(10)	78.0	100.0
...	...	Bolt.	SA-354	BC	(9)(10)	99.0	115.0
...	...	Bolt.	SA-354	BD	(9)(10)	125.0	150.0

TABLE UCS-23 (CONT'D)
MAXIMUM ALLOWABLE STRESS VALUES IN TENSION FOR CARBON AND LOW-ALLOY STEEL, IN KIPS/SQ IN. (MULTIPLY BY 1000 TO OBTAIN PSI)
(See UW-12(c) for vessels constructed under Part UW that include welded joints that are neither fully radiographed nor spot radiographically examined)

For Metal Temperatures Not Exceeding Deg F												Specification Number	Grade
–20 to 650	700	750	800	850	900	950	1000	1050	1100	1150	1200		
LOW ALLOY STEELS (Cont'd)													
...	...	...	...	...	...	...	...	...	...	...	...	SA-372	IV
13.2	13.2	13.2	13.0	12.7	12.5	10.0	6.2	...	...	...	...	SA-209	T1b
13.7	13.7	13.7	13.4	13.1	12.5	10.0	6.2	...	...	...	...	SA-209	T1
												SA-335	P1
												SA-369	FP1
15.0	15.0	15.0	14.4	13.7	12.5	10.0	6.2	...	...	...	...	SA-209	T1a
16.2	16.2	16.2	15.6	14.4	12.5	10.0	6.2	...	...	...	...	SA-204	A
												SA-217	WC1
16.2	...	...	...	...	...	...	...	...	...	...	...	SA-352	LC1
17.5	17.5	17.5	16.9	15.0	12.7	10.0	6.2	...	...	...	...	SA-204	B
												SA-182	F1
												SA-336	F1
18.7	18.7	18.7	18.0	15.9	13.0	10.0	6.2	...	...	...	...	SA-204	C
18.7	18.7	18.7	18.0	15.9	13.0	10.0	6.2	...	...	...	...	SA-302	A
20.0	20.0	20.0	19.1	16.8	13.2	10.0	6.2	...	...	...	...	SA-302	B,C,D
												SA-533	A, Cl1
20.0	20.0	20.0	19.1	...	...	...	...	...	...	...	...	SA-533	B, Cl1
												SA-533	C, Cl1
17.5	17.5	17.5	...	...	...	...	...	...	...	...	...	SA-225	A
18.7	18.7	18.7	...	...	...	...	...	...	...	...	...	SA-225	B
...	...	...	...	...	...	...	...	...	...	...	...	SA-487	IN
18.7	17.7	16.6	12.6	9.5	6.5	4.5	2.5	...	...	...	...	SA-202	A
21.2	19.8	17.7	12.8	9.9	6.5	4.5	2.5	...	...	...	...	SA-202	B
15.0	...	...	...	...	...	...	...	...	...	...	...	SA-410	...
												SA-333	4
												SA-350	LF4
												SA-423	1
												SA-423	2
...	...	...	...	...	...	...	...	...	...	...	...	SA-372	V (C & D)
												SA-372	V (A, B & E)
17.5	17.5	17.5	17.0	15.8	14.0	10.0	6.2	...	...	...	...	SA-217	WC4
17.5	17.5	17.5	17.0	15.8	14.0	11.0	7.8	5.5	4.0	...	...	SA-217	WC5
...	...	...	...	...	...	...	...	...	...	...	...	SA-487	4N
...	...	...	...	...	...	...	...	...	...	...	...	SA-320	L7, L43
19.5	...	...	...	...	...	...	...	...	...	...	...	SA-354	B8
23.0	...	...	...	...	...	...	...	...	...	...	...	SA-354	BC
30.0	...	...	...	...	...	...	...	...	...	...	...	SA-354	BD

TABLE UCS-23 (CONT'D)
MAXIMUM ALLOWABLE STRESS VALUES IN TENSION FOR CARBON AND LOW-ALLOY STEEL, IN KIPS/SQ IN. (MULTIPLY BY 1000 TO OBTAIN PSI)
(See UW-12(c) for vessels constructed under Part UW that include welded joints that are neither fully radiographed nor spot radiographically examined)

Nominal Composition	P Number	Product Form	Specification Number	Grade	Notes	Specified Minimum Yield	Specified Minimum Tensile
LOW ALLOY STEELS (Cont'd)							
2 Ni	9A	Smls. Pp.	SA-333	9	(14)	46.0	63.0
2 Ni	9A	Smls. Tb.	SA-334	9	(14)		
2½ Ni	9A	Smls. Pp.	SA-333	7	...	35.0	65.0
2½ Ni	9A	Smls. Tb.	SA-334	7	...	35.0	
2½ Ni	9A	Cast.	SA-352	LC2	...	40.0	
3½ Ni	9B	Smls. Pp.	SA-333	3	...	35.0	
3½ Ni	9B	Smls. Tb.	SA-334	3	...	35.0	
3½ Ni	9B	Cast.	SA-352	LC3	...	40.0	
2½ Ni	9A	Plate	SA-203	A	...	37.0	65.0
3½ Ni	9B	Plate	SA-203	D	...		
2½ Ni	9A	Plate	SA-203	B	...	40.0	70.0
3½ Ni	9B	Plate	SA-203	E	...		
3½ Ni	9B	Forg.	SA-350	LF3	...	40.0	70.0
½ Cr-½ Mo	3	Plate	SA-387	A annealed	...	33.0	55.0
½ Cr-½ Mo	3	Plate	SA-387	A norm. and temp.	(30)	45.0	70.0
½ Cr-½ Mo	3	Smls. Pp.	SA-335	P2	...	30.0	55.0
	3	Smls. Pp.	SA-369	FP2	...		
½ Cr-½ Mo	3	Smls. Tb.	SA-213	T2	...	30.0	60.0
½ Cr-½ Mo	3	Forg.	SA-182	F2	...	40.0	70.0
1 Cr-V	10B	Smls. Tb.	SA-213	T17	(5)	30.0	60.0
1 Cr-$^1/_5$ Mo	...	Bolt.	SA-193	B7 > 4"	...	75.0	100.0
1 Cr-$^1/_5$ Mo	...	Bolt.	SA-193	B7 > 2½" ≤ 4"	...	95.0	115.0
1 Cr-$^1/_5$ Mo	...	Bolt.	SA-193	B7 ≤ 2½"	...	105.0	125.0
1 Cr-½ Mo	4	Plate	SA-387	B annealed	...	33.0	55.0
1 Cr-½ Mo	4	Plate	SA-387	B norm. and temp.	(14)(30)	40.0	65.0
1 Cr-½ Mo	4	Smls. Tb.	SA-213	T12	...	30.0	60.0
1 Cr-½ Mo	4	Smls. Pp.	SA-335	P12	...		
1 Cr-½ Mo	4	Smls. Pp.	SA-369	FP12	...		
1 Cr-½ Mo	4	Forg.	SA-182	F12	(14)	40.0	70.0
1 Cr-½ Mo	4	Forg.	SA-336	F2	(14)		
1 Cr-½ Mo-V	...	Bolt.	SA-193	B16 > 4"	...	85.0	100.0
1 Cr-½ Mo-V	...	Bolt.	SA-193	B16 > 2½" ≤ 4"	...	95.0	110.0
1 Cr-½ Mo-V	...	Bolt.	SA-193	B16 ≤ 2½"	...	105.0	125.0
1¼ Cr-½ Mo-Si	4	Smls. Tb.	SA-199	T11	...	25.0	60.0
1¼ Cr-½ Mo-Si	4	Smls. Tb.	SA-213	T11	...	30.0	
1¼ Cr-½ Mo-Si	4	Smls. Pp.	SA-335	P11	...	30.0	
1¼ Cr-½ Mo-Si	4	Smls. Pp.	SA-369	FP11	...	30.0	
1¼ Cr-½ Mo-Si	4	Plate	SA-387	C annealed	...	35.0	
1¼ Cr-½ Mo	4	Forg.	SA-182	F11	(14)	40.0	70.0

TABLE UCS-23 (CONT'D)
MAXIMUM ALLOWABLE STRESS VALUES IN TENSION FOR CARBON AND LOW-ALLOY STEEL, IN KIPS/SQ IN. (MULTIPLY BY 1000 TO OBTAIN PSI)
(See UW-12(c) for vessels constructed under Part UW that include welded joints that are neither fully radiographed nor spot radiographically examined)

For Metal Temperatures Not Exceeding Deg F												Specification Number	Grade
−20 to 650	700	750	800	850	900	950	1000	1050	1100	1150	1200		
													LOW ALLOY STEELS (Cont'd)
...	...	...	...	...	...	...	...	...	...	...	...	SA-333	9
												SA-334	9
												SA-333	7
												SA-334	7
												SA-352	LC2
16.2	...	...	...	...	...	...	...	...	...	...	...	SA-333	3
												SA-334	3
												SA-352	LC3
16.2	15.5	13.8	11.4	8.9	6.5	4.5	2.5	...	...	...	...	SA-203	A
												SA-203	D
17.5	16.6	14.7	12.0	9.2	6.5	4.5	2.5	...	...	...	...	SA-203	B
												SA-203	E
17.5	...	...	...	...	...	...	...	...	...	...	...	SA-350	LF3
13.7	13.7	13.7	13.4	13.1	12.5	10.7	6.2	...	...	...	...	SA-387	A annealed
13.7	13.7	13.7	13.4	13.1	12.5	10.7	6.2	...	...	...	...	SA-387	A norm. and temp.
13.7	13.7	13.7	13.4	13.1	12.5	10.0	6.2	...	...	...	...	SA-335	P2
												SA-369	FP2
15.0	15.0	15.0	14.4	13.7	12.5	10.0	6.2	...	...	...	...	SA-213	T2
17.5	17.5	17.5	17.5	16.8	14.5	10.0	6.2	...	...	...	...	SA-182	F2
15.0	...	...	...	...	...	...	...	...	...	...	...	SA-213	T17
18.7	18.7	18.7	18.0	16.2	12.5	8.5	4.5	...	...	...	...	SA-193	B7 > 4"
23.0	23.0	22.0	20.0	16.2	12.5	8.5	4.5	...	...	...	...	SA-193	B7 > 2½" ≤ 4"
25.0	25.0	23.6	21.0	17.0	12.5	8.5	4.5	...	...	...	...	SA-193	B7 ≤ 2½"
13.7	13.7	13.7	13.7	13.6	13.0	11.0	7.5	5.0	2.8	1.5	1.0	SA-387	B annealed
...	15.1	15.1	15.1	14.6	13.7	11.0	7.5	5.0	2.8	1.5	1.0	SA-387	B norm. and temp.
												SA-213	T12
15.0	15.0	15.0	14.7	14.2	13.1	11.0	7.5	5.0	2.8	1.5	1.0	SA-335	P12
												SA-369	FP12
												SA-182	F12
...	16.1	15.5	14.8	14.2	13.1	11.0	7.5	5.0	2.8	1.5	1.0	SA-336	F2
20.0	20.0	20.0	20.0	18.7	16.6	14.2	11.0	6.2	2.7	...	...	SA-193	B16 > 4"
22.0	22.0	22.0	22.0	21.0	18.5	15.3	11.0	6.2	2.7	...	...	SA-193	B16 > 2½" ≤ 4"
25.0	25.0	25.0	25.0	23.5	20.5	16.0	11.0	6.2	2.7	...	...	SA-193	B16 ≤ 2½"
												SA-199	T11
												SA-213	T11
15.0	15.0	15.0	15.0	14.4	13.1	11.0	7.8	5.5	4.0	2.5	1.2	SA-335	P11
												SA-369	FP11
												SA-387	C annealed
...	16.1	15.5	15.0	14.4	13.1	11.0	7.8	5.5	4.0	2.5	1.2	SA-182	F11

TABLE UCS-23 (CONT'D)
MAXUMUM ALLOWABLE STRESS VALUES IN TENSION FOR CARBON AND LOW-ALLOY STEEL, IN KIPS/SQ IN. (MULTIPLY BY 1000 TO OBTAIN PSI)
(See UW-12(c) for vessels constructed under Part UW that include welded joints that are neither fully radiographed nor spot radiographically examined)

Nominal Composition	P Number	Product Form	Specification Number	Grade	Notes	Specified Minimum Yield	Specified Minimum Tensile
LOW ALLOY STEELS (Cont'd)							
1¼ Cr-½ Mo	4	Cast.	SA-217	WC6	(8)	40.0	70.0
1¼ Cr-½ Mo-Si	4	Plate	SA-387	C norm. and temp.	(14)(30)	45.0	75.0
1½ Si-½ Mo	3	Smls. Pp.	SA-335	P15	...	30.0	60.0
2 Cr-½ Mo	4	Smls. Tb.	SA-199	T3b	...	25.0	60.0
2 Cr-½ Mo	4	Smls. Pp.	SA-369	FP3b	...	30.0	
2¼ Cr-1 Mo	5	Smls. Tb.	SA-199	T22	...	25.0	60.0
2¼ Cr-1 Mo	5	Smls. Tb.	SA-213	T22	...	30.0	
2¼ Cr-1 Mo	5	Smls. Pp.	SA-335	P22	...	30.0	
2¼ Cr-1 Mo	5	Smls. Pp.	SA-369	FP-22	...	30.0	
2¼ Cr-1 Mo	5	Plate	SA-387	D annealed	...	30.0	
2¼ Cr-1 Mo	5	Forg.	SA-182	F22	...	40.0	70.0
2¼ Cr-1 Mo	5	Cast.	SA-217	WC9	(8)	40.0	70.0
2¼ Cr-1 Mo	5	Plate	SA-387	D norm. and temp.	(14)(30)	45.0	75.0
2¼ Cr-1 Mo	5	Forg.	SA-336	F22	(14)	40.0	75.0
2¼ Cr-1 Mo	10F	Cast.	SA-487	8N	(14)	55.0	85.0
3 Cr-1 Mo	5	Plate	SA-387	E annealed	...	30.0	60.0
3 Cr-0.9 Mo	5	Smls. Tb.	SA-199	T21	...	25.0	
3 Cr-0.9 Mo	5	Smls. Tb.	SA-213	T21	...	30.0	
3 Cr-0.9 Mo	5	Smls. Pp.	SA-335	P21	...	30.0	
3 Cr-1 Mo	5	Smls. Pp.	SA-369	FP21	...	30.0	
3 Cr-0.9 Mo	5	Forg.	SA-182	F21	(14)	40.0	70.0
3 Cr-1 Mo	5	Plate	SA-387	E norm. and temp.	(14)(30)	45.0	75.0
5 Cr-½ Mo	5	Plate	SA-357	...	(14)	30.0	60.0
5 Cr-½ Mo	5	Smls. Tb.	SA-199	T5	(14)	25.0	
5 Cr-½ Mo	5	Smls. Pp.	SA-213	T5	(14)	30.0	
5 Cr-½ Mo	5	Smls. Pp.	SA-335	P5	(14)	30.0	
5 Cr-½ Mo	5	Smls. Pp.	SA-369	FP5	(14)	30.0	
5 Cr-½ Mo	5	Forg.	SA-182	F5	(14)	30.0	
5 Cr-½ Mo	5	Forg.	SA-336	F5	(14)	36.0	
5 Cr-½ Mo	5	Smls. Tb.	SA-213	T5b	(14)	30.0	
5 Cr-½ Mo-Si	5	Smls. Pp.	SA-335	P5b	(14)	30.0	
5 Cr-½ Mo-Si	5	Smls. Tb.	SA-213	T5c	(14)	30.0	
5 Cr-½ Mo-Ti	5	Smls. Pp.	SA-335	P5c	(14)	30.0	
5 Cr-½ Mo-Ti or Cb							
5 Cr-½ Mo	5	Forg.	SA-336	F5a	(14)	60.0	80.0
5 Cr-½ Mo	5	Forg.	SA-182	F5a	(14)	65.0	90.0
5 Cr-½ Mo	5	Cast.	SA-217	C5	(8)	60.0	90.0
5 Cr-½ Mo	...	Bolt.	SA-193	B5	(9)(10)	80.0	100.0

TABLE UCS-23 (CONT'D)
MAXIMUM ALLOWABLE STRESS VALUES IN TENSION FOR CARBON AND LOW-ALLOY STEEL, IN KIPS/SQ IN. (MULTIPLY 1000 TO OBTAIN PSI)
(See UW-12(c) for vessels constructed under Part UW that include welded joints that are neither fully radiographed nor spot radiographically examined)

For Metal Temperatures Not Exceeding Deg F												Specification Number	Grade
–20 to 650	700	750	800	850	900	950	1000	1050	1100	1150	1200		
LOW ALLOY STEELS (Cont'd)													
17.5	17.5	17.5	17.0	15.8	14.0	11.0	7.8	5.5	4.0	...	...	SA-217	WC6
...	17.2	17.2	17.2	16.7	15.0	11.0	7.8	5.5	4.0	2.5	1.2	SA-387	C norm. and temp.
15.0	15.0	15.0	14.4	13.7	12.5	10.0	6.2	....	...	...	...	SA-335	P15
												SA-799	T3b
15.0	15.0	15.0	14.7	14.0	12.5	10.0	6.2	4.2	2.7	1.7	1.2	SA-369	FP3b
												SA-199	T22
												SA-213	T22
15.0	15.0	15.0	15.0	14.4	13.1	11.0	7.8	5.8	4.2	3.0	2.0	SA-335	P22
												SA-369	FP22
												SA-387	D annealed
17.5	17.5	17.5	17.5	16.0	14.0	11.0	7.8	5.8	4.2	3.0	2.0	SA-182	F22
17.5	17.5	17.5	17.0	15.8	14.0	11.0	7.8	5.8	4.2	3.0	2.0	SA-217	WC9
...	17.1	17.0	16.8	16.3	14.7	11.0	7.8	5.8	4.2	3.0	2.0	SA-387	D norm. and temp.
...	17.5	17.5	17.5	16.3	14.7	11.0	7.8	5.8	4.2	3.0	2.0	SA-336	F22
...	...	...	...	...	...	...	...	...	...	...	...	SA-487	8N
												SA-387	E annealed
												SA-199	T21
15.0	14.8	14.5	13.9	13.2	12.0	9.0	7.0	5.5	4.0	2.7	1.5	SA-213	T21
												SA-335	P21
												SA-369	FP21
...	15.1	14.6	13.9	13.2	12.0	9.0	7.0	5.5	4.0	2.7	1.5	SA-182	F21
...	17.1	17.0	16.8	15.7	...	9.0	7.0	5.5	4.0	2.7	1.5	SA-387	E norm. and temp.
												SA-357	...
												SA-199	T5
												SA-213	T5
												SA-335	P5
												SA-369	FP5
...	13.4	13.1	12.8	12.0	10.3	7.6	5.6	4.1	3.0	2.0	1.3	SA-182	P5
												SA-336	F5
												SA-213	T5b
												SA-335	P5b
												SA-213	T5c
												SA-335	P5c
...	16.5	15.5	14.5	12.8	10.3	7.6	5.6	4.1	3.0	2.0	1.3	SA-336	F5a
...	17.5	16.0	14.5	12.8	10.3	7.6	5.6	4.1	3.0	2.0	1.3	SA-182	F5a
22.5	21.6	20.4	19.0	14.5	10.3	7.6	5.6	4.1	3.0	2.0	1.3	SA-217	C5
20.0	20.0	20.0	18.5	14.5	10.3	7.6	5.6	4.1	3.0	2.0	1.3	SA-193	B5

TABLE UCS-23 (CONT'D)
MAXIMUM ALLOWABLE STRESS VALUES IN TENSION FOR CARBON AND LOW-ALLOY STEEL, IN KIPS/SQ IN. (MULTIPLY BY 1000 TO OBTAIN PSI)
(See UW-12(c) for vessels constructed under Part UW that include welded joints that are neither fully radiographed nor spot radiographically examined)

Nominal Composition	P Number	Product Form	Specification Number	Grade	Notes	Specified Minimum Yield	Specified Minimum Tensile
LOW ALLOY STEELS (Cont'd)							
7 Cr-½ Mo	5	Smls. Tb.	SA-199	T7	(14)	25.0	60.0
7 Cr-½ Mo	5	Smls. Tb.	SA-213	T7	(14)	30.0	
7 Cr-½ Mo	5	Smls. Pp.	SA-335	P7	(14)	30.0	
7 Cr-½ Mo	5	Smls. Pp.	SA-369	FP7	(14)	30.0	
7 Cr-½ Mo	5	Forg.	SA-182	F7	(14)	36.0	
9 Cr-1 Mo	5	Smls. Tb.	SA-199	T9	(14)	25.0	60.0
9 Cr-1 Mo	5	Smls. Tb.	SA-213	T9	(14)	30.0	
9 Cr-1 Mo	5	Smls. Pp.	SA-335	P9	(14)	30.0	
9 Cr-1 Mo	5	Smls. Pp.	SA-369	FP9	(14)	30.0	
9 Cr-1 Mo	5	Cast.	SA-217	C12	(8)	60.0	90.0
9 Cr-1 Mo	5	Forg.	SA-182	F9	(14)	70.0	100.0

TABLE UCS-23 (CONT'D)
MAXIMUM ALLOWABLE STRESS VALUES IN TENSION FOR CARBON AND LOW-ALLOY STEEL, IN KIPS/SQ IN. (MULTIPLY 1000 TO OBTAIN PSI)
(See UW-12(c) for vessels constructed under Part UW that include welded joints that are neither fully radiographed nor spot radiographically examined)

For Metal Temperatures Not Exceeding Deg F												Specification Number	Grade
-20 to 650	700	750	800	850	900	950	1000	1050	1100	1150	1200		
LOW ALLOY STEELS (Cont'd)													
												SA-199	T7
												SA-213	T7
...	13.4	13.1	12.5	11.5	9.5	7.0	5.0	3.5	2.5	1.8	1.2	SA-335	P7
												SA-369	FP7
												SA-182	F7
												SA-199	T9
												SA-213	T9
...	13.4	13.1	12.8	12.5	12.0	10.8	8.5	5.5	3.3	2.2	1.5	SA-335	P9
												SA-369	FP9
22.5	22.0	21.0	19.4	17.3	15.0	11.7	8.5	5.5	3.3	2.2	1.5	SA-217	C12
...	21.2	20.0	17.7	15.4	13.4	10.8	8.5	5.5	3.3	2.2	1.5	SA-182	F9

(See pages 120–121 for Notes to Table UCS-23.)

NOTES: The stress values in this table may be interpolated to determine values for intermediate temperatures.

Stress values in restricted shear such as dowel bolts, rivets, or similar construction in which the shearing member is so restricted that the section under consideration would fail without reduction of area shall be 0.80 times the values in the above table.

Stress values in bearing shall be 1.60 times the values in the above table.

(1) See UCS-6(b).

(3) These stress values are one-fourth the specified minimum tensile strength multiplied by a quality factor of 0.92, except for SA-283, Grade D, SA-7 and SA-36.

(4) For service temperatures above 850 F it is recommended that killed steels containing not less than 0.10 percent residual silicon be used. Killed steels which have been deoxidized with large amounts of aluminum and rimmed steels may have creep and stress rupture properties in the temperature range above 850 F, which are somewhat less than those on which the values in the above table are based.

(5) Between temperatures of 650 and 1000 F, inclusive, the stress values for Specification SA-201, Grade B, may be used until high temperature test data become available.

(6) Only killed steel shall be used above 850 F.

(7) To these stress values a quality factor as specified in UG-24 shall be applied for castings.

(8) These stress values apply to normalized and drawn material only.

(9) These stress values are established from a consideration of strength only and will be satisfactory for average service. For bolted joints, where freedom from leakage over a long period of time without retightening is required, lower stress values may be necessary as determined from the relative flexibility of the flange and bolts, and corresponding relaxation properties.

(10) Between temperatures of –20 and 400 F, stress values equal to the lower of the following will be permitted: 20 percent of the specified tensile strength, or 25 percent of the specified yield strength.

(11) Not permitted above 450 F; allowable stress value 7000 psi.

(12) Between temperatures of 750 and 1000 F, inclusive, the stress values for Specification SA-515, Grade 70, may be used until high temperature test data become available.

(13) The stress values to be used for temperatures below –20 F when steels are made to conform with Specification SA-593 shall be those that are given in the column for –20 to 650 F.

(14) Maximum allowable stress values for temperatures below 700 F are given in the following table:

Nominal Composition	P Number	Product Form	Specification Number	Grade	For Metal Temperatures Not Exceeding Deg F: –20 to 100	200	300	400	–20 to 400	500	600	650
C-Mn-Si	1	Plate	SA-537	A>1¼"	16.2	16.2	15.9	15.9	...	15.9	15.9	15.9
C-Mn-Si	1	Plate	SA-537	A≤1¼"	17.5	17.5	17.2	17.2	...	17.2	17.2	17.2
C-Mn-Si	12B Sub 2	Plate	SA-537	B>1¼"	18.7	18.7	18.7	18.5	...	18.5	18.5	18.4
C-Mn-Si	12B Sub 2	Plate	SA-537	B≤1¼"	20.0	20.0	20.0	19.8	...	19.8	19.8	19.6
1 Mn-0.1 V	10A	Cast	SA-487	IN	21.2	20.2	19.6	18.4	...	18.1	17.2	16.9
½ Ni-½ Cu	10F	Cast	SA-487	4N	22.5	21.4	21.0	21.0	...	21.0	21.0	21.0
1 Cr-½ Mo	12B Sub 3	Plate	SA-387	B, norm. and temp.	16.2	15.7	15.1	15.1	...	15.1	15.1	15.1
1 Cr-½ Mo	4	Forg.	SA-182	F12	...	...	...	...	17.5	17.5	17.5	16.8
1 Cr-½ Mo	4	Forg.	SA-336	F2								
1¼ Cr-½ Mo	4	Forg.	SA-182	F11								
1¼ Cr-½ Mo	12B Sub 3	Plate	SA-387	C, norm. and temp.	18.7	17.8	17.2	17.2	...	17.2	17.2	17.2
1¼ Cr-1 Mo	12B Sub 4	Plate	SA-387	D, norm. and temp.	18.7	18.6	17.9	17.4	...	17.2	17.2	17.2
¼ Cr-1 Mo	5	Forg.	SA-336	F22								
¼ Cr-1 Mo	10F	Cast	SA-487	8N	21.2	20.6	20.0	19.5	...	19.0	19.0	19.0
Cr-0.9 Mo	5	Forg.	SA-182	F21	...	...	...	...	17.5	16.8	16.0	15.6
Cr-1 Mo	12B Sub 4	Plate	SA-387	E, norm. and temp.	18.7	18.6	17.9	17.4	...	17.2	17.2	17.2

Nominal Composition	P Number	Product Form	Specification Number	Grade	For Metal Temperatures Not Exceeding Deg F: –20 to 100	200	300	400	–20 to 400	500	600	650
5 Cr-½ Mo	5	Forg.	SA-182	F5	...	...	...	...	15.0	14.5	14.0	13.7
5 Cr-½ Mo	5	Smls. Tb.	SA-199	T5								
5 Cr-½ Mo	5	Smls. Tb.	SA-213	T5								
5 Cr-½ Mo	5	Smls. Pp.	SA-335	P5								
5 Cr-½ Mo	5	Forg.	SA-336	F5								
5 Cr-½ Mo	5	Plate	SA-387	...								
5 Cr-½ Mo	5	FB Pp.	SA-369	FP5								
5 Cr-½ Mo-Si	5	Smls. Tb.	SA-213	T5b								
5 Cr-½ Mo-Si	5	Smls. Pp.	SA-335	P5b								
5 Cr-½ Mo-Ti	5	Smls. Tb.	SA-213	T5c								
5 Cr-½ Mo-Ti	5	Smls. Pp.	SA-335	P5c								
5 Cr-½ Mo	5	Forg.	SA-336	F5a	...	...	...	...	20.0	19.2	18.0	17.3
5 Cr-½ Mo	5	Forg.	SA-182	F5a	...	...	...	...	22.5	21.6	20.1	19.0
7 Cr-½ Mo	5	Forg.	SA-182	F7	...	...	...	...	15.0	14.5	14.0	13.7
7 Cr-½ Mo	5	Smls. Tb.	SA-199	T7								
7 Cr-½ Mo	5	Smls. Tb.	SA-213	T7								
7 Cr-½ Mo	5	Smls. Pp.	SA-335	P7								
7 Cr-½ Mo	5	FB Pp.	SA-369	FP7								
9 Cr-1 Mo	5	Smls. Tb.	SA-199	T9	...	...	...	...	25.0	24.0	22.7	22.0
9 Cr-1 Mo	5	Smls. Tb.	SA-213	T9								
9 Cr-1 Mo	5	Smls. Pp.	SA-335	P9								
9 Cr-1 Mo	5	FB Pp.	SA-369	FP9								
9 Cr-1 Mo	5	Forg.	SA-182	F9	...	...	...	...	25.0	24.0	22.7	22.0
2 Ni	9A	Smls. Pp.	SA-333	9	15.7	...	...	...	...	...	...	...
2 Ni	9A	Smls. Tb.	SA-334	9								

(15) For temperatures below 400 F, stress values equal to 20 percent of the specified minimum tensile strength will be permitted.

(19) These allowable stress values apply also to structural shapes and bars.

(20) Stress values apply to normalized, or normalized and tempered or oil quenched and tempered material only, as per applicable specification.

(21) Stress values apply to quenched and tempered material only, as per applicable specification.

(22) Welding or brazing is not permitted when carbon context exceeds 0.35 percent by ladle analysis except for limited types of welding as allowed in Part UF.

(24) Maximum allowable stress values shall be as follows:

Grade	Normalized or Normalized and Tempered: –20 to 650F	Liquid Quenched and Tempered: –20 to 100	200	300	400	500	600	650
I	15,000	15,000	15,000	...	...	...	...	...
II	18,750	18,750	18,750	...	...	...	...	...
III	22,500	22,500	22,500	...	...	...	...	...
IV	26,250	26,250	25,050	24,600	24,600	24,600	24,600	24,600
V A	...	30,000	28,850	28,850	28,850	28,850	28,850	28,850
V B	...	30,000	29,050	28,500	28,250	28,200	27,800	26,750
V E	...	30,000	29,800	28,700	28,700	28,700	28,700	27,500
VC&D	...	30,000	30,000	...	...	...	...	...

(25) See UCS-6(c).

(26) This material shall not be used in thicknesses above 0.58 in.

(27) Upon prolonged exposure to temperatures above about 800 F, the carbide phase of carbon steel may be converted to graphite.

(28) Upon prolonged exposure to temperatures above about 875 F, the carbide phase of carbon-molybdenum steel may be converted to graphite.

(29) The material shall not be used in thickness above 0.375 in.

(30) For temperatures above which stresses are given, the allowable stresses for the annealed plate shall be used.

(31) Where the fabricator performs the heat treatment the requirements of UHT-81 shall be met.

TABLE UCS-27
MAXIMUM ALLOWABLE STRESS VALUES IN TENSION FOR CARBON AND LOW-ALLOY PIPE AND TUBES OF WELDED MANUFACTURE, IN KIPS/SQ IN. (MULTIPLY BY 1000 TO OBTAIN PSI)
(See UW-12(c) for vessels constructed under Part UW that include welded joints that are neither fully radiographed nor spot radiographically examined)

Joint efficiencies used for preparing this table are:
Electric Resistance Welded – 85%, Lap Welded – 80%, Butt Welded – 60%

Nominal Composition	P Number	Product Form	Specification Number	Grade	Notes	Weld	Specified Minimum Yield	Specified Minimum Tensile
Carbon Steel	1	Wld. Tb.	SA-557	A2	(2)(3)	Resis.	26.0	47.0
Carbon Steel	1	Wld. Pp.	SA-53	A	(1)(2)	Resis.	30.0	48.0
Carbon Steel	1	Wld. Pp.	SA-135	A	(2)(3)	Resis.		
Carbon Steel	1	Wld. Tb.	SA-178	A	(2)(3)	Resis.	...	...
Carbon Steel	1	Wld. Tb.	SA-214	...	(2)(3)	Resis.		
Carbon Steel	1	Wld. Tb.	SA-226	...	(2)(3)	Resis.		
Carbon Steel	1	Wld. Pp.	SA-333	1	...	Resis.	30.0	55.0
Carbon Steel	1	Wld. Tb.	SA-334	1	...	Resis.		
Carbon Steel	1	Wld. Pp.	SA-53	B	(1)(2)	Resis.	35.0	60.0
Carbon Steel	1	Wld. Pp.	SA-135	B	(2)(3)	Resis.		
Carbon Steel	1	Wld. Pp.	SA-333	6	...	Resis.	35.0	60.0
Carbon Steel	1	Wld. Tb.	SA-334	6	...	Resis.		
Med. Carbon Steel	1	Wld. Tb.	SA-178	C	(2)(3)	Resis.	37.0	60.0
Carbon Steel	1	Wld. Tb.	SA-557	B2	(2)(3)	Resis.		
Carbon Steel	1	Wld. Tb.	SA-557	C2	(2)(3)	Resis.	40.0	70.0
C-½ Mo	3	Wld. Tb.	SA-250	T1b	...	Resis.	28.0	53.0
C-½ Mo	3	Wld. Tb.	SA-250	T1	...	Resis.	30.0	55.0
C-½ Mo	3	Wld. Tb.	SA-250	T1a	...	Resis.	32.0	60.0
¾ Cr-½ Ni-0.4 Cu	4	Wld. Tb.	SA-423	1	...	Elect.	37.0	60.0
¾ Ni-0.6 Cu-0.1 Mo	4	Wld. Tb.	SA-423	2	...	Elect.		
2½ Ni	9A	Wld. Pp.	SA-333	7	...	Resis.	35.0	65.0
2½ Ni	9A	Wld. Tb.	SA-334	7	...	Resis.		
3½ Ni	9B	Wld. Pp.	SA-333	3	...	Resis.		
3½ Ni	9B	Wld. Pp.	SA-334	3	...	Resis.		

TABLE UCS-27 (Cont'd)
MAXIMUM ALLOWABLE STRESS VALUES IN TENSION FOR CARBON AND LOW-ALLOY PIPE AND TUBES OF WELDED MANUFACTURE, IN KIPS/SQ IN. (MULTIPLY BY 1000 TO OBTAIN PSI)
(See UW-12(c) for vessels constructed under Part UW that include welded joints that are neither fully radiographed nor spot radiographically examined)

Joint efficiencies used for preparing this table are:
Electric Resistance Welded – 85%, Lap Welded – 80%, Butt Welded – 60%

For Metal Temperatures Not Exceeding Deg F												Specification Number	Grade
–20 to 650	700	750	800	850	900	950	1000	1050	1100	1150	1200		
10.0	9.7	8.2	7.8	6.6	4.2	2.5	1.2	...	...	...	...	SA-557	A2
10.2	9.9	9.1	7.9	6.7	5.5	...	...	...	...	...	...	SA-53	A
												SA-135	A
10.0	9.7	8.9	7.8	6.6	5.5	3.8	2.1	...	...	...	...	SA-178	A
												SA-214	...
												SA-226	...
11.7	...	...	...	...	...	...	...	...	...	...	...	SA-333	1
												SA-334	1
12.7	12.2	11.0	9.2	7.3	5.5	...	...	...	...	...	...	SA-53	B
												SA-135	B
12.7	...	...	...	...	...	...	...	...	...	...	...	SA-333	6
												SA-334	6
12.7	12.2	11.0	9.2	7.3	5.5	3.8	2.1	...	...	...	...	SA-178	C
												SA-557	B2
15.0	14.1	12.5	10.2	7.3	5.5	3.8	2.1	...	...	...	...	SA-557	C2
11.2	11.2	11.2	11.0	10.8	10.6	8.5	5.3	...	...	...	...	SA-250	T1b
11.7	11.7	11.7	11.4	11.2	10.6	8.5	5.3	...	...	...	...	SA-250	T1
12.7	12.7	12.7	12.2	11.7	10.6	8.5	5.3	...	...	...	...	SA-250	T1a
12.7	...	...	...	...	...	...	...	...	...	...	...	SA-423	1
												SA-423	2
13.8	...	...	...	...	...	...	...	...	...	...	...	SA-333	7
												SA-334	7
												SA-333	3
												SA-334	3

NOTES: The stress values in this table may be interpolated to determine values for intermediate temperatures.

(1) These stress values permitted for open-hearth, basic oxygen or electric-furnace steels only.

(2) For service temperatures above 850 F it is recommended that killed steels containing not less than 0.10% residual silicon be used.

Killed steels which have been deoxidized with large amounts of aluminum and rimmed steels may have creep and stress-rupture properties in the temperature range above 850 F, which are somewhat less than those on which the values in the above table are based.

(3) Only killed steel shall be used above 850 F.

(4) Not permitted above 100 F; allowable stress value 13.3 csi, –20 to 100 F.

UCS-56 Requirements for Postweld Heat Treatment

(*a*) Before applying the detailed requirements and exemptions in these paragraphs, satisfactory weld procedure qualifications of the procedures to be used shall be performed in accordance with all the essential variables of Section IX of the Code including conditions of postweld heat treatment or lack of postweld heat treatment and including other restrictions listed below.

Except as otherwise specifically provided in the notes to Table UCS-56 all welded pressure vessels or pressure vessel parts shall be given a postweld heat treatment at a temperature not less than specified in Table UCS-56 when the nominal thickness, including corrosion allowance, of any welded joint in the vessel or vessel part exceeds the limits in the notes to Table UCS-56. The exemptions provided for in the notes to Table UCS-56 are not permitted when postweld heat treatment is a service requirement as set forth in UCS-67.

The materials in Table UCS-56 are listed in accordance with Section IX P-Number material groupings of Table Q-11.1 and also listed in Tables UCS-23 and UCS-27.

(*b*) Except for materials covered by notes (8) and (9) of Table UCS-56, holding temperatures and/or holding times in excess of the minimum values given in Table UCS-56 may be used. Intermediate postweld heat treatments need not conform to the requirements of Table UCS-56.

(*c*) When pressure parts of two different P-number groups are joined by welding, the postweld heat treatment shall be that specified in Table UCS-56 with applicable notes for the material requiring the higher postweld temperature. When nonpressure parts are welded to pressure parts, the postweld heat treatment temperature of the pressure part shall control.

(*d*) When the welded joint connects parts that are of different thickness, the thickness to be used in applying the requirements for postweld heat treatment in (a) shall be the following:

(*1*) The thinner of two adjacent butt-welded plates including head to shell connections;

(*2*) The thicker of the shell or head plate in connections to intermediate heads of the type shown in Fig. UW-13.1(f);

(*3*) The thickness of the shell in connections to tube sheets, flat heads, covers, or similar constructions;

(*4*) The thickness of the shell or head plate in nozzle attachment welds;

(*5*) The thickness of the nozzle neck at the joint in nozzle neck to flange connections;

(*6*) The thickness of the pressure part, at the point of attachment, where a nonpressure part is welded to a pressure part.

(*e*) The operation of postweld heat treatment shall be carried out by one of the procedures given in UW-40 in accordance with the following requirements:

(*1*) The temperature of the furnace shall not exceed 600 F at the time the vessel or part is placed in it;

(*2*) Above 600 F, the rate[1] of heating shall be not more than 400 F per hour divided by the maximum metal thickness of the shell or head plate in inches, but in no case more than 400 F per hour. During the heating period there shall not be a greater variation in temperature throughout the portion of the vessel being heated than 250 F within any 15 ft interval of length;

(*3*) The vessel or vessel part shall be held at or above the temperature specified in Table UCS-56 for the period of time specified in the Table. During the holding period there shall not be a greater difference than 150 F between the highest and lowest temperature throughout the portion of the vessel being heated, except that for P-9 and P-10 materials the temperature shall be maintained within the range given in the notes to Table UCS-56;

(*4*) During the heating and holding periods, the furnace atmosphere shall be so controlled as to avoid excessive oxidation of the surface of the vessel. The furnace shall be of such design as to prevent direct impingement of the flame on the vessel;

(*5*) Above 600 F, cooling shall be done in a closed furnace or cooling chamber at a rate[2] not greater than 500 F per hour divided by the maximum metal thickness of the shell or head plate in inches, but in no case more than 500 F per hour. From 600 F the vessel may be cooled in still air.

[1]The rates of heating and cooling need not be less than 100 F per hour. However, in all cases consideration of closed chambers and complex structures may indicate reduced rates of heating and cooling to avoid structural damage due to excessive thermal gradients.

TABLE UCS-56
POSTWELD HEAT TREATMENT REQUIREMENTS FOR CARBON AND LOW ALLOY STEELS

Material	Notes	Minimum Holding Temperature F	Minimum Holding Time at Temperature, hr per in. of thickness (Note 2)
P-1	(1)(3)	1100	1
P-2	(1)(4)	1100	1
P-3	(1)(5)	1100	1
P-4	(6)	1100	1
P-5	(7)	1250	1
P-9A	(1)(6)	1100	1
P-9B	(1)(8)	1100	1
P-10A	(1)(5)	1100	1
P-10B	(6)	1100	1
P-12B Sub 1	(1)(5)(9)	1100	1
P-12B Sub 2	(1)(3)(9)	1100	1

NOTES TO TABLE UCS-56

(1) When it is impractical to postweld heat treat at the temperature specified in this table, it is permissible to carry out the postweld heat treatment at lower temperatures for longer periods of time in accordance with the following tabulation:

Decrease in Temperature below minimum Specified Temperature, deg F	Minimum Holding Time at Decreased Temperature, hr per in. of Thickness
50	2
100	3
150	5
200	10

(2) The minimum holding time at temperature for material under $^1/_4$ in. in thickness shall be $^1/_4$ hr.

(3) Postweld heat treatment of P-1 and P-12B, Subgroup 2 materials is not mandatory under the following conditions:

(a) For material up to and including 1½ in. thickness, provided that material over 1¼ in. thickness is preheated to a minimum temperature of 200 F during welding and provided postweld heat treatment is not required as a service requirement as set forth in UW-2.

(b) For material over $1^1/_2$ in. thickness and for material of any thickness when the vessel requires postweld heat treatment in UW-2, all welded connections and attachments shall be postweld heat treated except that:

(1) Postweld heat treatment is not mandatory for fillet welds and groove welds of not over $^1/_2$ in. in size that attach nozzle connections that have a finished inside diameter not greater than 2 in. provided the connections do not form ligaments that require an increase in shell or head thickness, and preheat to a minimum temperature of 200 F is applied.

(2) Postweld heat treatment is not mandatory for fillet welds having a throat thickness of $^1/_2$ in. or less used for attaching nonpressure parts to pressure parts and preheat to a minimum temperature of 200 F is applied when the thickness of the pressure part exceeds $^3/_4$ in.

(4) Postweld heat treatment of P-2 materials is not mandatory for material having a thickness at the joint of $^3/_4$ in. or less and provided postweld heat treatment is not required as a service requirement as set forth in UW-2.

(5) Postweld heat treatment of P-3, P-10A and P-12B Materials except for SA-302 and SA-533 materials, is not mandatory under the following conditions: (Postweld heat treatment is mandatory for SA-302 and SA-533 material for all thicknesses.)

(a) For material up to and including $^5/_8$ in. in thickness provided a welding procedure qualification described in UCS-56(a) has been made in equal or greater thickness than the production weld and provided postweld heat treatment is not required as a service requirement as set forth in UW-2.

(b) For material over $^5/_8$ in. thickness and for material of any thickness when the vessel requires postweld heat treatment in UW-2, all welded connections and attachments shall be postweld heat treated except that

(1) Postweld heat treatment is not mandatory for attaching to pressure parts which have a specified maximum carbon content[1] of not more than 0.25 percent nonpressure parts with fillet welds that have a throat thickness of $^1/_2$ in. or less, providing preheat to a minimum temperature of 200 F is applied.

(2) Postweld heat treatment is not mandatory for circumferential welds in pipe or tubes where the pipe or tubes have both a nominal wall thickness of $^1/_2$ in. or less and a specified maximum carbon content[1] of not more than 0.25 percent.

(6) Postweld heat treatment of P-4, P-9A and P-10B materials is not mandatory under the following conditions:

(a) For materials of Specification SA-202, SA-203, Grades A and B and SA-352, Grade LC2, up to and including $^5/_8$ in. in thickness provided a welding procedure qualification described in UCS-56(a) has been made in equal or greater thickness than the production weld and provided postweld heat treatment is not required as a service requirement as set forth in UW-2.

(b) For circumferential butt welds in pipe or tubes of P-4 materials where the pipe or tubes comply with all of the following conditions:

(1) A maximum nominal outside diameter of 4 in.

(2) A maximum thickness of $^1/_2$ in.

(3) A maximum specified carbon content[1] of not more than 0.15 percent.

(4) A minimum preheat of 250 F.

(c) For P-4 pipe or tube materials, meeting the requirements of (6) (b) (1), (2) and (3) having attachments nonpressure fillet welded to them provided:

(1) The fillet welds have a maximum throat thickness of ½ in.

(2) A minimum preheat temperature of 250 F is applied.

(7) Postweld heat treatment of P-5 materials is not mandatory under the following conditions:

(a) For circumferential butt welds in pipe or tubes of P-5 materials where the pipe or tubes comply with all of the following conditions:

(1) A maximum specified chromium content of 3.00 percent.

(2) A maximum nominal outside diameter of 4 in.

(3) A maximum thickness of $^1/_2$ in.

(4) A maximum specified carbon content[1] of not more than 0.15 percent.

(5) A minimum preheat of 300 F.

(b) For pipe or tube materials meeting the requirements of (7)(a)(1), (2), (3), and (4) having attachments nonpressure fillet welded to them provided.

(1) The fillet welds have a maximum throat thickness of ½ in.

(2) A minimum preheat temperature of 300 F is applied.

(8)(a) For postweld heat treatment of P-9 materials, the holding temperature shall not exceed 1175 F.

(b) Postweld heat treatment of P-9 materials is not mandatory for materials up to and including $^5/_8$ in. in thickness provided a welding procedure qualification described in UCS-56(a) has been made in equal or greater thickness than the production weld and provided postweld heat treatment is not required as a service requirement as set forth in UW-2.

(9) Consideration shall be given to the limitation of interpass temperature for various thicknesses to avoid detrimental effects on the mechanical properties of heat treated materials.

[1]SA-Material Specification carbon content, except when further limited by the purchaser to a value within the Specification limits.

[2]The rates of heating and cooling need not be less than 100 F per hour. However, in all cases consideration of closed chambers and complex structures may indicate reduced rates of heating and cooling to avoid structural damage due to excessive thermal gradients.

(*f*) Vessels or parts of vessels that have been postweld heat treated in accordance with the requirements of this paragraph shall again be postweld heat treated after repairs or alterations have been made if the welds made in such repairs or alterations require postweld treatment under the requirements given in (a).

UCS-57 Radiographic Examination

In addition to the requirements of UW-11, complete radiographic examination is required for each butt-welded joint at which the thinner of the plate or vessel wall thicknesses at the welded joint exceeds the thickness limit above which full radiography is required in Table UCS-57.

TABLE UCS-57
THICKNESS ABOVE WHICH FULL RADIOGRAPHIC EXAMINATION OF BUTT-WELDED JOINTS IS MANDATORY

P-Number Classification of Material	Nominal Thickness Above Which Butt-Welded Joints Shall be Fully Radiographed, in.
1	1¼
3	¾
4	⅝
5	0
9A	⅝
9B	⅝
9C	⅝
10A	¾
10B	⅝
12A	
Subgroup 1	1¼
12B	
Subgroup 1	¾
Subgroup 2	1¼
Subgroup 3	⅝
Subgroup 4	0
12C	
Subgroup 1	⅝

LOW-TEMPERATURE OPERATION

UCS-65 Scope

The following paragraphs contain mandatory requirements for vessels and vessel parts constructed of carbon and low-alloy steels that are to be used at operating temperatures below —20 F. Many of the materials acceptable for service at normal temperatures suffer such a decrease in impact resistance at subzero temperatures as to be unable safely to resist shock loading, sudden changes of stress, or high stress concentrations.

UCS-66 Materials

(*a*) Materials used in the construction of vessels to operate below —20 F shall conform to the specifications given in Table UCS-23 and to the requirements of this paragraph and of UCS-67. (See UG-84.)

(*b*) Vessels intended for service at temperatures below —20 F shall not be constructed of materials complying with Specifications SA-7, SA-36, SA-113 or SA-283.

(*c*) All materials shall meet the impact test requirements of UG-84 unless exempted as follows:

(*1*) No impact test is required on any material for use at temperatures of —20 F and above, or for use below that temperature when due to a lower seasonal atmospheric temperature;

(*2*) No impact test is required for materials used in fabricating a vessel for metal temperatures below —20 F when the minimum thickness is the greater of those determined under the most severe condition of coincident pressure (external or internal) and temperature in accordance with UG-21 for temperatures of: (a) —20 F and above, and (b) below —20 F in which case the coincident pressure (internal if above atmospheric and external if below atmospheric) shall be multiplied by two and one half;

(*3*) No impact test is required on rivets, nuts, or material less than 0.098 in. thick or on material added around openings that do not require reinforcement in accordance with UG-36(c)(3).

(*d*) For certification by the manufacturer of materials as provided in UG-84, all materials shall be given an appropriate normalizing heat-treatment. If welded, the deposited weld metal and the heat-affected zone shall also meet the impact test requirements of UG-84.

(*e*) The material manufacturer's identification marking required by the material specification shall not be die-stamped on plate material less than ¼ in. in thickness.

UCS-67 Design

(*a*) In addition to the requirements of this paragraph, vessels that are to operate at temperatures of below —20 F shall conform to the design and construction rules of this Division that are applicable to the type of fabrication used.

(*b*) When impact tests in accordance with UG-84 are required for the material or weld metal, the welded joints shall meet the requirements of UW-2(b).

(*c*) Vessels of welded construction shall be postweld heat treated in accordance with the provisions of UW-40, unless the vessels are in a classification exempted from the impact tests by UCS-66(c). Exempted vessels shall comply with the postweld heat treatment requirements of UW-10 and UCS-56.

(*d*) The allowable stress values to be used in design shall not exceed those given in Table UCS-23 for temperatures of —20 F to 650 F.

FABRICATION

UCS-75 General

The rules in the following paragraphs apply specifically to the fabrication of unfired pressure vessels and vessel parts that are constructed of carbon and low-alloy steel and shall be used in conjunction with the general requirements for *Fabrication* in Subsection A, and with the specific requirements for *Fabrication* in Subsection B that pertain to the method of fabrication used.

UCS-79 Forming Shell Sections and Heads

(*a*) The following provisions shall apply in addition to the general rules for forming given in UG-79.

(*b*) Carbon and low-alloy steel plates shall not be formed cold by blows.

(*c*) Carbon and low-alloy steel plates may be formed by blows at a forging temperature provided the blows do not objectionably deform the plate and it is subsequently postweld heat treated.

(*d*) Vessel shell sections and heads of P-1 materials fabricated by cold forming shall be heat treated subsequently (see UCS-56) when the resulting maximum extreme fiber elongation[1] is

(*1*) more than 40 percent from the as-rolled condition or

(*2*) more than 5 percent when any of the following conditions exist:

(a) The vessel will contain lethal substances, either liquid or gaseous.

(b) The material requires impact testing.

(c) The thickness of the part before cold forming exceeds ⅝ in.

(d) The reduction by cold forming from the as-rolled thickness is more than 10 percent.

[1]The responsibility for the determination of the fiber elongation shall rest with the vessel or vessel part fabricator.

(*e*) The temperature of the material during forming is more than 100 F but less than 800 F.

(*e*) When shell sections or heads of P-1 materials are cold formed by other than the manufacturer of the vessel, the required certification for the part shall indicate whether or not the requirements of UCS-79(d) have been satisfied.

UCS-85 Heat Treatment

(*a*) The following provisions shall apply in addition to, or as exceptions to the general rules for heat treatment given in UG-85.

(*b*) The material used in the vessel shall be represented by test specimens which have been subjected to the same manner of heat treatment. The kind and number of tests and test results shall be as required by the material specification. The vessel manufacturer shall specify the temperature, time, and cooling rates to which the material will be subjected during fabrication. Material from which the specimens are prepared shall be heated at the specified temperature within reasonable tolerances such as are normal in actual fabrication. The total time at temperature shall be at least 80 percent of the total time at temperature during actual heat treatment of the product, and may be performed in a single cycle.

(*c*) Heat treatment of material is not intended to include such local heating as flame or arc cutting, preheating, welding, local postweld heat treatment, or heating below the critical range of tubing and pipe for bending or sizing.

(*d*) An exception to the requirements of UG-85 and UCS-85(b) shall apply to standard items such as described in UG-11(a). These may be subject to postweld heat treatment with the vessel or vessel part without the same treatment being required of the test specimens. This exception shall not apply to specially designed cast or wrought fittings.

(*e*) Materials conforming to one of the specifications listed in Classification P-1 of Table Q-11.1 of Section IX are exempt from the requirements of UCS-85(b) when the heat treatment during fabrication is limited to a postweld heat treatment.

INSPECTION AND TESTS

UCS-90 General

The provisions for inspection and testing in Subsections A and B shall apply without supplement to vessels constructed of carbon and low-alloy steels.

STAMPING AND REPORTS

UCS-115 General

The provisions for stamping and reports in UG-115 through UG-120 shall apply without supplement to pressure vessels constructed of carbon and low-alloy steels.

PRESSURE RELIEF DEVICES

UCS-125 General

The provisions for pressure relief devices in UG-125 through UG-134 shall apply without supplement to pressure vessels constructed of carbon and low-alloy steels.

PART UNF

REQUIREMENTS FOR PRESSURE VESSELS CONSTRUCTED OF NONFERROUS MATERIALS

GENERAL

UNF-1 Scope

The rules in Part UNF are applicable to pressure vessels and vessel parts that are constructed of nonferrous materials and shall be used in conjunction with the general requirements in Subsection A, and with the specific requirements in Subsection B that pertain to the method of fabrication used.

UNF-3 Uses

Some of the uses of nonferrous materials are to resist corrosion, to facilitate cleaning of vessels for processing foods, to provide strength or scaling-resistance at high temperatures, and to provide notch toughness at low temperatures.

UNF-4 Conditions of Service

Specific chemical compositions, heat-treatment procedures, fabrication requirements, and supplementary tests may be required to assure that the vessel will be in its most favorable condition for the intended service. This is particularly true for vessels subject to severe corrosion. These rules do not indicate the selection of nonferrous material suitable for the intended service or the amount of the corrosion allowance to be provided. It is recommended that users assure themselves by appropriate tests, or otherwise, that the nonferrous material selected will be suitable for the intended service both with respect to corrosion and to retention of satisfactory mechanical properties during the desired service life, taking into account any heating or heat treatment that might be performed during fabrication.

MATERIALS

UNF-5 General

(*a*) All nonferrous materials subject to stress due to pressure shall conform to one of the specifications given in Section II and shall be limited to those listed in Table UNF-23 except as otherwise provided in UG-10 and UG-11.

(*b*) Appendix NF of this Division of Section VIII and the paragraph entitled *Basis of Purchase* and the appendix of the applicable material specification contain information relative to the fabricating characteristics of the material. They are intended to help the manufacturer in ordering the correct material, and in fabricating it, and to help the producer to select the material best able to fulfill the requirements of the fabricating procedures to be used.

UNF-6 Nonferrous Plate

Approved specifications for nonferrous plates are given in Table UNF-23 together with a tabulation of allowable stress values at different temperatures (see UG-6).

UNF-7 Forgings[1]

Approved specifications for nonferrous forgings are given in Table UNF-23 together with allowable stress values at different temperatures (see UG-7).

UNF-8 Castings

Approved specifications for nonferrous castings are given in Table UNF-23 together with allowable stress values at different temperatures. These stress values are to be multiplied by the casting quality factors of UG-24. Castings that are to be welded shall be of a weldable grade.

UNF-9 Pipe and Tubes

Approved specifications for nonferrous pipe and tubes are given in Table UNF-23 together with allowable stress values for seamless pipe and tubes. These stress values shall be multiplied by a joint efficiency factor of 0.85 to make them applicable to tubes of welded construction.

UNF-12 Bolt and Rivet Materials

(*a*) Approved specifications for bolt and rivet materials are given in Table UNF-23 together with allowable stress values at different temperatures.

(*b*) When bolts or rivets are machined from heat treated, hot rolled, or cold worked material and are not subsequently hot worked or annealed, the allowable stress values in Table UNF-23 to be used in design shall be based on the condition of the material selected.

(*c*) When bolts or rivets are fabricated by hot-heading, the allowable stress values for annealed material in Table UNF-23 shall apply unless the manufacturer can furnish adequate control data to show that the tensile properties of hot rolled bars or hot finished forgings are being met, in which case the allowable stress values for the material in the hot finished condition may be used.

(*d*) When bolts or rivets are fabricated by cold heading, the allowable stress values for annealed material in Table UNF-23 shall apply unless the manufacturer can furnish adequate control data to show that higher design stresses, as agreed upon, may be used. In no case shall such stresses exceed the allowable stress values given in Table UNF-23 for cold worked bar stock.

(*e*) Ferrous bolts, studs, and nuts may be used provided they are suitable for the application. They shall conform to the requirements of UCS-10 and 11.

UNF-13 Nuts and Washers

Nuts and washers may be made from any suitable material listed in Table UNF-23.

UNF-14 Rods, Bars, and Shapes

Rods, bars and shapes shall conform to one of the specifications in Table UNF-23.

UNF-15 Other Materials

(*a*) Other materials, either ferrous or nonferrous, may be used for parts of vessels provided that they are suitable for the purpose intended.

(*b*) The user shall satisfy himself that the coupling of dissimilar metals will have no harmful effect on the corrosion rate or service life of the vessel for the service intended.

(*c*) Other materials used in conjunction with nonferrous metals shall meet the requirements given for those materials in other parts of this Division.

DESIGN

UNF-16 General

(*a*) The rules in the following paragraphs apply specifically to the design of pressure vessels and vessel parts of nonferrous materials and shall be used in conjunction with the general requirements for *Design* in Subsection A, and with the specific requirements for Design in Subsection B that pertain to the method of fabrication used.

(*b*) *Minimum Thickness of Plate.* The minimum thickness after forming of any plate subject to pressure shall be not less than $^1/_{16}$ in. for welded construction in noncorrosive service, $^3/_{32}$ in. for welded construction in corrosive service, and $^3/_{16}$ in. for riveted construction. There is no specified minimum thickness requirement for brazed construction except that the thickness used must meet the brazing qualification requirements of Section IX, Part C.

UNF-18 Lap Joints in Riveted Vessels

Lap joints of the types covered in UR-18(a) shall not be used for nonferrous materials at design metal temperatures for which the allowable stress value as

[1]When there is no specification for forgings in Table UNF-23 for a material which is listed, the user and the manufacturer shall agree on a specification in Table UNF-23 covering rod or bar material to be used as a guide to design information and acceptability of the material.

given in Table UNF-23 is lower than the allowable stress value at 100 F.

UNF-19

(*a*) For vessels constructed of unalloyed titanium, all joints of categories A and B shall be of types No. (1) or No. (2) of Table UW-12.

(*b*) Unalloyed titanium shall not be welded to other materials.

UNF-23 Maximum Allowable Stress Values

(*a*) Table UNF-23 gives the maximum allowable stress values at the temperatures indicated for materials conforming to the specifications listed therein.[1] Values may be interpolated for intermediate temperatures. (See UG-23.)

(*b*) When welding or brazing is to be done on material having increased tensile strength produced by hot or cold working, the allowable stress value for the material in the annealed condition shall be used for joint design. One-piece heads and seamless shells may be designed on the basis of the actual temper of the material.

(*c*) When welding or brazing is to be done on material having increased tensile strength produced by heat treatment, the allowable stress value for the material in the annealed condition shall be used for the joint design unless the stress values for welded construction are given in the Table UNF-23 or unless the finished construction is subjected to the same heat treatment as that which produced the temper in the "as-received" material, provided the welded joint and the base metal are similarly affected by the heat treatment.

UNF-28 Thickness of Shells Under External Pressure

(*a*) Cylindrical and spherical shells under external pressure shall be designed by the rules in UG-28, using the applicable figure in Appendix V.

(*b*) Examples illustrating the use of the charts in the figures for the design of vessels under external pressure are given in Appendix L.

UNF-30 Stiffening Rings

Rules covering the design and attachment of stiffening rings are given in UG-29—30.

[1]See Appendix Q for the basis on which the allowable stress values have been established for nonferrous materials.

UNF-33 Formed Heads, Pressure on Convex Side

Ellipsoidal, torispherical, hemispherical, and conical heads having pressure on the convex side (minus heads) shall be designed by the rules of UG-33, using Figs. UNF-28.1 through 28.23. Examples illustrating the application of this paragraph are given in Appendix L.

UNF-56 Postweld Heat Treatment

(*a*) Postweld heat treatment of nonferrous materials is not normally necessary nor desirable.

(*b*) No postweld heat treatment shall be performed except by agreement between the user and the manufacturer. The temperature, time, and method of heat treatment shall be covered by agreement.

UNF-57 Radiographic Examination

(*a*) Vessels or parts of vessels constructed of nonferrous materials shall be radiographed in accordance with the requirements of UW-11.

(*b*) In addition, for vessels constructed of unalloyed titanium, all joints of Categories A and B shall be fully radiographed in accordance with UW-51.

(*c*) Welded butt joints in vessels constructed of materials covered by Specifications SB-163, SB-333, SB-334, SB-335, SB-336, SB-407, SB-408, and SB-409 shall be examined radiographically for their full length as prescribed in UW-51 when the thinner of the plate or vessel wall thicknesses at the welded joint exceeds $^3/_8$ in.

UNF-58 Liquid Penetrant Examination

(*a*) All welds, both groove and fillet, in vessels constructed of materials covered by Specifications SB-333, SB-334, SB-335, and SB-336 shall be examined for the detection of cracks by the liquid penetrant method. This examination shall be made following heat treatment if heat treatment is performed. All defects shall be removed by grinding, or grinding and filing.

(*b*) All joints in vessels constructed of unalloyed titanium shall be examined by the liquid penetrant method of Appendix VIII.

Unacceptable defects shall be removed only by mechanical methods.

(*c*) Welded joints in vessels or parts of vessels constructed of materials conforming to Specifications SB-163, SB-407, SB-408, and SB-409 and not required to be radiographed shall be examined by the liquid penetrant method.

TABLE UNF-23.1
MAXIMUM ALLOWABLE STRESS VALUES IN TENSION FOR NONFERROUS METALS, in kips/sq in. (Multiply by 1000 to obtain psi)
(See UW-12(c) for vessels constructed under Part UW that include welded joints that are neither fully radiographed nor spot radiographically examined.)

Spec. No.	Alloy Designation	Temper	Size or Thickness, in.	Specified Min. Tensile, kips/sq. in.	Specified Min. Yield, kips/sq. in.	Notes	For Metal Temperatures Not Exceeding Deg F: 100	150	200	250	300	350	400
ALUMINUM AND ALUMINUM ALLOY PRODUCTS													
SHEET AND PLATE													
SB-209	1060	-O	0.051–3.000	8.0	2.5	...	1.6	1.6	1.6	1.4	1.2	1.0	0.8
		-H12	0.051–2.000	11.0	9.0	(1)	2.7	2.7	2.6	2.3	2.0	1.8	1.1
		-H14	0.051–1.000	12.0	10.0	(1)	3.0	3.0	3.0	2.9	2.6	1.8	1.1
		-H112	0.250–0.499	11.0	7.0	(1)	2.7	2.6	2.4	2.0	1.8	1.6	1.0
			0.500–1.000	10.0	5.0	(1)	2.5	2.4	2.1	1.9	1.6	1.4	1.0
			1.001–3.000	9.0	4.0	(1)	2.2	2.1	1.9	1.7	1.4	1.0	0.8
SB-209	1100	-O	0.051–3.000	11.0	3.5	...	2.3	2.3	2.3	2.2	1.7	1.3	1.0
		-H12	0.051–2.000	14.0	11.0	(1)	3.5	3.5	3.5	3.2	2.8	1.9	1.1
		-H14	0.051–1.000	16.0	14.0	(1)	4.0	4.0	4.0	3.6	2.8	1.9	1.1
		-H112	0.250–0.499	13.0	7.0	(1)	3.2	3.2	3.0	2.7	2.4	1.6	1.0
			0.500–2.000	12.0	5.0	(1)	3.0	3.0	2.8	2.5	2.2	1.6	1.0
			2.001–3.000	11.5	4.0	(1)	2.6	2.6	2.6	2.4	1.7	1.3	1.0
SB-209	3003	-O	0.051–3.000	14.0	5.0	...	3.3	3.3	3.3	3.0	2.4	1.8	1.4
		-H12	0.051–2.000	17.0	12.0	(1)	4.2	4.2	4.2	3.9	3.6	3.0	2.3
		-H14	0.051–1.000	20.0	17.0	(1)	5.0	5.0	5.0	4.8	4.3	3.0	2.3
		-H112	0.250–0.499	17.0	10.0	(1)	4.2	4.2	4.2	3.9	3.6	3.0	2.3
			0.500–2.000	15.0	6.0	(1)	3.7	3.7	3.7	3.2	2.4	1.8	1.4
			2.001–3.000	14.5	6.0	(1)	3.6	3.6	3.5	3.2	2.4	1.8	1.4
SB-209	Alclad 3003	-O	0.051–0.499	13.0	4.5	(6)	3.0	3.0	3.0	2.7	2.1	1.6	1.2
			0.500–3.000	14.0	5.0	(8)	3.0	3.0	3.0	2.7	2.1	1.6	1.2
		-H12	0.051–0.499	16.0	11.0	(1) (6)	3.8	3.8	3.8	3.5	3.2	2.7	2.1
			0.500–2.000	17.0	12.0	(1) (8)	3.8	3.8	3.8	3.5	3.2	2.7	2.1
		-H14	0.051–0.499	19.0	16.0	(1) (6)	4.5	4.5	4.5	4.3	3.8	2.7	2.1
			0.500–1.000	20.0	17.0	(1) (8)	4.5	4.5	4.5	4.3	3.8	2.7	2.1
		-H112	0.250–0.499	16.0	9.0	(1) (6)	3.8	3.8	3.8	3.5	3.2	2.7	2.1
			0.500–2.000	15.0	6.0	(1) (9)	3.4	3.4	3.3	2.9	2.1	1.6	1.2
			2.001–3.000	14.5	6.0	(1) (9)	3.2	3.2	3.1	2.9	2.1	1.6	1.2
SB-209	3004	-O	0.051–3.000	22.0	8.5	...	5.5	5.5	5.5	5.5	5.0	3.8	2.3
		-H32	0.051–2.000	28.0	21.0	(1)	7.0	7.0	7.0	7.0	5.7	3.8	2.3
		-H34	0.051–1.000	32.0	25.0	(1)	8.0	8.0	8.0	8.0	5.7	3.8	2.3
		-H112	0.250–3.000	23.0	9.0	(1)	5.7	5.7	5.7	5.7	5.1	3.8	2.3
SB-209	Alclad 3004	-O	0.051–0.499	21.0	8.0	(6)	4.9	4.9	4.9	4.9	4.5	3.4	2.1
			0.500–3.000	22.0	8.5	(8)	4.9	4.9	4.9	4.9	4.5	3.4	2.1
		-H32	0.051–0.499	27.0	20.0	(1) (6)	6.3	6.3	6.3	6.3	5.2	3.4	2.1
			0.500–2.000	28.0	21.0	(1) (8)	6.3	6.3	6.3	6.3	5.2	3.4	2.1
		-H34	0.051–0.499	31.0	24.0	(1) (6)	7.2	7.2	7.2	7.2	5.2	3.4	2.1
			0.500–1.000	32.0	25.0	(1) (8)	7.2	7.2	7.2	7.2	5.2	3.4	2.1
		-H112	0.250–0.499	22.0	8.5	(1) (6)	5.2	5.2	5.2	5.2	4.6	3.4	2.1
			0.500–3.000	23.0	9.0	(1) (8)	5.2	5.2	5.2	5.2	4.6	3.4	2.1
SB-209	5050	-O	0.051–3.000	18.0	6.0	...	4.0	4.0	4.0	4.0	4.0	2.8	1.4
		-H32	0.051–0.249	22.0	16.0	(1)	5.5	5.5	5.5	5.5	5.3	2.8	1.4
		-H34	0.051–0.249	25.0	20.0	(1)	6.2	6.2	6.2	6.2	5.3	2.8	1.4
		-H112	0.250–3.000	20.0	8.0	(1)	5.0	5.0	5.0	5.0	4.9	2.8	1.4
SB-209	5052	-O	0.051–3.000	25.0	9.5	...	6.2	6.2	6.2	6.2	5.6	4.1	2.3
		-H32	0.051–2.000	31.0	23.0	(1)	7.7	7.7	7.7	7.5	6.1	4.1	2.3
		-H34	0.051–1.000	34.0	26.0	(1)	8.5	8.5	8.5	8.4	6.1	4.1	2.3
		-H112	0.250–0.499	28.0	16.0	(1)	7.0	7.0	7.0	7.0	6.1	4.1	2.3
			0.500–3.000	25.0	9.5	(1)	6.2	6.2	6.2	6.2	6.0	4.1	2.3

TABLE UNF-23.1 (CONT'D)
MAXIMUM ALLOWABLE STRESS VALUES IN TENSION FOR NONFERROUS METALS, in kips/sq in. (Multiply by 1000 to obtain psi)
(See UW-12(c) for vessels constructed under Part UW that include welded joints that are neither fully radiographed nor spot radiographically examined.)

ALUMINUM AND ALUMINUM ALLOY PRODUCTS

Spec. No.	Alloy Designation	Temper	Size or Thickness, in.	Specified Min. Tensile, kips/sq. in.	Specified Min. Yield, kips/sq. in.	Notes	For Metal Temperatures Not Exceeding Deg F: 100	150	200	250	300	350	400
SHEET AND PLATE (Cont'd)													
SB-209	5083	-O	0.051–1.500	40.0	18.0	(4)	10.0	10.0	...	...	...	...	...
			1.501–3.000	39.0	17.0	(4)	9.7	9.7	...	...	...	...	...
			3.001–5.000	38.0	16.0	(4)	9.5	9.5	...	...	...	...	...
			5.001–7.000	37.0	15.0	(4)	9.2	9.2	...	...	...	...	...
			7.001–8.000	36.0	14.0	(4)	9.0	9.0	...	...	...	...	...
		-H112	0.250–1.500	40.0	18.0	(1) (4)	10.0	10.0	...	...	...	...	...
			1.501–3.000	39.0	17.0	(1) (4)	9.7	9.7	...	...	...	...	...
		-H321	0.188–1.500	44.0	31.0	(1) (4)	11.0	11.0	...	...	...	...	...
			1.501–3.000	41.0	29.0	(1) (4)	10.2	10.2	...	...	...	...	...
		-H323	0.051–0.249	45.0	34.0	(1) (4)	11.2	11.2	...	...	...	...	...
		-H343	0.051–0.249	50.0	39.0	(1) (4)	12.5	12.5	...	...	...	...	...
SB-209	5086	-O	0.051–2.000	35.0	14.0	(4)	8.7	8.7	...	...	...	...	...
		-H32	0.051–2.000	40.0	28.0	(1) (4)	10.0	10.0	...	...	...	...	...
		-H34	0.051–1.000	44.0	34.0	(1) (4)	11.0	11.0	...	...	...	...	...
		-H112	0.188–0.499	36.0	18.0	(1) (4)	9.0	9.0	...	...	...	...	...
			0.500–1.000	35.0	16.0	(1) (4)	8.7	8.7	...	...	...	...	...
			1.001–2.000	35.0	14.0	(1) (4)	8.7	8.7	...	...	...	...	...
			2.001–3.000	34.0	14.0	(4)	8.5	8.5	...	...	...	...	...
SB-209	5154	-O	0.051–3.000	30.0	11.0	(4)	7.5	7.5	7.5	7.3	6.5	...	...
		-H32	0.051–2.000	36.0	26.0	(1) (4)	9.0	9.0	9.0	8.8	6.7	...	...
		-H34	0.051–1.000	39.0	29.0	(1) (4)	9.7	9.7	9.7	9.4	6.7	...	...
		-H112	0.250–0.499	32.0	18.0	(1) (4)	8.0	8.0	8.0	8.0	6.7	...	...
			0.500–3.000	30.0	11.0	(1) (4)	7.3	7.3	7.3	7.3	6.5	...	...
SB-209	5454	-O	0.051–3.000	31.0	12.0	...	7.7	7.7	7.7	7.4	5.5	4.1	3.0
		-H32	0.051–2.000	36.0	26.0	(1)	9.0	9.0	9.0	7.5	5.5	4.1	3.0
		-H34	0.051–1.000	39.0	29.0	(1)	9.7	9.7	9.7	7.5	5.5	4.1	3.0
		-H112	0.250–0.499	32.0	18.0	(1)	8.0	8.0	8.0	8.0	5.5	4.1	3.0
			0.500–3.000	31.0	12.0	(1)	7.7	7.7	7.7	7.4	5.5	4.1	3.0
SB-209	5456	-O	0.051–1.500	42.0	19.0	(4)	10.5	10.5	...	...	...	...	...
			1.501–3.000	41.0	18.0	(4)	10.2	10.2	...	...	...	...	...
			3.001–5.000	40.0	17.0	(4)	10.0	10.0	...	...	...	...	...
			5.001–7.000	39.0	16.0	(4)	9.7	9.7	...	...	...	...	...
			7.001–8.000	38.0	15.0	(4)	9.5	9.5	...	...	...	...	...
		-H112	0.250–1.500	42.0	19.0	(1) (4)	10.5	10.5	...	...	...	...	...
			1.501–3.000	41.0	18.0	(1) (4)	10.2	10.2	...	...	...	...	...
		-H321	0.188–1.250	46.0	33.0	(1) (4)	11.5	11.5	...	...	...	...	...
			1.251–1.500	44.0	31.0	(1) (4)	11.0	11.0	...	...	...	...	...
			1.501–3.000	41.0	29.0	(1) (4)	10.2	10.2	...	...	...	...	...
		-H323	0.051–0.249	48.0	36.0	(1) (4)	12.0	12.0	...	...	...	...	...
		-H343	0.051–0.249	53.0	41.0	(1) (4)	13.2	13.2	...	...	...	...	...
SB-209	6061	-T4	0.051–3.000	30.0	16.0	(2) (5)	7.5	7.5	7.5	7.4	6.9	6.3	4.4
		-T4 Welded	0.051–3.000	24.0*	...	(5)	6.0	6.0	6.0	5.9	5.5	4.6	3.5
		-T6	4.001–	40.0	35.0	(2) (9) (5)	9.0	9.0	9.0	8.6	7.4	5.6	4.0
		-T6 Welded	0.51–6.000	24.0*	...	...	6.0	6.0	6.0	5.9	5.5	4.6	3.5
		-T651	0.051–0.499	38.0	32.0	(2) (6) (5)	9.5	9.5	9.5	8.9	7.6	5.6	4.0
SB-209	Alclad 6061	-T4	0.051–0.499	27.0	14.0	(2) (6)	6.7	6.7	6.7	6.6	6.2	5.6	4.0
			0.500–3.000	30.0	16.0	(2) (8)	6.7	6.7	6.7	6.6	6.2	5.6	4.0
		-T4 Welded	0.051–3.000	24.0*	...	...	6.0	6.0	6.0	5.9	5.5	4.6	3.5
		-T6	0.051–0.499	38.0	32.0	(2) (6)	9.5	9.5	9.5	8.9	7.6	5.6	4.0
			0.500–4.000	42.0	35.0	(2) (8)	9.5	9.5	9.5	8.9	7.6	5.6	4.0
			4.001–5.000	40.0	35.0	(2) (9)	9.0	9.0	9.0	8.6	7.4	5.6	4.0
		-T6 Welded	0.051–5.000	24.0*	...	...	6.0	6.0	6.0	5.9	5.5	4.6	3.5

TABLE UNF-23.1 (CONT'D)
MAXIMUM ALLOWABLE STRESS VALUES IN TENSION FOR NONFERROUS METALS, in kips/sq in. (Multiply by 1000 to obtain psi)
(See UW-12(c) for vessels constructed under Part UW that include welded joints that are neither fully radiographed nor spot radiographically examined.)

ALUMINUM AND ALUMINUM ALLOY PRODUCTS

Spec. No.	Alloy Designation	Temper	Size or Thickness, In.	Specified Min. Tensile, kips/sq. in.	Specified Min. Yield, kips/sq. in.	Notes	For Metal Temperatures Not Exceeding Deg F: 100	150	200	250	300	350	400
RODS, BARS AND SHAPES													
SB-211	2024	-T4	0.125–0.499	62.0	45.0	(2)	15.5	15.5	15.5	13.6	10.3	6.5	4.5
			0.500–4.500	62.0	42.0	(2)	15.5	15.5	15.5	13.6	10.3	6.5	4.5
			4.501–6.500	62.0	40.0	(2)	15.5	15.5	15.5	13.6	10.3	6.5	4.5
			6.501–8.000	58.0	38.0	(2)	14.5	14.5	14.5	12.7	9.7	6.0	4.2
SB-211	6061	-T6	0.125–8.000	42.0	35.0	(2) (5)	10.5	10.5	10.5	9.9	8.4	6.3	4.4
		-T6 Welded	0.125–8.000	24.0*	...	(5)	6.0	6.0	6.0	5.9	5.5	4.6	3.5
SB-221	1060	-O	All	8.5	2.5	...	1.6	1.6	1.6	1.4	1.2	1.0	0.8
		-H112	All	8.5	2.5	(1)	1.6	1.6	1.6	1.4	1.2	1.0	0.8
SB-221	1100	-O	All	11.0	3.0	...	2.0	2.0	2.0	1.9	1.7	1.3	1.0
		-H112	All	11.0	3.0	(1)	2.0	2.0	2.0	1.9	1.7	1.3	1.0
SB-221	3003	-O	All	14.0	5.0	...	3.3	3.3	3.3	3.0	2.4	1.8	1.4
		-H112	All	14.0	5.0	(1)	3.3	3.3	3.3	3.0	2.4	1.8	1.4
SB-221	2024	-T4	Up thru 0.249	57.0	42.0	(2) (5)	14.2	14.2	14.2	12.5	9.5	5.9	4.1
			0.250–0.749	60.0	44.0	(2) (5)	15.0	15.0	15.0	13.2	10.0	6.3	4.3
			0.750–1.499	65.0	46.0	(2) (5)	16.2	16.2	16.2	14.3	10.8	6.8	4.7
			1.500 and over	68.0	48.0	(2) (5)	17.0	17.0	17.0	14.9	11.3	7.1	4.9
SB-221	5083	-O	Up thru 5.000	39.0	16.0	(4)	9.7	9.7	...	...	...	...	...
		-H111	Up thru 5.000	40.0	24.0	(1) (4)	10.0	10.0	...	...	...	...	...
SB-221	5083	-H112	Up thru 5.000	39.0	16.0	(2)	9.7	9.7	...	...	...	...	...
SB-221	5154	-O	All	30.0	11.0	(4)	7.5	7.5	7.5	7.3	6.5	...	...
		-H112	All	30.0	11.0	(1) (4)	7.5	7.5	7.5	7.3	6.5	...	...
SB-308	6061	-T6	...	38.0	35.0	(2)	9.5	9.2	9.0	8.5	7.2	5.6	4.0
		-T6 Welded	...	24.0*	...	...	6.0	5.9	5.7	5.4	5.0	4.2	3.2
BOLTING													
SB-211	2014	-T6	0.125–8.000	65.0	55.0	(2) (3) (5)	13.0	12.2	11.6	10.4	7.2	4.4	3.0
	2024	-T4	0.125–0.499	62.0	45.0	(2) (3)	11.2	10.9	10.6	9.9	7.9	6.3	4.8
			0.500–4.500	62.0	42.0	(2) (3)	10.5	10.1	9.9	9.5	7.9	6.3	4.8
			4.501–6.500	62.0	40.0	(2) (3)	10.0	9.7	9.4	9.0	7.8	6.2	4.6
			6.501–8.000	58.0	38.0	(2) (3)	9.5	9.2	8.9	8.6	7.4	5.8	4.3
SB-211	6061	-T6	0.125–8.000	42.0	35.0	(2) (3) (5)	8.4	8.2	7.9	7.5	6.3	4.9	3.3
		-T6 Welded	0.125–8.000	24.0*	...	(5)	4.8	4.7	4.6	4.4	4.0	3.4	2.6
DRAWN SEAMLESS TUBE													
SB-210	1060	-O	0.010–0.500	8.5	2.5	...	1.6	1.6	1.6	1.4	1.2	1.0	0.8
		-H14	0.010–0.500	12.0	10.0	(1)	3.0	3.0	3.0	2.9	2.6	1.8	1.1
		-H112	0.010–0.500	8.5	2.5	(1)	1.6	1.6	1.6	1.4	1.2	1.0	0.8
SB-210	3003	-O	0.010–0.500	14.0	5.0	...	3.3	3.3	3.3	3.0	2.4	1.8	1.4
		-H12	0.010–0.500	17.0	12.0	(1)	4.2	4.2	4.2	3.9	3.6	3.0	2.3
		-H14	0.010–0.500	20.0	17.0	(1)	5.0	5.0	5.0	4.8	4.3	3.0	2.3
		-H18	0.010–0.500	27.0	24.0	(1)	6.7	6.7	6.6	6.3	5.3	3.5	2.5
		-H112	0.010–0.500	14.0	5.0	(1)	3.3	3.3	3.3	3.0	2.4	1.8	1.4

TABLE UNF-23.1 (CONT'D)
MAXIMUM ALLOWABLE STRESS VALUES IN TENSION FOR NONFERROUS METALS, in kips/sq in. (Multiply by 1000 to obtain psi)
(See UW-12(c) for vessels constructed under Part UW that include welded joints that are neither fully radiographed nor spot radiographically examined.)

ALUMINUM AND ALUMINUM ALLOY PRODUCTS

Spec. No.	Alloy Designation	Temper	Size or Thickness, in.	Specified Min. Tensile, kips/sq. in.	Specified Min. Yield, kips/sq. in.	Notes	For Metal Temperatures Not Exceeding Deg F: 100	150	200	250	300	350	400
DRAWN SEAMLESS TUBE (Cont'd)													
SB-210	Alclad 3003	-O	0.010–0.500	13.0	4.5	(6)	3.0	3.0	3.0	2.7	2.1	1.6	1.2
		-H14	0.010–0.500	19.0	16.0	(1) (6)	4.5	4.5	4.5	4.3	3.8	2.7	2.1
		-H18	0.010–0.500	26.0	23.0	(1) (6)	6.1	6.1	6.0	5.6	4.8	3.1	2.2
		-H112	0.050–0.500	13.0	4.5	(1) (6)	3.0	3.0	3.0	2.7	2.1	1.6	1.2
SB-210	5154	-O	0.018–0.450	30.0	11.0	(4)	7.5	7.5	7.5	7.3	6.5	...	...
		-H34	0.018–0.450	39.0	29.0	(1) (4)	9.7	9.7	9.7	9.4	6.7	...	...
SB-210	6061	-T4	0.025–0.500	30.0	16.0	(2)	7.5	7.5	7.5	7.4	6.9	6.3	4.4
		-T6	0.025–0.500	42.0	35.0	(2)	10.5	10.5	10.5	9.9	8.4	6.3	4.4
		-T4, -T6 Welded	0.025–0.500	24.0*	...	...	6.0	6.0	6.0	5.9	5.5	4.6	3.5
SB-210	6063	-T6	0.025–0.500	33.0	28.0	(2)	8.2	8.2	7.9	7.4	5.4	3.4	2.0
		-T6 Welded	0.025–0.500	17.0*	...	...	4.2	4.2	4.2	4.2	3.9	3.0	2.0
SEAMLESS PIPE													
SB-241	3003	-H18	Under 1	27.0	24.0	(2)	6.7	6.7	6.6	6.3	5.3	3.5	2.5
		-H112	1 and over	14.0	6.0	(2)	3.5	3.5	3.4	3.0	2.4	1.8	1.4
SB-241	6061	-T6	Under 1	42.0	35.0	(2)	10.5	10.5	10.5	9.9	8.4	6.3	4.4
			1 and over	38.0	35.0	(2)	9.5	9.5	9.5	9.1	7.9	6.3	4.4
		-T6 Welded	All	24.0*	...	...	6.0	6.0	6.0	5.9	5.5	4.6	3.5
SB-241	6063	-T6	All	30.0	25.0	(2)	7.5	7.5	7.4	6.7	4.9	3.4	2.0
		-T6 Welded	All	17.0*	...	...	4.2	4.2	4.2	4.2	3.9	3.0	2.0
SEAMLESS EXTRUDED TUBE													
SB-241	1060	-O	All	8.5	2.5	...	1.6	1.6	1.6	1.4	1.2	1.0	0.8
		-H112	All	8.5	2.0	(1)	2.5	2.4	2.1	1.9	1.6	1.4	1.0
SB-241	1100	-O	All	11.0	3.0	...	2.0	2.0	2.0	1.9	1.7	1.3	1.0
		-H112	All	11.0	3.0	(1)	2.0	2.0	2.0	1.9	1.7	1.3	1.0
SB-241	3003	-O	All	14.0	5.0	...	3.3	3.3	3.3	3.0	2.4	1.8	1.4
		-H112	All	14.0	5.0	(1)	3.3	3.3	3.3	3.0	2.4	1.8	1.4
SB-241	Alclad 3003	-O	All	13.0	4.5	(6)	3.0	3.0	3.0	2.7	2.1	1.6	1.2
		-H112	All	13.0	4.5	(1) (6)	3.0	3.0	3.0	2.7	2.1	1.6	1.2
SB-241	5052	-O	All	25.0	10.0	...	6.2	6.2	6.2	6.2	5.6	4.1	2.3
SB-241	5083	-O	Up thru 5.000	39.0	16.0	(4)	9.7	9.7	...	...	...	...	...
		-H111	Up thru 5.000	40.0	24.0	(1) (4)	10.0	10.0	...	...	...	...	...
		-H112	Up thru 5.000	39.0	16.0	(1) (4)	9.7	9.7	...	...	...	...	...
SB-241	5086	-O	Up thru 5.000	35.0	14.0	(4)	8.7	8.7	...	...	...	...	...
		-H111	Up thru 5.000	36.0	21.0	(1) (4)	9.0	9.0	...	...	...	...	...
		-H112	Up thru 5.000	35.0	14.0	...	8.7	8.7	...	...	...	...	...
SB-241	5454	-O	Up thru 5.000	31.0	12.0	...	7.7	7.7	7.7	7.4	5.5	4.1	3.0
		-H111	Up thru 5.000	33.0	19.0	(1)	8.2	8.2	8.2	7.5	5.5	4.1	3.0
		-H112	Up thru 5.000	31.0	12.0	(1)	7.7	7.7	7.7	7.4	5.5	4.1	3.0
SB-241	5456	-O	Up thru 5.000	41.0	19.0	(4)	10.2	10.2	...	...	...	...	...
		-H111	Up thru 5.000	42.0	26.0	(1) (4)	10.5	10.5	...	...	...	...	...
		-H112	Up thru 5.000	41.0	19.0	(1) (4)	10.2	10.2	...	...	...	...	...

TABLE UNF-23.1 (CONT'D)
MAXIMUM ALLOWABLE STRESS VALUES IN TENSION FOR NONFERROUS METALS, in kips/sq in. (Multiply by 1000 to obtain psi)
(See UW-12(c) for vessels constructed under Part UW that include welded joints that are neither fully radiographed nor spot radiographically examined.)

ALUMINUM AND ALUMINUM ALLOY PRODUCTS

Spec. No.	Alloy Designation	Temper	Size or Thickness, in.	Specified Min. Tensile kips/sq. in.	Specified Min. Yield kips/sq. in.	Notes	For Metal Temperatures Not Exceeding Deg F: 100	150	200	250	300	350	400
SEAMLESS EXTRUDED TUBE (Cont'd)													
SB-241	6061	-T4	All	26.0	16.0	(2) (5)	6.5	6.5	6.5	6.4	6.0	5.8	4.4
		-T6	All	38.0	35.0	(2) (5)	9.5	9.5	9.5	9.1	7.9	6.3	4.4
		-T4, -T6 Welded	All	24.0*	...	(5)	6.0	6.0	6.0	5.9	5.5	4.6	3.5
SB-241	6063	-T1	Up thru 0.500	17.0	9.0	(2)	4.2	4.2	4.2	4.2	4.2	3.4	2.0
			0.501–1.000	16.0	8.0	(2)	4.0	4.0	4.0	4.0	4.0	3.4	2.0
		-T5	Up thru 0.500	22.0	16.0	(2)	5.5	5.5	5.4	5.1	4.6	3.4	2.0
			0.501–1.000	21.0	15.0	(2)	5.2	5.2	5.1	4.9	4.3	3.4	2.0
		-T6	Up thru 1.000	30.0	25.0	(2)	7.5	7.5	7.4	6.7	4.9	3.4	2.0
		-T5, -T6 Welded	Up thru 1.000	17.0*	...	...	4.2	4.2	4.2	4.2	3.9	3.0	2.0
CONDENSER AND HEAT EXCHANGER TUBE													
SB-234	1060	-H14	0.010–0.500	12.0	10.0	(2)	3.0	3.0	3.0	2.9	2.6	1.8	1.1
SB-234	3003	-H14	0.010–0.200	20.0	17.0	(2)	5.0	5.0	5.0	4.8	4.3	3.0	2.3
		-H25	0.010–0.200	22.0	19.0	(2)	5.5	5.5	5.5	5.2	4.3	3.0	2.3
SB-234	Alclad 3003	-H14	0.010–0.200	19.0	16.0	(2) (6)	4.5	4.5	4.5	4.3	3.8	2.7	2.1
		-H25	0.010–0.200	21.0	18.0	(2) (6)	4.9	4.9	4.9	4.7	3.8	2.7	2.1
SB-234	5052	-H32	0.010–0.200	31.0	23.0	(2)	7.7	7.7	7.7	7.5	6.1	4.1	2.3
		-H34	0.010–0.200	34.0	26.0	(2)	8.5	8.5	8.5	8.4	6.1	4.1	2.3
SB-234	5454	-H32	0.010–0.250	36.0	26.0	(2)	9.0	9.0	9.0	7.5	5.5	4.1	3.0
		-H34	0.010–0.250	39.0	29.0	(2)	9.7	9.7	9.7	7.5	5.5	4.1	3.0
SB-234	6061	-T4	0.025–0.249	30.0	16.0	(2)	7.5	7.5	7.5	7.4	6.9	6.3	4.4
		-T6	0.025–0.249	42.0	35.0	(2)	10.5	10.5	10.5	9.9	8.4	6.3	4.4
		-T4, -T6 Welded	0.025–0.249	24.0*	...	...	6.0	6.0	6.0	5.9	5.5	4.6	3.5
DIE AND HAND FORGINGS													
SB-247	2014 Die	-T4	Up thru 4.000	55.0	30.0	(2)	13.7	13.7	13.2	12.5	11.4	6.8	3.9
		-T6	Up thru 2.000	64.0	55.0	(2)	16.0	16.0	15.8	14.8	11.4	6.8	3.9
			2.001–4.000	63.0	54.0	(2)	15.7	15.7	15.7	14.8	11.4	6.8	3.9
SB-247	3003 Die	-H112	Up thru 4.000	14.0	5.0	...	3.3	3.3	3.3	3.0	2.4	1.8	1.4
		-H112 Welded	Up thru 4.000	14.0	...	...	3.3	3.3	3.3	3.0	2.4	1.8	1.4
SB-247	5083	-H111	Up thru 4.000	39.0	20.0	(2) (4)	9.7	9.7	...	...	...	...	...
		-H112	Up thru 4.000	39.0	16.0	(2) (4)	9.7	9.7	...	...	...	...	...
		-H111, -H112 Welded	Up thru 4.000	38.0*	...	(4)	9.5	9.5	...	...	...	...	...
SB-247	6061 Die	-T6	Up thru 4.000	38.0	35.0	(2)	9.5	9.5	9.5	9.1	7.9	6.3	4.4
SB-247	6061 Hand	-T6	Up thru 4.000	37.0	33.0	(2)	9.2	9.2	9.2	8.8	7.7	6.3	4.4
			4.001–8.000	35.0	32.0	(2)	8.7	8.7	8.3	8.3	7.3	6.1	4.4
SB-247	6061	-T6 Welded	Up thru 8.000	24.0*	...	...	6.0	6.0	6.0	5.9	5.5	4.6	3.5

TABLE UNF-23.1 (Cont'd)
MAXIMUM ALLOWABLE STRESS VALUES IN TENSION FOR NONFERROUS METALS, in kips sq in. (Multiply by 1000 to obtain psi)
(See UW-12(c) for vessels constructed under Part UW that include welded joints that are neither fully radiographed nor spot radiographically examined.)

ALUMINUM AND ALUMINUM ALLOY PRODUCTS

Spec. No.	Alloy Designation	Temper	Size or Thickness, in.	Specified Min. Tensile, kips/sq. in.	Specified Min. Yield, kips/sq. in.	Notes	For Metal Temperatures Not Exceeding Deg F: 100	150	200	250	300	350	400
CASTINGS													
SB-26	S5A (43)	-F	...	17.0	6.0	(2) (7)	4.0	4.0	4.0	3.7	3.4	3.1	2.8
SB-26	SG70A (356)	-T6	...	30.0	20.0	(2) (7)	7.5	7.5	7.5	6.3	...	...	...
		-T71	...	25.0	18.0	(2) (7)	6.2	6.2	6.2	6.1	5.4	4.1	2.4

* Strength of reduced-section tensile specimen required to qualify welding procedures. See QN-6.

NOTES: a The stress values in this table may be interpolated to determine values for intermediate temperature.
b Stress values in restricted shear such as dowel bolts, rivets, or similar construction in which the shearing member is so restricted that the section under consideration would fail without reduction of areas shall be 0.80 times the values in the above table.
c Stress values in bearing shall be 1.60 times the values in the above table.

(1) For welded construction, stress values for O material shall be used.
(2) The stress values given for this material are not applicable when either welding or thermal cutting is employed.
(3) See UNF-12 and UNF-23.
(4) See NF-13(b).
(5) For stress relieved tempers (T351, T3510, T3511, T451, T4510, T4511, T651, T6510, T6511) stress values for material in the basic temper shall be used.
(6) Allowable stress values shown are 90 percent of those for the corresponding core material.
(7) To these stress values a quality factor as specified in UG-24 shall be applied.
(8) The tension test specimen from plate 0.500 in. and thicker is machined from the core and does not include the cladding alloy; therefore the allowable stress values for thicknesses less than 0.500 in. shall be used.
(9) The tension test specimen from plate 0.500 in. and thicker is machined from the core and does not include the cladding alloy, therefore the allowable stress values shown are 90 percent of those for the core material of the same thickness.

UNF-65 Low-Temperature Operation

The materials listed in Table UNF-23, together with deposited weld metal within the range of composition for material in that table, do not undergo a marked drop in impact resistance at subzero temperature. Therefore, no additional requirements are specified for wrought aluminum alloys when they are used at temperatures down to —452 F; for copper and copper alloys, nickel and nickel alloys, and cast aluminum alloys when they are used at temperatures down to —325 F; and for unalloyed titanium used at temperatures down to —75 F. The materials listed in Table UNF-23 may be used at lower temperatures than those specified herein and for other weld metal compositions provided the user satisfies himself by suitable test results such as determinations of tensile elongation and sharp-notch tensile strength (compared to unnotched tensile strength) that the material has suitable ductility at the design temperature.

FABRICATION

UNF-75 General

The rules in the following paragraphs apply specifically to the fabrication of pressure vessels and vessel parts that are constructed of nonferrous materials and shall be used in conjunction with the general requirements for *Fabrication* in Subsection A, and with the specific requirements for *Fabrication* in Subsection B that pertain to the method of fabrication used.

UNF-77 Forming Shell Sections and Heads

(*a*) The following provisions shall apply in addition to the general rules for forming given in UG-79.

(*b*) The selected thickness of material shall be such that the forming processes will not reduce the thickness of the material at any point below the minimum value required by the design computation.

(*c*) Relatively small local bulges and buckles may be removed from formed parts for shells and heads by hammering or by local heating and hammering. For limiting temperatures see Appendix NF.

(*d*) A shell section that has been formed by rolling may be brought true-to-round for its entire length by pressing, rolling, or hammering.

UNF-78

Welding of unalloyed titanium is to be by the gas shielded tungsten arc process or the gas-shielded metal arc (consumable-electrode) process, meeting the requirements of Part B of Section IX.

INSPECTION AND TESTS

UNF-90 General

The rules in the following paragraphs apply specifically to the inspection and testing of pressure vessels and vessel parts that are constructed of nonferrous materials and shall be used in conjunction with the general requirements for *Inspection and Tests* in Subsection A, and with the specific requirements for *Inspection and Tests* in Subsection B that pertain to the method of fabrication used.

UNF-91 Requirements for Penetrameter

If the filler metal is of the same composition as the base metal, the penetrameter may be placed adjacent to the weld, otherwise it shall be placed on the deposited weld metal (see UW-51(e)).

UNF-95

If a vessel of welded unalloyed titanium construction incorporates joints of categories A or B as described in UW-3, a production test plate of the same specification, grade, and thickness shall be made of sufficient size to provide at least one face and one root bend specimen. Where longitudinal joints are involved, the test plate shall be attached to one end of the longitudinal joint and welded continuously with the joint. Where circumferential joints only are involved, the test plate need not be attached but shall be welded along with the joint. One test plate is required for each vessel by each welder or welding operator working on the vessel, provided not over 100 ft of category A or B joints are involved. An additional test plate, meeting the same requirements as outlined above, shall be made for each additional 100 ft of category A or B joints involved. The bend specimens shall be tested in accordance with Section IX, QN-7 and QN-8. Failure of either bend specimen constitutes rejection of the weld.

STAMPING AND REPORTS

UNF-115 General

The provisions for stamping and reports in UG-115 through UG-120 shall apply without supplement to pressure vessels constructed of nonferrous materials.

TABLE UNF-23.2
MAXIMUM ALLOWABLE STRESS VALUES IN TENSION FOR NONFERROUS METALS, in kips/sq in. (Multiply by 1000 to obtain psi)
(See UW-12(c) for vessels constructed under Part UW that include welded joints that are neither fully radiographed nor spot radiographically examined.)

COPPER AND COPPER ALLOYS

Spec. No.	Alloy Designation		Condition	Size, in.	Specified Min. Tensile, kips/sq. in.
SHEET AND PLATE					
SB-11	Copper Plates	CDA 110, 122, 125, 141, 142	Annealed	...	30.0
SB-152	Copper Plate, Sheet & Strip	CDA 102, 104, 105, 107, 122, 123	Annealed	...	30.0
SB-171	Admiralty, A, B, C, D Tubes Plates	CDA 442, 443, 444, 445	Annealed	...	45.0
SB-171	Naval Brass Tube Plates	CDA 464	Annealed	3" & under	50.0
			Annealed	over 3" – 5" incl.	50.0
SB-171	Leaded Muntz Metal Tube Plates	CDA 365	Annealed	2" & under	50.0
			Annealed	over 2" – 3.5" incl.	45.0
			Annealed	over 3.5" – 5" incl.	40.0
SB-171	Cu-Ni 70/30 Tube Plates	CDA 715	Annealed	2.5" & under	50.0
			Annealed	over 2.5" – 5" incl.	45.0
SB-402	Cu-Ni 70/30 Plate & Sheet	CDA 715	Annealed	...	45.0
SB-171	Cu-Ni 90/10 Tube Plates	CDA 706	Annealed	2.5" & under	40.0
SB-402	Cu-Ni 90/10 Plate & Sheet	CDA 706	Annealed	...	38.0
SB-169	Al Bronze C Plate & Sheet	CDA 612	Annealed	...	50.0
SB-169	Al Bronze D Plate & Sheet	CDA 614	Annealed	2" & under	70.0
			Annealed	over 2" – 5" incl.	65.0
SB-171	Al Bronze D Tube Plates	CDA 614	Annealed	2" & under	70.0
			Annealed	over 2" – 5" incl.	65.0
SB-171	Al Bronze E Tube Plates	CDA 628	Annealed	2" & under	90.0
			Annealed	over 2" – 3.5" incl.	85.0
			Annealed	over 3.5" – 5" incl.	80.0
SB-96	Cu-Si A & C Plates & Sheet	CDA 655 and 653	Annealed	...	50.0
PIPE AND TUBES					
SB-42	Copper Pipe	CDA 102, 120, 122	Annealed	...	30.0
			Drawn	1/8" – 3" incl.	45.0
			Drawn	2 1/2" – 12 incl.	36.0
SB-75	Copper Sml. Tube	CDA 102, 120, 122, 142	Annealed	...	30.0
			Light Drawn	...	36.0
			Hard Drawn	...	45.0
SB-111	Copper Sml. Condenser Tube	CDA 102, 120, 122, 142	Light Drawn	...	36.0
			Hard Drawn	...	45.0
SB-395	Copper U-Bend Sml. Tube	CDA 102, 120, 122, 142	Light Drawn	...	36.0
SB-43	Red Brass Pipe	CDA 230	Annealed	...	40.0
SB-111	Red Brass Sml. Cond. Tube	CDA 230	Annealed	...	40.0

TABLE UNF-23.2 (CONT'D)
MAXIMUM ALLOWABLE STRESS VALUES IN TENSION FOR NONFERROUS METALS, in kips/sq in. (Multiply by 1000 to obtain psi)
(See UW-12(c) for vessels constructed under Part UW that include welded joints that are neither fully radiographed nor spot radiographically examined.)

COPPER AND COPPER ALLOYS

Specified Min. Yield, kips/sq. in.	Notes	For Metal Temperatures Not Exceeding Deg F															Spec. No.
		100	150	200	250	300	350	400	450	500	550	600	650	700	750	800	
SHEET AND PLATE																	
10.0	...	6.7	5.7	5.5	5.1	5.0	4.0	3.0	...	...	...	...	...	...	...	...	SB-11
10.0	...	6.7	5.7	5.5	5.1	5.0	4.0	3.0	...	...	...	...	...	...	...	...	SB-152
15.0	...	10.0	10.0	10.0	10.0	10.0	9.8	3.5	2.0	...	...	...	...	...	...	...	SB-171
20.0	...	12.5	12.5	12.5	12.5	12.5	6.2	2.5	...	...	...	...	...	...	...	...	SB-171
18.0	...	12.0	12.0	12.0	12.0	12.0	6.2	2.5	...	...	...	...	...	...	...	...	
20.0	...	12.5	12.5	12.5	12.5	12.5	10.7	5.2	...	...	...	...	...	...	...	...	SB-171
15.0	...	10.0	10.0	10.0	10.0	10.0	10.0	5.2	...	...	...	...	...	...	...	...	
12.0	...	8.0	8.0	8.0	8.0	8.0	8.0	5.2	...	...	...	...	...	...	...	...	
20.0	...	12.5	11.3	10.5	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4	...	...	SB-171
18.0	...	11.2	10.1	9.4	9.3	9.3	9.3	9.3	9.3	9.3	9.3	9.3	9.3	9.3	...	...	
18.0	...	11.2	10.1	9.4	9.3	9.3	9.3	9.3	9.3	9.3	9.3	9.3	9.3	9.3	...	...	SB-402
15.0	...	10.0	9.7	9.5	9.3	9.0	8.7	8.5	8.2	8.0	7.0	6.0	...	...	...	...	SB-171
15.0	...	9.5	9.5	9.2	8.9	8.5	8.2	8.0	7.8	7.6	7.0	6.0	...	...	...	...	SB-402
20.0	...	12.5	12.5	...	...	...	...	...	...	...	...	...	...	...	...	...	SB-169
30.0	...	17.5	17.5	17.5	17.5	17.5	17.5	17.0	16.5	16.0	...	...	...	...	...	...	SB-169
28.0	...	16.2	16.2	16.2	16.2	16.2	16.2	15.9	15.3	14.7	...	...	...	...	...	...	
30.0	...	17.5	17.5	17.5	17.5	17.5	17.5	17.0	16.5	16.0	...	...	...	...	...	...	SB-171
28.0	...	16.2	16.2	16.2	16.2	16.2	16.2	15.9	15.3	14.7	...	...	...	...	...	...	
36.0	...	22.5	22.5	22.5	22.5	22.5	22.5	22.4	22.0	21.3	16.0	12.0	8.6	6.0	...	...	SB-171
33.0	...	21.2	21.2	21.2	21.2	21.0	20.8	20.2	20.1	19.5	16.0	12.0	8.6	6.0	...	...	
30.0	...	20.0	19.7	19.6	19.3	19.1	18.9	18.6	18.2	17.7	16.0	12.0	8.6	6.0	...	...	
18.0	(1)	12.0	12.0	11.9	11.7	10.0	5.0	...	...	...	...	...	...	...	...	...	SB-96
PIPE AND TUBES																	
9.0	...	6.0	5.1	4.8	4.7	4.7	4.0	3.0	...	...	...	...	...	...	...	...	SB-42
40.0	...	11.2	11.2	11.2	11.2	11.0	10.3	4.2	...	...	...	...	...	...	...	...	
30.0	...	9.0	9.0	9.0	9.0	8.7	8.5	8.2	...	...	...	...	...	...	...	...	
9.0	...	6.0	5.1	4.8	4.7	4.7	4.0	3.0	...	...	...	...	...	...	...	...	SB-75
30.0	...	9.0	9.0	9.0	9.0	8.7	8.5	8.2	...	...	...	...	...	...	...	...	
40.0	...	11.2	11.2	11.2	11.2	11.0	10.3	4.2	...	...	...	...	...	...	...	...	
30.0	...	9.0	9.0	9.0	9.0	8.7	8.5	8.2	...	...	...	...	...	...	...	...	SB-111
40.0	...	11.2	11.2	11.2	11.2	11.0	10.3	4.2	...	...	...	...	...	...	...	...	
30.0	...	9.0	9.0	9.0	9.0	8.7	8.5	8.2	...	...	...	...	...	...	...	...	SB-395
12.0	...	8.0	8.0	8.0	8.0	8.0	7.0	5.0	2.0	...	...	...	...	...	...	...	SB-43
12.0	...	8.0	8.0	8.0	8.0	8.0	7.0	5.0	2.0	...	...	...	...	...	...	...	SB-111

TABLE UNF-23.2 (CONT'D)
MAXIMUM ALLOWABLE STRESS VALUES IN TENSION FOR NONFERROUS METALS, in kips/sq in. (Multiply by 1000 to obtain psi)
(See UW-12(c) for vessels constructed under Part UW that include welded joints that are neither fully radiographed nor spot radiographically examined.)

COPPER AND COPPER ALLOYS

Spec. No.	Alloy Designation		Condition	Size, in.	Specified Min. Tensile, kips/sq. in.
PIPE AND TUBES (Cont'd)					
SB-395	Red Brass U-Bend Sml. Tube	CDA 230	Annealed	...	40.0
SB-111	Admiralty, A, B, C, D Sml. Condenser Tube	CDA 442, 443, 444, 445	Annealed	...	45.0
SB-395	Admiralty, A, B, C, D U-Bend Sml. Tube	CDA 442, 443, 444, 445	Annealed	...	45.0
SB-111	Al-Brass Sml. Bond Tube	CDA 687	Annealed	...	50.0
SB-395	Al-Brass U-Bend Sml. Tube	CDA 687	Annealed	...	50.0
SB-111	Muntz Sml. Condenser Tube	CDA 280	Annealed	...	50.0
SB-111	Cu-Ni 70/30 Sml. Cond. Tube	CDA 715	Annealed	...	52.0
SB-111	Cu-Ni 70/30 Sml. Cond. Tube	CDA 715	Drawn, Stress Relieved	2" & under	72.0
SB-395	Cu-Ni 70/30 U-Bend Sml. Tube	CDA 715	Annealed	...	52.0
SB-395	Cu-Ni 70/30 U-Bend Sml. Tube	CDA 715	Drawn, Stress Relieved	2" & under	72.0
SB-466	Cu-Ni 90/10	CDA 706	Annealed	...	38.0
SB-466	Cu-Ni 80/20	CDA 710	Annealed	...	45.0
SB-466	Cu-Ni 70/30	CDA 715	Annealed	...	50.0
SB-467	Cu-Ni 70/30 Welded Pipe & Tube	CDA 715	Annealed	up to 4½" incl.	50.0
			Welded & Drawn	over 4½"	45.0
				up to 2"	72.0
SB-111	Cu-Ni 80/20 Sml. Cond. Tube	CDA 710	Annealed	...	45.0
SB-395	Cu-Ni 80/20 U-Bend Sml. Tube	CDA 710	Annealed	...	45.0
SB-467	Cu-Ni 80/20 Welded Pipe & Tube	CDA 710	Annealed	up to 2" incl.	45.0
SB-467	Cu-Ni 80/20 Welded Pipe & Tube	CDA 706	Annealed	up to 4½" incl.	40.0
				over 4½"	38.0
SB-111	Cu-Ni 90/10 Sml. Cond. Tube	CDA 706	Annealed	...	40.0
SB-395	Cu-Ni 90/10 U-Bend Sml. Tube	CDA 706	Annealed	...	40.0
SB-111	Cu-Ni-Fe Sml. Cond. Tube	CDA 716	Annealed	...	74.0
SB-395	Cu-Ni-Fe U-Bend Sml. Tube	CDA 716	Annealed	...	74.0
SB-111	Al-Bronze Sml. Cond. Tube	CDA 608	Annealed	...	50.0
SB-395	Al-Bronze U-Bend Sml. Tube	CDA 608	Annealed	...	50.0
SB-315	Cu-Si A Pipe and Tube	CDA 655	Annealed	...	50.0

TABLE UNF-23.2 (CONT'D)
MAXIMUM ALLOWABLE STRESS VALUES IN TENSION FOR NONFERROUS METALS, in kips/sq in. (Multiply by 1000 to obtain psi)
(See UW-12(c) for vessels constructed under Part UW that include welded joints that are neither fully radiographed nor spot radiographically examined.)

COPPER AND COPPER ALLOYS

Specified Min. Yield, kips/sq. in.	Notes	For Metal Temperatures Not Exceeding Deg F															Spec. No.
		100	150	200	250	300	350	400	450	500	550	600	650	700	750	800	
																	PIPE AND TUBES (Cont'd)
12.0	...	8.0	8.0	8.0	8.0	8.0	7.0	5.0	2.0	...	...	...	...	...	...	...	SB-395
15.0	...	10.0	10.0	10.0	10.0	10.0	9.8	3.5	2.0	...	...	...	...	...	...	...	SB-111
15.0	...	10.0	10.0	10.0	10.0	10.0	9.8	3.5	2.0	...	...	...	...	...	...	...	SB-395
18.0	...	12.0	11.9	11.8	11.7	11.7	6.5	3.2	1.7	...	...	...	...	...	...	...	SB-111
18.0	...	12.0	11.9	11.8	11.7	11.7	6.5	3.2	1.7	...	...	...	...	...	...	...	SB-395
20.0	...	12.5	12.5	12.5	12.5	12.5	10.7	5.2	...	...	...	...	...	...	...	...	SB-111
18.0	...	12.0	11.6	11.3	11.0	10.8	10.6	10.3	10.1	9.9	9.8	9.6	9.5	9.4	...	...	SB-111
50.0	...	18.0	18.0	18.0	18.0	18.0	17.6	17.3	16.9	16.6	16.2	16.1	16.0	15.8	15.0	8.5	SB-111
18.0	...	12.0	11.6	11.3	11.0	10.8	10.6	10.3	10.1	9.9	9.8	9.6	9.5	9.4	...	...	SB-395
50.0	...	18.0	18.0	18.0	18.0	18.0	17.6	17.3	16.9	16.6	16.2	16.1	16.0	15.8	15.0	8.5	SB-395
13.0	...	9.5	9.3	9.0	8.8	8.5	8.2	8.1	7.8	7.6	7.0	6.0	...	...	...	...	SB-466
16.0	...	10.7	10.6	10.5	10.4	10.3	10.1	9.9	9.6	9.3	8.9	8.4	7.7	7.0	...	...	SB-466
18.0	...	12.0	11.6	11.3	11.0	10.8	10.6	10.3	10.1	9.9	9.8	9.6	9.5	9.4	...	...	SB-466
20.0	(5)	11.3	10.9	10.6	10.4	10.2	10.0	9.7	9.5	9.3	9.2	9.1	8.9	8.8	...	...	SB-467
15.0	(5)	8.5	8.1	7.9	7.7	7.6	7.5	7.3	7.1	7.0	6.9	6.8	6.7	6.6	...	...	
50.0	(5)	15.3	14.8	14.5	14.2	13.9	13.6	13.3	13.1	12.8	12.5	12.4	12.3	12.2	12.2	6.4	
16.0	...	10.7	10.6	10.5	10.4	10.3	10.1	9.9	9.6	9.3	8.9	8.4	7.7	7.0	...	...	SB-111
16.0	...	10.7	10.6	10.5	10.4	10.3	10.1	9.9	9.6	9.3	8.9	8.4	7.7	7.0	...	...	SB-395
16.0	(5)	9.1	9.0	8.9	8.8	8.7	8.5	8.4	8.1	7.9	7.5	7.1	6.5	5.9	...	...	SB-467
15.0	(5)	8.5	8.5	8.3	8.0	7.9	7.6	7.4	7.0	6.3	5.7	5.1	...	...	...	...	SB-467
13.0	(5)	7.4	7.4	7.2	6.9	6.8	6.6	6.3	6.1	5.5	4.9	4.4	...	...	...	...	
15.0	...	10.0	9.7	9.5	9.3	9.0	8.7	8.5	8.2	8.0	7.0	6.0	...	...	...	...	SB-111
15.0	...	10.0	9.7	9.5	9.3	9.0	8.7	8.5	8.2	8.0	7.0	6.0	...	...	...	...	SB-395
36.0	...	18.5	18.5	18.5	18.5	18.5	18.0	17.7	17.5	17.2	16.9	16.7	...	...	...	...	SB-111
36.0	...	18.5	18.5	18.5	18.5	18.5	18.0	17.7	17.5	17.2	16.9	16.7	...	...	...	...	SB-395
19.0	...	12.5	12.4	12.2	11.9	11.6	10.0	6.0	4.0	2.0	...	...	...	...	...	...	SB-111
19.0	...	12.5	12.4	12.2	11.9	11.6	10.0	6.0	4.0	2.0	...	...	...	...	...	...	SB-395
15.0	...	10.0	10.0	10.0	10.0	10.0	5.0	5.0	...	...	...	...	...	...	...	...	SB-315

TABLE UNF-23.2 (CONT'D)
MAXIMUM ALLOWABLE STRESS VALUES IN TENSION FOR NONFERROUS METALS, in kips/sq in. (Multiply by 1000 to obtain psi)
(See UW-12(c) for vessels constructed under Part UW that include welded joints that are neither fully radiographed nor spot radiographically examined.)

COPPER AND COPPER ALLOYS

Spec. No.	Alloy Designation		Condition	Size, in.	Specified Min. Tensile, kips/sq. in.
RODS AND BARS					
SB-12	Copper Rod	CDA 102, 122, 125, 141, 142	Annealed	...	30.0
SB-152	Copper Bar	CDA 102, 104, 105, 107, 122, 123	Annealed	...	30.0
SB-98	Cu-Si A Rods	CDA 655	Soft	...	52.0
			Half Hard	...	70.0
SB-98	Cu-Si B Rods	CDA 651	Soft	...	40.0
			Half Hard	...	55.0
BOLTING					
SB-12	Copper (Rod)	CDA 102, 110, 120, 122, 125, 141, 142	Soft	...	30.0
SB-98	Cu-Si A & D Rod	CDA 655 and 661	Soft	...	52.0
			Quarter Hard	...	55.0
			Half Hard	...	70.0
SB-98	Cu-Si B Rod	CDA 651	Soft		40.0
			Bolt Temper	up to ½" incl.	85.0
			Bolt Temper	up to ½"–1" incl.	75.0
			Bolt Temper	up to 1"–1½" incl.	75.0
SB-150	Alloy No. 1	CDA 642	...	up to ½" incl.	80.0
				up to ½"–1" incl.	75.0
				over 1" incl.	72.0
	Alloy No. 2	CDA 630	...	up to ½"–1" incl.	100.0
				over 1"–2" incl.	90.0
				over 2"–4" incl.	85.0
	Alloy No. 3	CDA 614	...	up to ½" incl.	80.0
				over ½"–1" incl.	75.0
				over 1"–2" incl.	70.0
CASTINGS					
SB-61	Alloy 2A	...	...	...	34.0
SB-62	Alloy 85	...	...	...	30.0
SB-143	Alloy 2A	...	...	...	34.0
SB-144	Alloy 3A	...	...	...	25.0
SB-149	Alloy 11A	...	...	...	30.0

NOTES:
The stress values in this table may be interpolated to determine values for immediate temperature.
Stress values in restricted shear such as dowel bolts, rivets, or similar construction in which the shearing member is so restricted that the section under consideration would fail without reduction of area shall be 0.80 times the values in the above table.
Stress values in bearing shall be 1.60 times the values in the above table.

TABLE UNF-23.2 (CONT'D)
MAXIMUM ALLOWABLE STRESS VALUES IN TENSION FOR NONFERROUS METALS, in kips/sq in. (Multiply by 1000 to obtain psi)
(See UW-12(c) for vessels constructed under Part UW that include welded joints that are neither fully radiographed nor spot radiographically examined.)

COPPER AND COPPER ALLOYS

Specified Min. Yield, kips/sq. in.	Notes	For Metal Temperatures Not Exceeding Deg F														Spec. No.
		100	150	200	250	300	350	400	450	500	550	600	650	700	750	800	
RODS AND BARS																	
10.0		6.7	5.7	5.5	5.1	5.0	4.0	3.0	...	...	...	...	...	...	...	...	SB-12
10.0		6.7	5.7	5.5	5.1	5.0	4.0	3.0	...	...	...	...	...	...	...	...	SB-152
15.0	(1)	10.0	10.0	10.0	10.0	10.0	5.0	...	...	...	...	...	...	...	...	...	SB-98
38.0	(1)	17.5	17.5	17.5	17.5	17.5	10.0	...	...	...	...	...	...	...	...	...	
12.0	(1)	8.0	8.0	8.0	8.0	7.0	5.0	...	...	...	...	...	...	...	...	...	SB-98
20.0	(1)	13.3	13.3	13.3	12.8	10.0	8.0	...	...	...	...	...	...	...	...	...	
BOLTING																	
	(3)																
10.0	...	2.5	2.2	2.0	1.9	1.9	1.8	1.8	...	...	...	...	...	...	...	...	SB-12
15.0	(1)	3.8	3.8	3.8	3.8	3.8	3.5	...	...	...	...	...	...	...	...	...	SB-98
24.0	...	6.0	6.0	5.9	5.8	5.6	5.5	...	...	...	...	...	...	...	...	...	
38.0	...	9.5	9.5	9.3	9.0	8.8	8.5	...	...	...	...	...	...	...	...	...	
12.0	(1)	3.0	3.0	3.0	3.0	2.9	2.8	...	...	...	...	...	...	...	...	...	SB-98
55.0	...	13.8	13.8	13.5	13.1	12.7	12.0	...	...	...	...	...	...	...	...	...	
45.0	...	11.2	11.2	11.1	10.8	10.5	10.0	...	...	...	...	...	...	...	...	...	
40.0	...	10.0	10.0	9.8	9.6	9.4	9.0	...	...	...	...	...	...	...	...	...	
40.0	...	10.0	10.0	10.0	10.0	10.0	9.8	9.6	9.5	9.4	9.2	9.0	...	...	...	...	SB-150
37.5	...	9.4	9.4	9.4	9.4	9.4	9.2	9.0	8.9	8.8	8.6	8.4	...	...	...	...	
35.0	...	8.8	8.8	8.8	8.8	8.8	8.6	8.4	8.3	8.2	8.0	7.8	...	...	...	...	
50.0	...	12.5	12.3	12.2	12.0	11.9	11.8	11.6	11.4	11.0	10.5	9.6	8.3	6.0	...	...	
45.0	...	11.2	11.1	11.0	10.8	10.7	10.6	10.5	10.3	9.9	9.4	8.6	6.6	6.0	...	...	
42.5	...	10.6	10.5	10.4	10.3	10.2	10.0	9.9	9.6	9.4	8.9	8.1	7.1	5.4	...	...	
40.0	...	10.0	9.9	9.9	9.8	9.8	9.7	9.6	9.5	9.5	...	...	...	...	...	...	
35.0	...	8.7	8.7	8.6	8.6	8.5	8.5	8.4	8.3	8.2	...	...	...	...	...	...	
32.0	...	8.0	8.0	7.9	7.9	7.8	7.8	7.7	7.6	7.5	...	...	...	...	...	...	
CASTINGS																	
	(2)																
16.0	...	8.5	8.5	8.5	8.5	8.5	8.5	8.2	7.7	7.2	5.0	...	...	...	...	...	SB-61
14.0	...	7.5	7.5	7.5	7.5	7.3	7.1	6.9	6.8	...	...	...	...	...	...	...	SB-62
16.0	...	8.5	8.5	8.5	8.5	8.5	8.5	8.2	7.7	7.2	5.0	...	...	...	...	...	SB-143
12.0	(4)	6.2	6.2	6.1	5.8	5.6	5.4	5.3	...	...	...	...	...	...	...	...	SB-144
17.0	(4)	6.0	6.0	5.8	5.5	5.0	...	...	...	...	...	...	...	...	...	...	SB-149

NOTES:
(1) Copper-silicon alloys are not always suitable when exposed to certain media and high temperatures, particularly steam above 212 F. The user should satisfy himself that the alloy selected is satisfactory for the service for which it is to be used.
(2) To these stress values a quality factor as specified in UG-24 shall be applied for castings. This is not intended to apply to valves and fittings made to recognized standards.
(3) See UNF-12
(4) No welding or brazing permitted.
(5) These stress values multiplied by a joint efficiency factor of 0.85.

TABLE UNF-23.3
MAXIMUM ALLOWABLE STRESS VALUES IN TENSION FOR NONFERROUS METALS, in kips/sq in. (Multiply by 1000 to obtain psi)
(See UW-12(c) for vessels constructed under Part UW that include welded joints that are neither fully radiographed nor spot radiographically examined.)

NICKEL AND HIGH-NICKEL ALLOYS

Spec. No.	Alloy Designation	Nominal Composition	Condition	Size, in.	Specified Min. Tensile, kips/sq. in.	Specified Min. Yield, kips/sq. in.	Notes	For Metal Temperature Not Exceeding Deg F: 100	200	300	400	500
PLATE, SHEET & STRIP												
SB-127	400	Ni-Cu	Annealed	...	70.0	28.0	...	18.6	16.4	15.4	14.8	14.7
SB-127	400	Ni-Cu	Hot Rolled	...	75.0	40.0	(4)	18.7	18.7	18.7	18.7	18.7
SB-162	200	Ni	Annealed	...	55.0	15.0	...	10.0	10.0	10.0	10.0	10.0
SB-162	200	Ni	Hot Rolled	...	55.0	20.0	(4)	13.3	13.3	13.3	13.3	12.5
SB-162	201	Ni Low C	Hr/Ann	...	50.0	12.0	...	8.0	7.7	7.5	7.5	7.5
SB-168	600	Ni-Cr-Fe	Annealed	...	80.0	35.0	...	20.0	20.0	20.0	20.0	20.0
SB-168	600	Ni-Cr-Fe	Annealed	...	80.0	35.0	(1)	20.0	20.0	20.0	20.0	20.0
SB-168	600	Ni-Cr-Fe	Hot Rolled	...	85.0	35.0	(4)	21.2	21.2	21.2	21.2	21.2
SB-168	600	Ni-Cr-Fe	Hot Rolled	...	85.0	35.0	(1) (4)	21.2	21.2	21.2	21.2	21.2
SB-409	800	Ni-Fe-Cr	Ann., Gr.1	...	75.0	30.0	...	18.7	18.7	17.9	17.2	16.7
SB-409	800	Ni-Fe-Cr	Ann., Gr.1	...	75.0	30.0	(1)	18.7	18.7	18.7	18.7	18.7
SB-409	800	Ni-Fe-Cr	Ann., Gr.2	...	65.0	25.0	...	16.7	14.3	12.9	11.9	11.0
SB-424	825	Ni-Fe-Cr-Mo-Cu	Annealed	...	65.0	25.0	(1)	16.7	16.7	16.7	15.8	14.9
SB-424	825	Ni-Fe-Cr-Mo-Cu	Annealed	...	85.0	35.0	...	21.2	21.2	20.4	19.2	18.3
SHEET & PLATE					85.0	35.0	(1)	21.2	21.2	21.2	21.2	21.2
SB-333	Alloy B	Ni-Mo	Annealed	under 3/16"	115.0	50.0	(1)	28.8	28.8	28.8	28.8	28.8
SB-333	Alloy B	Ni-Mo	Annealed	under 3/16"	115.0	50.0	...	28.8	28.8	28.8	27.9	26.3
SB-333	Alloy B	Ni-Mo	Annealed	3/16"–3/4", incl.	100.0	45.0	(1)	25.0	25.0	25.0	24.7	24.3
SB-333	Alloy B	Ni-Mo	Annealed	3/16"–3/4", incl.	100.0	45.0	...	25.0	25.0	25.0	24.7	23.6
			Annealed	over 3/4"	90.0	45.0	...	22.5	22.5	22.5	22.3	21.9
SB-334	Alloy C	Ni-Mo-Cr	Annealed	3/16"	115.0	50.0	(1)	28.8	28.8	28.8	28.6	28.1
SB-334	Alloy C	Ni-Mo-Cr	Annealed	3/16"	115.0	50.0	...	28.8	28.8	28.8	27.9	26.9
SB-334	Alloy C	Ni-Mo-Cr	Annealed	3/16"–3/4", incl.	100.0	45.0	(1)	25.0	25.0	25.0	24.8	24.3
SB-334	Alloy C	Ni-Mo-Cr	Annealed	3/16"–3/4", incl.	100.0	45.0	...	25.0	25.0	25.0	24.8	24.1
			Annealed	over 3/4"	90.0	45.0	...	22.5	22.5	22.5	22.3	21.8
PIPE & TUBE												
SB-161	200	Ni	Annealed	5"OD & under	55.0	15.0	...	10.0	10.0	10.0	10.0	10.0
SB-161	200	Ni	Annealed	over 5"OD	55.0	12.0	...	8.0	8.0	8.0	8.0	8.0
SB-161	200	Ni	Str. Rel.	All Sizes	65.0	40.0	...	16.3	16.3	16.3	16.3	16.0
SB-161	201	Ni Low C	Annealed	5"OD & under	50.0	12.0	...	8.0	7.7	7.5	7.5	7.5
SB-161	201	Ni Low C	Annealed	over 5"OD	50.0	10.0	...	6.7	6.4	6.3	6.2	6.2
SB-161	201	Ni Low C	Str. Rel.	All Sizes	60.0	30.0	...	15.0	15.0	15.0	14.8	14.7
SB-163	200	Ni	Annealed	...	55.0	15.0	...	10.0	10.0	10.0	10.0	10.0
SB-163	200	Ni	Str. Rel.	...	65.0	40.0	...	16.3	16.3	16.3	16.3	16.0
SB-163	201	Ni Low C	Annealed	...	50.0	12.0	...	8.0	7.7	7.5	7.5	7.5
SB-163	201	Ni Low C	Str. Rel.	...	60.0	30.0	...	16.5	15.6	15.0	14.8	14.7
SB-163	400	Ni-Cu	Annealed	All Sz. to 3" incl.	70.0	28.0	...	17.5	16.4	15.4	14.8	14.7
SB-163	400	Ni-Cu	Str. Rel	All Sizes	85.0	55.0	(3)	21.2	21.2	21.2	21.0	21.0
SB-163	600	Ni-Cr-Fe	Annealed	All Sz. to 3" incl.	80.0	35.0	...	20.0	20.0	20.0	20.0	20.0
SB-163	600	Ni-Cr-Fe	Annealed	All Sz. to 3" incl.	80.0	35.0	(1)	20.0	20.0	20.0	20.0	20.0
SB-163	800	Ni-Fe-Cr	Ann., Gr.1	...	75.0	30.0	...	18.7	18.7	17.9	17.2	16.7
SB-163	800	Ni-Fe-Cr	Ann., Gr.1	...	75.0	30.0	(1)	18.7	18.7	18.7	18.7	18.7
SB-163	800	Ni-Fe-Cr	Ann., Gr.2	...	70.0	25.0	...	16.7	14.3	12.9	11.9	11.0
SB-163	825	Ni-Fe-Cr-Mo-Cu	Annealed	...	70.0	25.0	(1)	16.7	16.7	16.7	15.8	14.9
SB-163	825	Ni-Fe-Cr-Mo-Cu	Annealed	...	85.0	35.0	...	21.2	21.2	20.4	19.2	18.3
					85.0	35.0	(1)	21.2	21.2	21.2	21.2	21.2

TABLE UNF-23.3 (CONT'D)
MAXIMUM ALLOWABLE STRESS VALUES IN TENSION FOR NONFERROUS METALS, in kips/sq in. (Multiply by 1000 to obtain psi)
(See UW-12(c) for vessels constructed under Part UW that include welded joints that are neither fully radiographed nor spot radiographically examined.)

NICKEL AND HIGH-NICKEL ALLOYS

For Metal Temperature Not Exceeding Deg F: 600	650	700	750	800	850	900	950	1000	1050	1100	1150	1200	1250	1300	1350	1400	1450	1500	Spec. No.
PLATE SHEET & STRIP																			
14.7	14.7	14.7	14.6	14.2	11.0	8.0	...	...	...	...	...	...	...	...	...	...	...	...	SB-127
18.7	18.7	18.0	17.2	14.2	8.2	4.0	...	...	...	...	...	...	...	...	...	...	...	...	SB-127
10.0	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	SB-162
11.5	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	SB-162
7.5	7.5	7.4	7.3	7.2	5.8	4.5	3.7	3.0	2.4	2.0	1.5	1.2	...	...	...	...	...	...	SB-162
20.0	19.8	19.6	19.4	19.1	18.7	16.0	10.6	7.0	4.5	3.0	2.2	2.0	...	...	...	...	...	...	SB-168
20.0	20.0	20.0	20.0	20.0	20.0	16.0	10.6	7.0	4.5	3.0	2.2	2.0	...	...	...	...	...	...	SB-168
21.2	21.2	21.1	21.0	20.4	20.2	19.6	19.3	14.5	10.3	7.2	5.8	5.5	...	...	...	...	...	...	SB-168
21.2	21.2	21.2	21.2	21.2	21.2	21.2	21.2	14.5	10.3	7.2	5.8	5.5	...	...	...	...	...	...	SB-168
16.3	16.1	15.9	15.7	15.5	15.3	15.1	14.9	14.7	14.5	13.0	9.8	6.6	4.2	2.0	1.6	1.1	1.0	0.8	SB-409
18.7	18.6	18.6	18.5	18.5	18.3	18.2	17.9	17.6	17.0	13.0	9.8	6.6	4.2	2.0	1.6	1.1	1.0	0.8	SB-409
10.6	10.5	10.2	10.1	9.9	9.8	9.7	9.6	9.4	9.4	9.4	9.3	7.9	6.0	4.6	3.6	2.8	2.1	1.7	SB-409
14.4	14.1	13.9	13.7	13.4	13.2	13.1	12.9	12.8	12.7	12.7	10.0	7.9	6.0	4.6	3.0	2.8	2.1	1.7	SB-409
17.8	17.6	17.3	17.2	17.1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	SB-424
21.2	21.1	21.0	20.9	20.8	...	...	...	...	...	...	...	...	...	...	...	...	...	...	SB-424
SHEET & PLATE																			
28.8	28.8	28.8	28.8	28.7	...	...	...	...	...	...	...	...	...	...	...	...	...	...	SB-333
25.7	25.3	25.0	24.7	24.5	...	...	...	...	...	...	...	...	...	...	...	...	...	...	SB-333
24.2	24.1	24.0	23.9	23.8	...	...	...	...	...	...	...	...	...	...	...	...	...	...	SB-333
23.1	22.8	22.5	22.3	22.1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	SB-333
21.8	21.7	21.6	21.5	21.4	...	...	...	...	...	...	...	...	...	...	...	...	...	...	SB-333
27.8	27.6	27.4	27.2	27.0	26.8	26.6	26.3	26.1	...	...	...	...	...	...	...	...	...	...	SB-334
25.5	25.3	25.2	25.0	24.9	24.8	24.7	24.6	24.5	...	...	...	...	...	...	...	...	...	...	SB-334
24.1	24.0	23.8	23.7	23.5	23.3	23.1	22.9	22.7	...	...	...	...	...	...	...	...	...	...	SB-334
23.0	22.7	22.6	22.5	22.4	22.3	22.2	22.1	22.0	...	...	...	...	...	...	...	...	...	...	SB-334
21.7	21.5	21.4	21.3	21.2	21.0	20.8	20.7	20.5	...	...	...	...	...	...	...	...	...	...	SB-334
PIPE & TUBE																			
10.0	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	SB-161
8.0	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	SB-161
15.4	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	SB-161
7.5	7.5	7.4	7.3	7.2	5.8	4.5	3.7	3.0	2.4	2.0	1.5	1.2	...	...	...	...	...	...	SB-161
6.2	6.2	6.2	6.0	5.9	5.8	4.5	3.7	3.0	2.4	2.0	1.5	1.2	...	...	...	...	...	...	SB-161
14.2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	SB-163
10.0	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	SB-163
15.4	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	SB-163
7.5	7.5	7.4	7.3	7.2	5.8	4.5	3.7	3.0	2.4	2.0	1.5	1.2	...	...	...	...	...	...	SB-163
14.2	14.0	13.4	12.8	12.1	11.7	11.1	...	...	...	...	...	...	...	...	...	...	...	...	SB-163
14.7	14.7	14.7	14.6	14.2	11.0	8.0	...	...	...	...	...	...	...	...	...	...	...	...	SB-163
21.0	20.6	20.1	18.0	12.7	(3)	(3)	...	...	...	...	...	...	...	...	...	...	...	...	SB-163
20.0	19.8	19.6	19.4	19.1	18.7	16.0	10.6	7.0	4.5	3.0	2.2	2.0	...	...	...	...	...	...	SB-163
20.0	20.0	20.0	20.0	20.0	20.0	16.0	10.6	7.0	4.5	3.0	2.2	2.0	...	...	...	...	...	...	SB-163
16.3	16.1	15.9	15.7	15.5	15.3	15.1	14.9	14.7	14.5	13.0	9.8	6.6	4.2	2.0	1.6	1.1	1.0	0.8	SB-163
18.7	18.6	18.6	18.5	18.5	18.3	18.2	17.9	17.6	17.0	13.0	9.8	6.6	4.2	2.0	1.6	1.1	1.0	0.8	SB-163
10.6	10.5	10.2	10.1	9.9	9.8	9.7	9.6	9.4	9.4	9.4	9.3	7.9	6.0	4.6	3.6	2.8	2.1	1.7	SB-163
14.4	14.1	13.9	13.7	13.4	13.2	13.1	12.9	12.8	12.7	12.7	10.0	7.9	6.0	4.6	3.6	2.8	2.1	1.7	SB-163
17.8	17.6	17.3	17.2	17.1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	SB-163
21.2	21.1	21.0	20.9	20.8	...	...	...	...	...	...	...	...	...	...	...	...	...	...	SB-163

TABLE UNF-23.3 (CONT'D)
MAXIMUM ALLOWABLE STRESS VALUES IN TENSION FOR NONFERROUS METALS, in kips/sq in. (Multiply by 1000 to obtain psi)
(See UW-12(c) for vessels constructed under Part UW that include welded joints that are neither fully radiographed nor spot radiographically examined.)

NICKEL AND HIGH-NICKEL ALLOYS

Spec. No.	Alloy Designation	Nominal Composition	Condition	Size, In.	Specified Min. Tensile, kips/sq. in.	Specified Min. Yield, kips/sq. in.	Notes	For Metal Temperature Not Exceeding Deg F 100	200	300	400	500
PIPE AND TUBE (Cont'd)												
SB-165	400	Ni-Cu	Annealed	5"OD & under	70.0	28.0	...	17.5	16.4	15.4	14.8	14.7
SB-165	400	Ni-Cu	Annealed	over 5"OD	70.0	25.0	...	16.6	14.6	13.6	13.2	13.1
SB-165	400	Ni-Cu	Str. Rel.	All Sizes	85.0	55.0	(2)	21.2	21.2	21.2	21.0	21.0
SB-167	600	Ni-Cr-Fe	Hot Fin/Ann	5"OD & under	80.0	30.0	...	20.0	19.1	18.2	17.5	16.9
SB-167	600	Ni-Cr-Fe	Hot Fin/Ann	5"OD & under	80.0	30.0	(1)	20.0	20.0	20.0	20.0	20.0
SB-167	600	Ni-Cr-Fe	Hot Fin/Ann	over 5"OD	75.0	25.0	...	16.7	15.3	14.5	14.0	13.6
SB-167	600	Ni-Cr-Fe	Hot Fin/Ann	over 5"OD	75.0	25.0	(1)	16.7	16.7	16.7	16.7	16.7
SB-167	600	Ni-Cr-Fe	CD/Ann.	5"OD & under	80.0	35.0	...	20.0	20.0	20.0	20.0	20.0
SB-167	600	Ni-Cr-Fe	CD/Ann.	5"OD & under	80.0	35.0	(1)	20.0	20.0	20.0	20.0	20.0
SB-167	600	Ni-Cr-Fe	CD/Ann.	over 5"OD	80.0	30.0	...	20.0	19.1	18.2	17.5	16.9
SB-407	800	Ni-Cr-Fe	Ann., Gr.1	over 5"OD	80.0	30.0	(1)	20.0	20.0	20.0	20.0	20.0
SB-407	800	Ni-Cr-Fe	Ann., Gr.1	...	75.0	30.0	...	18.7	18.7	17.9	17.2	16.7
SB-407	800	Ni-Cr-Fe	Ann., Gr.2	...	75.0	30.0	(1)	18.7	18.7	18.7	18.7	18.7
SB-407	800	Ni-Cr-Fe	Ann., Gr.2	...	65.0	25.0	...	16.7	14.3	12.9	11.9	11.0
SB-423	825	Ni-Fe-Cr-Mo-Cu	Annealed	...	65.0	25.0	(1)	16.7	16.7	16.7	15.8	14.9
SB-423	825	Ni-Fe-Cr-Mo-Cu	Annealed	...	85.0	35.0	...	21.2	21.2	20.4	19.2	18.3
					85.0	35.0	(1)	21.2	21.2	21.2	21.2	21.2
BARS, RODS, SHAPES, FORGINGS												
SB-160	200	Ni	Annealed	...	55.0	15.0	...	10.0	10.0	10.0	10.0	10.0
SB-160	200	Ni	Hot Rolled	...	60.0	15.0	...	10.0	10.0	10.0	10.0	9.5
SB-160	201	Ni Low C	Hr/Ann.	...	50.0	10.0	...	6.7	6.4	6.3	6.2	6.2
SB-164	400, 405	Ni-Cu	Annealed	All Sz. & Prod.	70.0	25.0	...	16.6	14.6	13.6	13.2	13.1
SB-164	400	Ni-Cu	Hot Fin.	All, exc. hex.>2 1/8"	80.0	40.0	...	20.0	20.0	20.0	20.0	20.0
SB-164	400	Ni-Cu	Hot Fin.	Hex over 2 1/8"	75.0	30.0	...	18.7	18.7	18.7	18.0	17.8
SB-164	405	Ni-Cu	Hot Fin.	Rnds. to 3", Incl.	75.0	35.0	...	18.7	18.7	18.7	18.7	18.7
SB-164	400	Ni-Cu	Str. Rel.	4" to 12" dia, incl.	80.0	40.0	...	20.0	20.0	20.0	20.0	20.0
SB-164	400	Ni-Cu	Str. Rel.	over 12" Dia.	75.0	40.0	...	18.7	18.7	18.7	18.7	18.7
SB-166	600	Ni-Cr-Fe	Annealed	...	80.0	35.0	...	20.0	20.0	20.0	20.0	20.0
SB-166	600	Ni-Cr-Fe	Annealed	...	80.0	35.0	(1)	20.0	20.0	20.0	20.0	20.0
SB-166	600	Ni-Cr-Fe	Hot Fin.	...	85.0	35.0	...	21.2	21.2	21.2	21.2	21.2
SB-166	600	Ni-Cr-Fe	Hot Fin.	...	85.0	35.0	(1)	21.2	21.2	21.2	21.2	21.2
SB-408	800	Ni-Fe-Cr	Ann., Gr.1	...	75.0	30.0	...	18.7	18.7	17.9	17.2	16.7
SB-408	800	Ni-Fe-Cr	Ann., Gr.1	...	75.0	30.0	(1)	18.7	18.7	18.7	18.7	18.7
SB-408	800	Ni-Fe-Cr	Ann., Gr.2	...	65.0	25.0	...	16.7	14.3	12.9	11.9	11.0
SB-408	800	Ni-Fe-Cr	Ann., Gr.2	...	65.0	25.0	(1)	16.7	16.7	16.7	15.8	14.9
SB-425	825	Ni-Fe-Cr-Mo-Cu	Annealed	...	85.0	35.0	...	21.2	21.2	20.4	19.2	18.3
SB-425	825	Ni-Fe-Cr-Mo-Cu	Annealed	...	85.0	35.0	(1)	21.2	21.2	21.2	21.2	21.2
ROD & BAR												
SB-335	Alloy B	Ni-Mo	Annealed	5/16"–1 1/2", Incl.	115.0	46.0	(1)	28.8	28.8	28.8	28.8	28.8
SB-335	Alloy B	Ni-Mo	Annealed	over 1 1/2"	100.0	46.0	(1)	25.0	25.0	25.0	24.7	24.3
SB-335	Alloy B	Ni-Mo	Annealed	5/16"–1 1/2", Incl.	115.0	46.0	...	28.8	28.4	27.2	25.7	24.6
SB-335	Alloy B	Ni-Mo	Annealed	over 1 1/2"	100.0	46.0	...	25.0	25.0	25.0	24.7	24.3
SB-336	Alloy C	Ni-Mo-Cr	Annealed	5/16"–1 1/2", Incl.	115.0	46.0	(1)	28.8	28.8	28.8	28.6	28.1
SB-336	Alloy C	Ni-Mo-Cr	Annealed	over 1 1/2"	100.0	46.0	(1)	25.0	25.0	25.0	24.8	24.3
SB-336	Alloy C	Ni-Mo-Cr	Annealed	5/16"–1 1/2", Incl.	115.0	46.0	...	28.8	28.8	27.3	25.7	24.3
SB-336	Alloy C	Ni-Mo-Cr	Annealed	over 1 1/2"	100.0	46.0	...	25.0	25.0	25.0	24.8	24.8

TABLE UNF-23.3 (CONT'D)
MAXIMUM ALLOWABLE STRESS VALUES IN TENSION FOR NONFERROUS METALS, in kips/sq in. (Multiply by 1000 to obtain psi)
(See UW-12(c) for vessels constructed under Part UW that include welded joints that are neither fully radiographed nor spot radiographically examined.)

NICKEL AND HIGH-NICKEL ALLOYS

For Metal Temperature Not Exceeding Deg F 600	650	700	750	800	850	900	950	1000	1050	1100	1150	1200	1250	1300	1350	1400	1450	1500	Spec. No.
PIPE & TUBE (Cont'd)																			
14.7	14.7	14.7	14.6	14.5	11.0	8.0	...	...	...	...	...	...	...	...	...	...	...	...	SB-165
13.1	13.1	13.1	13.0	12.7	11.0	8.0	...	...	...	...	...	...	...	...	...	...	...	...	SB-165
(1)	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	SB-165
16.1	16.0	15.6	15.5	15.3	15.0	14.9	10.6	7.0	4.5	3.0	2.2	2.0	...	...	...	...	...	...	SB-167
20.0	20.0	20.0	20.0	20.0	19.6	16.0	10.6	7.0	4.5	3.0	2.2	2.0	...	...	...	...	...	...	SB-167
13.2	13.1	13.0	12.9	12.7	12.3	11.8	10.6	7.0	4.5	3.0	2.2	2.0	...	...	...	...	...	...	SB-167
16.7	16.7	16.0	16.7	16.7	16.5	15.9	15.9	7.0	4.5	3.0	2.2	2.0	...	...	...	...	...	...	SB-167
20.0	19.8	19.6	19.4	19.1	18.7	16.0	10.6	7.0	4.5	3.0	2.2	2.0	...	...	...	...	...	...	SB-167
20.0	20.0	20.0	20.0	20.0	20.0	16.0	10.6	7.0	4.5	3.0	2.2	2.0	...	...	...	...	...	...	SB-167
16.1	16.0	15.6	15.5	15.3	15.0	14.9	10.6	7.0	4.5	3.0	2.2	2.0	...	...	...	...	...	...	SB-167
20.0	20.0	20.0	20.0	20.0	19.6	16.0	10.6	7.0	4.5	3.0	2.2	2.0	...	...	...	...	...	...	SB-167
16.3	16.1	15.9	15.7	15.5	15.3	15.1	14.9	14.7	14.5	13.0	9.8	6.6	4.2	2.0	1.6	1.1	1.0	0.8	SB-407
18.7	18.6	18.6	18.5	18.5	18.3	18.2	17.9	17.6	17.0	13.0	9.8	6.6	4.2	2.0	1.6	1.1	1.0	0.8	SB-407
10.6	10.5	10.2	10.1	9.9	9.8	9.7	9.6	9.4	9.4	9.4	9.3	7.9	6.0	4.6	3.6	2.8	2.1	1.7	SB-407
14.4	14.1	13.9	13.7	13.4	13.2	13.1	12.9	12.8	12.7	12.7	10.0	7.9	6.0	4.6	3.6	2.8	2.1	1.7	SB-407
17.8	17.6	17.3	17.2	17.1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	SB-423
21.2	21.1	21.0	20.9	20.8	...	...	...	...	...	...	...	...	...	...	...	...	...	...	SB-423
BARS, RODS, SHAPES, FORGINGS																			
10.0	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	SB-160
8.3	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	SB-160
6.2	6.2	6.2	6.0	5.9	5.8	4.8	3.7	3.0	2.4	2.0	1.6	1.2	...	...	...	...	...	...	SB-160
13.1	13.1	13.1	13.0	12.7	11.0	8.0	...	...	...	...	...	...	...	...	...	...	...	...	SB-164
20.0	20.0	19.2	18.5	14.5	8.5	4.0	...	...	...	...	...	...	...	...	...	...	...	...	SB-164
17.4	17.0	17.0	16.8	14.5	8.5	4.0	...	...	...	...	...	...	...	...	...	...	...	...	SB-164
18.7	18.7	18.0	17.2	14.5	8.5	4.0	...	...	...	...	...	...	...	...	...	...	...	...	SB-164
20.0	20.0	19.2	17.5	14.5	8.5	4.0	...	...	...	...	...	...	...	...	...	...	...	...	SB-164
18.7	18.7	18.0	17.2	14.5	8.5	4.0	...	...	...	...	...	...	...	...	...	...	...	...	SB-166
20.0	19.8	19.6	19.4	19.1	18.7	16.0	10.6	7.0	4.5	3.0	2.2	2.0	...	...	...	...	...	...	SB-166
20.0	20.0	20.0	20.0	20.0	20.0	16.0	10.6	7.0	4.5	3.0	2.2	2.0	...	...	...	...	...	...	SB-166
21.2	21.2	21.1	21.0	20.4	20.2	19.5	19.3	14.5	10.3	7.2	5.8	5.5	...	...	...	...	...	...	SB-166
21.2	21.2	21.2	21.2	21.2	21.2	21.2	21.2	14.5	10.3	7.2	5.8	5.5	...	...	...	...	...	...	SB-408
16.3	16.1	15.9	15.7	15.5	15.3	15.1	14.9	14.7	14.5	13.0	9.8	6.6	4.2	2.0	1.6	1.1	1.0	0.8	SB-408
18.7	18.6	18.6	18.5	18.5	18.3	18.2	17.9	17.6	17.0	13.0	9.8	6.6	4.2	2.0	1.6	1.1	1.0	0.8	SB-408
10.6	10.5	10.2	10.1	9.9	9.8	9.7	9.6	9.4	9.4	9.4	9.3	7.9	6.0	4.6	3.6	2.8	2.1	1.7	SB-408
14.4	14.1	13.9	13.7	13.4	13.2	13.1	12.9	12.8	12.7	12.7	10.0	7.9	6.0	4.6	3.6	2.8	2.1	1.7	SB-408
17.8	17.6	17.3	17.2	17.1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	SB-425
21.2	21.1	21.0	20.9	20.8	...	...	...	...	...	...	...	...	...	...	...	...	...	...	SB-425
ROD & BAR																			
28.8	28.8	28.8	28.8	28.7	...	...	...	...	...	...	...	...	...	...	...	...	...	...	SB-335
24.2	24.1	24.0	23.9	23.8	...	...	...	...	...	...	...	...	...	...	...	...	...	...	SB-335
23.7	23.3	23.0	22.8	22.5	...	...	...	...	...	...	...	...	...	...	...	...	...	...	SB-335
23.7	23.3	23.0	22.8	22.5	...	...	...	...	...	...	...	...	...	...	...	...	...	...	SB-335
27.8	27.6	27.4	27.2	27.0	26.8	26.6	26.3	26.1	...	...	...	...	...	...	...	...	...	...	SB-336
24.1	24.0	23.8	23.7	23.5	23.3	23.1	22.9	22.7	...	...	...	...	...	...	...	...	...	...	SB-336
23.5	23.0	23.1	23.0	22.9	22.8	22.7	22.6	22.5	...	...	...	...	...	...	...	...	...	...	SB-336
23.5	23.0	23.1	23.0	22.9	22.8	22.7	22.6	22.5	...	...	...	...	...	...	...	...	...	...	SB-336

TABLE UNF-23.3 (CONT'D)
MAXIMUM ALLOWABLE STRESS VALUES IN TENSION FOR NONFERROUS METALS, in kips/sq in. (Multiply by 1000 to obtain psi)
(See UW-12(c) for vessels constructed under Part UW that include welded joints that are neither fully radiographed nor spot radiographically examined.)

NICKEL AND HIGH-NICKEL ALLOYS

Spec. No.	Alloy Designation	Nominal Composition	Condition	Size, in.	Specified Min. Tensile, kips/sq. in.	Specified Min. Yield, kips/sq. in.	Notes	For Metal Temperature Not Exceeding Deg F: 100	200	300	400	500
BOLTING												
SB-335	Alloy B	Ni-Mo	Annealed	All	100.0	46.0	...	11.5	10.0	9.8	9.1	8.8
SB-336	Alloy C	Ni-Mo-Cr	Annealed	All	100.0	46.0	...	11.5	10.0	9.2	8.5	8.5
SB-160	200	Ni	Annealed	All Sizes	55.0	15.0	...	3.7	3.7	3.7	3.7	3.7
SB-160	200	Ni	Hot Fin.	All Sizes	60.0	15.0	...	3.7	3.7	3.7	3.7	3.7
SB-160	200	Ni	Cold Drawn	All Sizes	65.0	40.0	...	10.0	9.6	9.6	9.6	9.5
SB-160	201	Ni Low C	Ann/Hot Fin.	All Sizes	50.0	10.0	...	2.5	2.4	2.3	2.3	2.3
SB-164	400–405	Ni-Cu	Annealed	All Sizes	70.0	25.0	...	16.2	5.7	5.2	5.0	4.9
SB-164	400	Ni-Cu	Hot Fin.	All Sz. exc. Hex. over $2\frac{1}{8}$"	80.0	40.0	...	10.0	9.6	9.4	9.0	8.5
SB-164	400	Ni-Cu	Hot Fin.	Hex. over $2\frac{1}{8}$" Rnd. to 3", Incl.	75.0	30.0	...	7.5	7.4	7.1	6.8	6.5
SB-164	405	Ni-Cu	Hot Fin.	All Sizes	75.0	35.0	...	8.8	8.5	8.3	7.9	7.6
SB-164	400	Ni-Cu	CD-Str.Rel.	Rnd. to $3\frac{1}{2}$", incl.	84.0	50.0	(2)	12.5	11.9	11.5	11.3	11.3
SB-164	400	Ni-Cu	CD-Str.Eq.	All Sz. exc. Rnd. to $3\frac{1}{2}$", incl.	90.0	70.0	(2)	17.5	16.9	16.2	15.5	15.4
SB-164	400	Ni-Cu	CD-Str.Eq.	All Sizes	85.0	55.0	(2)	13.7	13.0	12.6	12.4	12.3
SB-164	405	Ni-Cu	Cold Drawn	All Sizes	85.0	55.0	(2)	13.7	13.0	12.6	12.4	12.3
SB-166	600	Ni-Cr-Fe	Cold Drawn	All Sizes	85.0	50.0	(2)	12.5	12.0	11.5	11.1	11.1
SB-166	600	Ni-Cr-Fe	Annealed	All Sizes	80.0	35.0	...	8.7	8.1	7.8	7.7	7.6
			Hot Fin.	Rnds over 3" & Shapes (All Sizes)	85.0	35.0	...	8.7	8.5	8.2	8.0	7.9
SB-166	600	Ni-Cr-Fe	Hot Fin.	Rnds to 3", incl.	90.0	40.0	...	10.0	9.5	9.2	9.1	9.1
SB-166	600	Ni-Cr-Fe	Cold Drawn	All Sizes	90.0	40.0	(2)(5)	10.0	9.5	9.2	9.1	9.1

NOTES:

The stress values in this table may be interpolated to determine values for intermediate temperatures.

Stress values in restricted shear such as dowel bolts, rivets, or similar construction in which the shearing member is so restricted that the section under consideration would fail without reduction of area shall be 0.80 times the values in the above table.

Stress values in bearing shall be 1.60 times the values in the above table.

(1) Due to the relatively low yield strength of these materials, these higher stress values were established at temperatures where the short-time tensile properties govern to permit the use of these alloys where slightly greater deformation is acceptable. These higher stress values exceed 62½ percent but not exceed 90 percent of the yield strength at temperature. Use of these stresses may result in dimensional changes due to permanent strain. These stress values are not recommended for the flanges of gasketed joints or other applications where slight amounts of distortion can cause leakage or malfunction.

(2) The maximum operating temperature is arbitrarily set at 500 F because harder temper adversely affects design stress in the creep rupture temperature range.

(3) 2000 psi at 900 F, use annealed condition above 800 F.

(4) For plate only.

(5) Design stresses for the cold drawn temper based on hot rolled properties until required data on cold drawn is submitted.

TABLE UNF-23.3
MAXIMUM ALLOWABLE STRESS VALUES IN TENSION FOR NONFERROUS METALS, in kips/sq in. (Multiply by 1000 to obtain psi)
(See UW-12(c) for vessles constructed under Part UW that include welded joints that are neither fully radiographically nor spot radiographically examined.)

NICKEL AND HIGH-NICKEL ALLOYS

For Metal Temperature Not Exceeding Deg F: 600	650	700	750	800	850	900	950	1000	1050	1100	1150	1200	1250	1300	1350	1400	1450	1500	Spec. No.
																			BOLTING
																			SB-335
																			SB-336
8.3	8.3	8.3	8.3	8.3	...	...	...	...	...	...	...	...	...	...	...	...	...	...	SB-160
8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	...	...	...	...	...	...	...	...	...	...	SB-160
3.7	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	SB-160
3.4	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	SB-160
9.2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	SB-164
2.3	...	2.3	...	2.2	...	2.1	...	2.0	...	1.8	...	1.2	...	...	...	...	...	...	SB-164
4.9	...	4.9	...	4.9	...	4.7	...	...	...	...	...	...	...	...	...	...	...	...	SB-164
8.5	...	8.5	...	8.3	...	4.0	...	...	...	...	...	...	...	...	...	...	...	...	SB-164
6.5	...	6.4	...	6.2	...	4.0	...	...	...	...	...	...	...	...	...	...	...	...	SB-164
7.6	...	7.5	...	7.3	...	4.0	...	...	...	...	...	...	...	...	...	...	...	...	SB-164
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	SB-164
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	SB-164
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	SB-164
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	SB-166
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	SB-166
7.5	...	7.3	...	7.1	...	6.9	...	6.8	...	3.0	...	2.0	...	...	...	...	...	...	SB-166
7.9	...	7.9	...	7.7	...	7.4	...	7.3	...	7.2	...	5.5	...	...	...	...	...	...	SB-166
9.1	...	8.9	...	8.8	...	8.6	...	8.3	...	7.3	...	5.5	...	...	...	...	...	...	SB-166
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	SB-166

TABLE UNF-23.4
MAXIMUM ALLOWABLE STRESS VALUES IN TENSION FOR NONFERROUS METALS, in kips/sq in.
(Multiply by 1000 to obtain psi)

Material; Form, and Spec. No.	Condition	Specified Tensile Strength, kips/sq. in.	Min. Yield Offset, kips/sq. in.	Notes	100	150	200	250	300	350	400	450	500	550	600
UNALLOYED TITANIUM															
Sheet Strip Plate SB-265	Grade 1-Annealed	40.0	30.0		10.0	9.6	8.7	7.9	7.3	6.6	6.2	5.7	5.3	5.0	4.6
	2-Annealed	50.0	40.0		12.5	12.0	10.9	9.9	9.0	8.4	7.7	7.2	6.6	6.2	5.7
	3-Annealed	60.0	50.0		15.0	14.3	13.0	11.9	10.9	10.0	9.2	8.6	7.9	7.5	6.9
Pipe SB-337	Grade 1-Smls-Ann	35.0	25.0		8.8	8.4	7.6	6.9	6.3	5.8	5.4	5.0	4.6	4.3	4.0
	2-Smls-Ann	50.0	40.0		12.5	12.0	10.9	9.9	9.0	8.4	7.7	7.2	6.6	6.2	5.7
	3-Smls-Ann	65.0	55.0		16.3	15.5	14.1	12.9	11.8	10.8	10.0	9.3	8.6	8.0	7.5
	7-Smls-Ann	50.0	40.0		12.5	12.0	10.9	9.9	9.0	8.4	7.7	7.2	6.6	6.2	5.7
	Grade 1-Weld-Ann	35.0	25.0	(1) (2)	7.5	7.1	6.5	5.9	5.4	4.9	4.6	4.3	3.9	3.7	3.4
	2-Weld-Ann	50.0	40.0	(1) (2)	10.6	10.2	9.3	8.4	7.7	7.1	6.5	6.1	5.6	5.3	4.8
	3-Weld-Ann	65.0	55.0	(1) (2)	13.9	13.2	12.0	11.0	10.0	9.2	8.5	7.9	7.3	6.8	6.4
	7-Weld-Ann	50.0	40.0	(1) (2)	10.6	10.2	9.3	8.4	7.7	7.1	6.5	6.1	5.6	5.3	4.8
Tubing SB-338	Grade 1-Smls-Ann	35.0	25.0		8.8	8.4	7.6	6.9	6.3	5.8	5.4	5.0	4.6	4.3	4.0
	2-Smls-Ann	50.0	40.0		12.5	12.0	10.9	9.9	9.0	8.4	7.7	7.2	6.6	6.2	5.7
	3-Smls-Ann	65.0	55.0		16.3	15.5	14.1	12.9	11.8	10.8	10.0	9.3	8.6	8.0	7.5
	7-Smls-Ann	50.0	50.0		12.5	12.0	10.9	9.9	9.0	8.4	7.7	7.2	6.6	6.2	5.7
	Grade 1-Weld-Ann	35.0	25.0	(1) (2)	7.5	7.1	6.5	5.9	5.4	4.9	4.6	4.3	3.9	3.7	3.4
	2-Weld-Ann	50.0	40.0	(1) (2)	10.6	10.2	9.3	8.4	7.7	7.1	6.5	6.1	5.6	5.3	4.8
	3-Weld-Ann	65.0	55.0	(1) (2)	13.9	13.2	12.0	11.0	10.0	9.2	8.5	7.9	7.3	6.8	6.4
	7-Weld-Ann	50.0	40.0	(1) (2)	10.6	10.2	9.3	8.4	7.7	7.1	6.5	6.1	5.6	5.3	4.8
Forgings SB-381	Grade F1 Annealed	40.0	30.0		10.0	9.6	8.7	7.9	7.3	6.6	6.2	5.7	5.3	5.0	4.6
	F2 Annealed	50.0	40.0		12.5	12.0	10.9	9.9	9.0	8.4	7.7	7.2	6.6	6.2	5.7
	F3 Annealed	60.0	50.0		15.0	14.3	13.0	11.9	10.9	10.0	9.2	8.6	7.9	7.5	6.9
Bar Billet SB-348	Grade 1-Annealed	40.0	30.0		10.0	9.6	8.7	7.9	7.3	6.6	6.2	5.7	5.3	5.0	4.6
	2-Annealed	50.0	40.0		12.5	12.0	10.9	9.9	9.0	8.4	7.7	7.2	6.6	6.2	5.7
	3-Annealed	60.0	50.0		15.0	14.3	13.0	11.9	10.9	10.0	9.2	8.6	7.9	7.5	6.9

NOTE (1) 85 percent joint efficiency has been used in determining the allowable stress values for welded pipe and tube.
(2) Filler metal shall not be used in the manufacture of welded tubing or pipe.

PRESSURE RELIEF DEVICES

UNF-125 General

The provisions for pressure relief devices in UG-125 through UG-134 shall apply without supplement to pressure vessels constructed of nonferrous materials.

APPENDIX NF

CHARACTERISTICS OF THE NONFERROUS MATERIALS

(Informative and Nonmandatory)

1 Purpose

This appendix summarizes the major properties and fabricating techniques suitable for the nonferrous materials.

2 General

The nonferrous materials can be formed and fabricated into a variety of types of assemblies with the same types of fabricating equipment as are used for steel. The details of some fabricating procedures vary among the several nonferrous materials and differ from those used for steel because of differences in the inherent mechanical properties of these materials. Detailed information regarding procedures best suited to the several metals may be obtained from the literature of the material producers, and from other reliable sources such as the latest editions of handbooks issued by the American Welding Society and the American Society for Metals.

3 Properties

The specified mechanical properties, as listed in Table UNF-23, show a wide range of strengths. The maximum allowable stress values show a correspondingly wide range and a variable relationship to service temperature. The maximum temperature listed for any material is the temperature above which that material is not customarily used. Table NF-1 gives additional mechanical properties, while physical properties are given in Table NF-2. Annealing temperatures are listed in Table NF-3 and hot working temperatures are set forth in Table NF-4.

4 Magnetic Properties

Both aluminum and copper are practically nonmagnetic, but nickel, like steel, is strongly magnetic at room temperature. The Curie temperature (the temperature at which a metal loses its magnetic properties) of nickel is 680 F. Nickel-copper alloy is slightly magnetic at room temperature and has a Curie temperature of 110-140 F, depending on slight variations in copper content and other alloy elements. Nickel-chromium-iron alloy is nonmagnetic at room temperature and has a Curie temperature of —40 F. These statements suggest a simple magnetic test for differentiating the nickel alloys.

5 Cooling Rates

The nonferrous alloys in general do not harden when quenched from an elevated temperature. Therefore the rate of cooling from an elevated temperature is unimportant, except where specifically indicated. Preheating for controlling the rate of cooling during welding is not necessary.

6 Low-Temperature Behavior

The nonferrous alloys listed in Table UNF-23 do not exhibit a transition range at low temperatures as do some ferrous materials and hence do not suffer a loss of impact resistance at low temperatures. The static tensile strength increases as the temperature decreases, and the ductility as measured by percent elongation is not adversely affected to any significant degree. For these reasons low-temperature impact

TABLE NF-1
TYPICAL MECHANICAL PROPERTIES OF MATERIALS

Material	Modulus of Elasticity, psi	Poisson's Ratio	Modulus of Rigidity, psi
Aluminum	10,000,000	0.33	3,800,000
Copper, Deoxidized	17,000,000	0.33	6,400,000
Red Brass	17,000,000	0.33	6,400,000
Admiralty	16,000,000	0.33	6,000,000
Aluminum Brass	16,000,000	0.33	6,000,000
Naval Brass	15,000,000	0.33	5,600,000
Muntz Metal	15,000,000	0.33	5,600,000
30% Cupro Nickel	22,000,000	0.33	8,200,000
20% Cupro Nickel	20,000,000	0.33	7,500,000
10% Cupro Nickel	18,000,000	0.33	6,800,000
Copper Silicon (A, C, D)	15,000,000	0.33	5,600,000
Copper Silicon (B)	17,000,000	0.33	6,400,000
Aluminum Bronze (D)	17,500,000	0.33	6,500,000
Aluminum Bronze (E)	17,000,000	0.33	6,400,000
Nickel	30,000,000	0.31	11,000,000
Nickel-Copper	26,000,000	0.32	9,500,000
Ni-Cr-Fe	31,000,000	0.29	11,000,000
Steel	29,000,000	0.30	11,200,000
Unalloyed Titanium	16,000,000	0.32	6,000,000
Nickel-Iron-Chromium	28,500,000	0.339	10,600,000

tests of nonferrous materials are not required by this Division of Section VIII.

7 Thermal Cutting

In general, nonferrous materials cannot be cut by the conventional oxyacetylene cutting equipment commonly used for steel. They may be melted and cut by oxyacetylene, powder cutting carbon arc, oxygen arc, and other means. When such thermal means for cutting are employed a shallow contaminated area adjacent to the cut results. This contamination should be removed by grinding, machining, or other mechanical means after thermal cutting and prior to use or further fabrication by welding.

8 Machining

The nonferrous materials can be machined with properly sharpened tools of high-speed steel or cemented-carbide tools. A coolant is necessary and should be used copiously. In general, the tools should have more side and top rake than required for cutting steel and the edges should be keen and smooth. Comparatively high speeds and fine feeds give best results. Information can be obtained from the material producers and the Metals Handbook for conditions to give optimum results.

9 Gas Welding

The commonly used gas processes for welding aluminum-base materials employ oxyhydrogen or oxyacetylene flames whereas only the latter produces sufficient heat for welding the copper-base and nickel-base alloys. For the aluminum, nickel and cupro-nickel alloys a neutral to slightly reducing flame should be used, whereas for copper base materials the flame should be neutral to slightly oxidizing. A suitable flux, applied to the welding rod and the work, shall be used except that no flux is required for nickel. Boron-free and phosphorus-free fluxes are required for nickel-copper alloy and for nickel-chromium-iron alloy. Residual deposits of flux shall be removed.

0 Metal Arc Welding

Metal arc welds can be made with standard dc equipment using reversed polarity (electrode-positive) and coated electrodes. A slightly greater included angle in butt welds for adequate manipulation of the electrode is required.

11 Inert Gas Metal Arc Welding

Both the consumable and nonconsumable electrode processes are particularly advantageous for use with the nonferrous materials. Best results are obtained through the use of special filler metals.

12 Resistance Welding

Electric resistance welding, which includes spot, line or seam, and butt or flash welding, can be used with the nonferrous materials. Proper equipment and technique are required for making satisfactory welds.

13 Corrosion

(*a*) *General.* The nonferrous materials listed on Table UNF-23 offer greater resistance to corrosion in many applications than does mild steel. For information on the differences that exist among the nonferrous materials on the subject of corrosion, reference may be made to the following sources:

(*1*) Corrosion Handbook (The Electro-Chemical Society);

(*2*) Metals Handbook (American Society for Metals);

(*3*) Metals of Construction, Industrial and Engineering Chemistry, Vol. 43, Oct., 1951;

(*4*) Corrosion Resistance of Metals and Alloys, McKay and Worthington (1936);

(*5*) Corrosion Guide, Erich Rabald (1951);

(*6*) Corrosion Data Survey, G. A. Nelson, Shell Development Company.

(*b*) *Stress Corrosion.* Because of the occasionally contingent danger from the failure of pressure vessels by stress corrosion cracking, the following seems pertinent. The materials listed in Table UNF-23 are suitable for engineering use under a wide variety of ordinary corrosive conditions, with no particular hazard in respect to stress corrosion. However, few alloys are completely immune to stress corrosion cracking in all combinations of stress and corrosive environments and the supplier of the material should be consulted.

(*c*) *Galvanic Corrosion.* By virtue of their relative solution potentials, some materials are anodic to others in the presence of an electrolyte. The extent of galvanic attack will vary with the nature, concentration, and temperature of the environment, and with the inherent characteristics of the dissimilar metals and their relative areas. Where practicable avoid dissimilar metals or select special precautions, such as insulation between dissimilar-metal parts. The use of protective coatings should be considered.

TABLE NF-2
TYPICAL PHYSICAL PROPERTIES OF MATERIALS

Material	ASME Spec. No.	Weight lb per cu in.	Approx. Melting Range deg F	Thermal Conductivity 32 F–212 F BTU/sq ft/hr deg F/in.	Thermal Expansion 10^{-6} in./in. deg F	Specific Heat BTU/lb/deg F at 212 F
A1 Alloy 1060	SB-209, SB-210	0.098	1195–1215	1625	13.1(a)	0.23
1100	SB-221, SB-234	0.098	1190–1215	1540	13.1(a)	0.23
2014	SB-209	0.101	950–1180	930[3]	12.8(a)	0.23
2024	SB-211, SB-247	0.100	935–1180	1070[5] 840[3]	12.9(a)	0.23
3003	SB-211, SB-221	0.099	1190–1210	1340[1]	12.9(a)	0.23
3004	SB-209, SB-210, SB-221, SB-234, SB-241, SB-247	0.098	1165–1205	1130	13.3(a)	0.23
5050	SB-209	0.097	1160–1205	1340	13.2(a)	0.23
5052	SB-209	0.097	1100–1200	960	13.2(a)	0.23
5083	SB-209, SB-234	0.096	1060–1180	810	13.2(a)	0.23
5086	SB-209, SB-221, SB-241, SB-247	0.096	1084–1184	870	13.2(a)	0.23
5154	SB-209	0.096	1100–1190	870	13.3(a)	0.23
5454	SB-209, SB-210, SB-221, SB-241	0.097	1115–1195	930	13.1(a)	0.23
5456	SB-209, SB-221, SB-234, SB-241	0.096	1060–1180	810	13.3(a)	0.23
6053	SB-209, SB-221, SB-241, SB-247	0.097	1100–1205	1130[5]	12.8(a)	0.23
6061	SB-247					
6063	SB-209, SB-210, SB-211, SB-221, SB-234, SB-241, SB-308	0.098	1100–1205	1070[3] 1160[5]	13.1(a)	0.23
S5A	SB-210, SB-221	0.097	1140–1205	1340[2] 1450[4] 1390[5]	13.0(a)	0.23
SG70A	SB-26	0.097	1065–1170	1015[6]	12.4(a)	0.23
Copper, Deoxidized	SB-26	0.097	1035–1135	1045[5] 1075[7]	11.9(a)	0.23
Red Brass	SB-11 & 111	0.323	1980	2352	9.8(b)	0.09
Admiralty	SB-111 & 43	0.316	1810–1880	1104	10.4(b)	0.09
Aluminum Brass	SB-111 & 171	0.308	1660–1720	768	11.2(b)	0.09
Naval Brass	SB-111	0.301	1710–1780	696	10.3(b)	0.09
Muntz Metal	SB-171	0.304	1630–1650	804	11.8(b)	0.09
30% Cupro Nickel	SB-171	0.303	1650–1660	852	11.6(b)	0.09
20% Cupro Nickel	SB-111 & 171	0.323	2140–2260	204	9.1(b)	0.09
10% Cupro Nickel	SB-111 & 171	0.323	2100–2200	240	9.3(b)	0.09
Copper Silicon (A,C,D)	SB-111	0.323	2020–2100	324	9.5(b)	0.09
Copper Silicon (B)	SB-96 & 98	0.308	1780–1880	252	10.0(b)	0.09
Aluminum Bronze (D)	SB-98	0.316	1890–1940	396	9.9(b)	0.09
Aluminum Bronze (E)	SB-171	0.281	1850–1900	552	9.0	0.09
Nickel and Low-Carbon Nickel	SB-171	0.274	1900–1980	264		0.09
Nickel-Copper	SB-162	0.321	2615–2635	420	7.2(c)	0.13
Ni-Cr-Fe	SB-127	0.319	2370–2460	180	7.8(c)	0.13
Carbon Steel	SB-168	0.300	2540–2600	104	6.4(c)	0.11
Unalloyed Titanium		0.279		460	6.7(c)	
Nickel-Iron-Chromium	SB-265, SB-337, SB-338, SB-381 SB-409	0.163 0.290	3100 2475–2525	105 80	4.7 7.9	0.13 0.12

(a) Thermal expansion per deg F from 68 F to 212 F.
(b) Thermal expansion per deg F from 68 F to 572 F.
(c) Thermal expansion per deg F from 32 F to 212 F.

1 Annealed Temper
2 T1 Temper
3 T4 Temper
4 T5 Temper
5 T6 Temper
6 F Temper
7 T71 Temper

TABLE NF-3
USUAL RANGES OF ANNEALING TEMPERATURE AND TIME

Material	ASME Spec. No.	Temperature Range deg F	Time at Temperature, min.
A1 Alloy 1060	SB-209, SB-210, SB-221, SB-234	650–750	Footnote 2
1100	SB-209	650–760	Footnote 2
2014[1]	SB-211, SB-247	750–800	120–180
2024[1]	SB-211, SB-221	750–800	120–180
3003	SB-209, SB-210, SB-221, SB-234,	750–800	Footnote 2
3004	SB-241, SB-247	650–750	
5050	SB-209	650–750	Footnote 2
5052	SB-209	650–750	Footnote 2
5083	SB-209, SB-234	650–750	Footnote 2
5086	SB-209, SB-221, SB-241, SB-247	650–750	Footnote 2
5154	SB-209	650–750	Footnote 2
5454	SB-209, SB-210, SB-221, SB-241	650–750	Footnote 2
5456	SB-209, SB-221, SB-234, SB-241	650–750	Footnote 2
6053[1]	SB-209, SB-221, SB-241, SB-247	650–750	Footnote 2
6061[1]	SB-247	650–750	Footnote 2
6063[1]	SB-209, SB-210, SB-211, SB-221,	750–800	120–180
Copper, Deoxidized	SB-234, SB-241, SB-247, SB-308	750–800	120–180
Red Brass	SB-210, SB-221	750–800	120–180
Admiralty	SB-11 & 111	700–1220	15–30
Aluminum Brass	SB-43 & 111	800–1350	15–30
Naval Brass	SB-111 & 171	800–1100	15–30
Muntz Metal	SB-111	800–1100	15–30
30% Cupro Nickel	SB-171	800–1100	15–30
20% Cupro Nickel	SB-111 & 171	1200–1600	15–30
10% Cupro Nickel	SB-111 & 171	1200–1600	15–30
Copper Silicon (A, C, D)	SB-111	1100–1500	15–30
Copper Silicon (B)	SB-111	900–1300	15–30
Aluminum Bronze (D)	SB-96 & 98	900–1250	15–30
Aluminum Bronze (E)	SB-98	1400–1500	15–30
Nickel and Low-Carbon Nickel	SB-171	1250–1350	15–60
Nickel-Copper	SB-171	1500–1700	15–30
Ni-Cr-Fe	SB-162	1600–1800	20–25
Unalloyed Titanium	SB-127	1750–1950	20–25
Nickel-Iron-Chromium	SB-168	(see Par. NF-14)	20–25
	SB-265, SB-337, SB-338, SB-381	1750–2150	15–60
	SB-409		

[1] Material initially in a heat treated temper. Annealing treatment should be followed by slow cool at 50 F per hour to 450–500 F. Subsequent rate of cool to room temperature not important.

[2] Actual attainment of annealing temperature is of more consequence than annealing time. Cooling rate is unimportant.

14 Special Comments

ALUMINUM

Threaded Connections. Under some conditions of loading, aluminum and aluminum-alloy threaded connections seize so that repeated tightening and loosening are impossible. All threaded connections should be treated with a suitable anti-seize compound.[1]

Dissimilar Metals. If dissimilar metals must be used in combination with aluminum alloys, the best choices would ordinarily be galvanized steel and stainless steel, austenitic types preferred.

NICKEL

Sulfur Embrittlement. Nickel combines with sulfur at elevated temperatures to form a brittle sulfide. This phenomenon takes place preferentially at the grain boundaries, and results in embrittlement which exhibits itself as a network of cracks when the material is stressed or bent. Nickel is affected most, nickel-copper somewhat less, and nickel-chromium-iron still less. Table NF-5 lists the normal limiting service temperatures. The more sulfur present or the higher the temperature, the more rapid and deep will be the attack.

Material which has been sulfur embrittled cannot be salvaged. It must be scrapped.

Prior to any operation which involves heating to a higher temperature such as welding, brazing, annealing, hot forming, and forging, it is imperative to remove all sulfur-containing substances such as oil, grease, marking pencil marks, paint, and drawing or threading lubricants. In addition, the atmosphere of the furnace in which heating is done should be essentially sulfur-free. A city gas or natural gas containing less than 25 grains of sulfur per 100 cubic feet or a fuel oil containing less than 0.5 per cent sulfur will be satisfactory for heating. Coal and coke are not satisfactory.

Lead Embrittlement. Lead causes embrittlement in all nickel-base alloys in much the same manner as sulfur. Lead-containing drawing or threading lubricants must be removed prior to a heating operation. Welding must not be done adjacent to or over soft solder. "Buttering" of threads with a lead-containing antigalling compound is to be avoided if the temperature of operation will exceed 400 F or if seal welding is done.

[1] Army-Navy Aeronautical Specification AN-C-53 Amend. I may be obtained from Sup't. of Documents, U.S. Printing Office.

UNALLOYED TITANIUM

(*a*) Heat treatment, although not mandatory after welding, is recommended after forming operations. Heat treatment shall be done in a furnace and at a metal temperature not less than 900 F or more than 1200 F, with time at temperature not to exceed 1 hr. The stress relieving heat treatment usually recommended for unalloyed titanium is 1000 F to 1100 F for ½ hr. Prolonged exposures at temperatures above 1100 F result in heavier surface films that are not satisfactorily removed by acid pickling, but require descaling treatment for their removal.

(*b*) In certain environments associated with pickling and annealing, as well as under actual operating conditions, absorption of hydrogen with resultant embrittling of the unalloyed titanium, or surface hydriding with loss of effective structural material, may occur. Scaling may result from

TABLE NF-4
TEMPERATURE RANGE FOR HOT WORKING NONFERROUS MATERIALS

Material	ASME No.	Temperature Range, deg F: For Work	For Work
A1 Alloy 1060	SB-209	300–500	500–850
1100			
3003	SB-209	400–600	600–900
3004	SB-209	400–600	600–850
5052	SB-209	400–600	600–850
6061[1]	SB-209	400–600	600–900
6061[2]	SB-209	300–350	350–400
Copper, Deoxidized	SB-11 & 111	1400	1600
Red Brass	SB-43 & 111	1450	1650
Admiralty	SB-111 & 171	1200	1450
Aluminum Brass	SB-111	1400	1600
Naval Brass	SB-171	1200	1500
Muntz Metal	SB-171	1150	1450
30% Cupro Nickel	SB-111 & 171	1700	2000
20% Cupro Nickel	SB-111	1600	1900
10% Cupro Nickel	SB-111	1400	1800
Copper Silicon (A, C, D)	SB-96	1300	1600
Copper Silicon (B)	SB-98	1300	1600
Aluminum Bronze (D)	SB-171	1400–1600	1500–1700
Aluminum Bronze (E)	SB-171	1450	1600
Nickel and Low-Carbon Nickel	SB-162	1000–1200	1200–2300
Nickel Copper	SB-127	1200–1700	1700–2150
Ni-Cr-Fe	SB-168	1600–1850	1850–2300
Nickel-Iron-Chromium	SB-409	1600–1850	1850–2200
Unalloyed Titanium	SB-265	–	600 max.

[1] Annealed and as-rolled tempers.

[2] T5 and T6 tempers.

excessive annealing time and temperatures in oxidizing environments, and reducing furnace atmospheres shall not be used. Suitable procedures are available from the manufacturers and other sources to minimize scaling of hydrogen pickup during the various steps associated with fabrication.

(*c*) Service environments should be considered from the standpoints of potential embrittlement, hydriding, oxide scaling, and rapid oxidation, particularly environments containing free oxygen gas.

Molten or very hot unalloyed titanium reacts readily with air. Contamination during welding by oxygen and nitrogen increases the weld metal hardness and decreases the ductility and notch toughness. An increase in weld metal hardness (in comparison with parent metal hardness) of more than about 40 VHN is indicative of possible excessive contamination. Substantial increases in hardness above this amount necessitates removal of the affected weld-metal area.

Special precautions should be taken to insure complete inert-gas shielding of the weld metal pool, the weld face, the back side of the weld, and the adjacent heat affected base metal surfaces. Close supervision and inspection throughout the welding operation, as well as inspection of the weld face after the completion of each pass, prior to brushing or cleaning, is desirable.

It is recommended that the Appendix of Specification SB-382 be used as a guide.

TABLE NF-5
LIMITING SERVICE TEMPERATURE, deg F

		Sulfur-Free Atmospheres				Sulfurous Atmospheres	
Material	ASME Spec. No.	Oxidizing	Reducing H_2	Reducing CO	Steam	Oxidizing	Reducing
Nickel	SB-162	1900	2300	2300	800	600	500
Ni-Cu	SB-127	1000	2000	1500	700	600	500
Ni-Cr-Fe	SB-168	2000	2100	2100	1500	1500	1000
Nickel-Iron-Chromium	SB-409	2000	2300	2100	1800	1500	1000

PART UHA

REQUIREMENTS FOR PRESSURE VESSELS CONSTRUCTED OF HIGH-ALLOY STEEL

GENERAL

UHA-1 Scope

The rules in Part UHA are applicable to pressure vessels and vessel parts that are constructed of high-alloy steel and shall be used in conjunction with the general requirements in Subsection A, and with the specific requirements in Subsection B that pertain to the method of fabrication used.

UHA-5 Uses

Some of the uses of high-alloy steel are to resist corrosion, to avoid contamination of contents with iron, to facilitate cleaning of vessels for processing foods, to provide strength or scaling resistance at high temperatures, and to provide impact resistance at low temperatures.

UHA-6 Conditions of Service

Specific chemical compositions, heat treatment procedures, fabrication requirements, and supplementary tests may be required to assure that the vessel will be in its most favorable condition for the intended service. This is particularly true for vessels subject to severe corrosion. These rules do not indicate the selection of an alloy suitable for the intended service or the amount of the corrosion allowance to be provided.

It is recommended that users assure themselves by appropriate tests, or otherwise, that the high-alloy steel selected and its heat-treatment during fabrication will be suitable for the intended service both with respect to corrosion resistance and to retention of satisfactory mechanical properties during the desired service life. (See Appendix HA, *Suggestions on the Selection and Treatment of Austenitic Chromium-Nickel Steels.*)

UHA-8 Material

(*a*) Approved specifications for castings of high alloy steel are given in Table UHA-23 together with a tabulation of allowable stress values at different temperatures. These stress values are to be multiplied by the casting quality factors of UG-24. Castings that are to be welded shall be of weldable grade.

(*b*) Cast high-alloy steel flanges and fittings complying with ANSI B16.5-1968 shall be used within the ratings assigned in these standards.

MATERIALS

UHA-11 General

(*a*) All materials subject to stress due to pressure shall conform to one of the specifications given in Section II of the Code, and shall be limited to those listed in Table UHA-23 except as otherwise provided in (b) and (c) and in UG-10 and UG-11.

(*b*) When the desired type of approved stainless steel is lacking in the specification covering the applicable form (tubing, casting, etc.), the material may be furnished to the general requirements of an approved specification with the chemical and mechanical properties conforming to those shown in another approved specification for the desired grade.

(*c*) Columbium or columbium plus tantalum may be added to Types 309, 310, and 316 material in an amount not less than 9 times the carbon content and not greater than 1.0 percent. These materials are designated Types 309Cb, 310Cb, and 316Cb, respectively, in these rules. (See UHA-106 for a suggested restricted composition for Type 316Cb.) The maximum allowable stress values for materials with columbium or columbium plus tantalum added shall be the same as given in Table UHA-23 for Types 309, 310, and 316, respectively.

(*d*) The specifications listed in Table UHA-23 do not use a uniform system for designating the grade

TABLE UHA-23 (CONT'D)
MAXIMUM ALLOWABLE STRESS VALUES IN TENSION FOR HIGH-ALLOY STEEL,
IN KIPS/SQ IN. (MULTIPLY BY 1000 TO OBTAIN PSI)
(See UW-12(c) for vessels constructed under Part UW that include welded joints that are neither fully radiographed nor spot radiographically examined)

Nominal Composition	P-Number	Product Form	Specification Number	Grade	Notes	Specified Minimum Yield	Specified Minimum Tensile	For Metal Temperatures Not Exceeding Deg F: −20 to 100	200	300	400	500	600	650
18 Cr-8 Ni	8	Smls. Pp.	SA-430	FP304	(1)(10)(13)	30.0	70.0	17.5	16.5	15.5	15.0	14.8	14.8	14.8
18 Cr-8 Ni	8	Smls. Pp.	SA-430	FP304H	(1)									
18 Cr-8 Ni	8	Forg.	SA-182	F304	(1)(10)(12)									
18 Cr-8 Ni	8	Forg.	SA-182	F304H	(1)(12)									
18 Cr-8 Ni	8	Forg.	SA-336	F8	(1)(10)(13)									
18 Cr-8 Ni	8	Smls. Pp.	SA-430	FP304	(10)(13)	30.0	70.0	17.5	15.6	14.0	12.9	12.1	11.4	11.2
18 Cr-8 Ni	8	Smls. Pp.	SA-430	FP304H	...									
18 Cr-8 Ni	8	Forg.	SA-182	F304	(10)(12)									
18 Cr-8 Ni	8	Forg.	SA-182	F304H	(12)									
18 Cr-8 Ni	8	Forg.	SA-336	F8	(10)(13)									
18 Cr-8 Ni	8	Plate	SA-240	302	(1)	30.0	75.0	18.7	17.7	16.6	16.1	15.9	15.9	15.9
18 Cr-8 Ni	8	Bar.	SA-479	302	(1)									
18 Cr-8 Ni	8	Plate	SA-240	302	...	30.0	75.0	18.7	15.6	14.0	12.9	12.1	11.4	11.2
18 Cr-8 Ni	8	Bar.	SA-479	302	...									
18 Cr-8 Ni	8	Plate	SA-240	304	(1)(10)(13)	30.0	75.0	18.7	17.7	16.6	16.1	15.9	15.9	15.9
18 Cr-8 Ni	8	Smls. Tb.	SA-213	TP304	(1)(10)									
18 Cr-8 Ni	8	Smls. Tb.	SA-213	TP304H	(1)									
18 Cr-8 Ni	8	Smls. Pp.	SA-312	TP304	(1)(10)									
18 Cr-8 Ni	8	Smls. Pp.	SA-312	TP304H	(1)									
18 Cr-8 Ni	8	Smls. Pp.	SA-376	TP304	(1)(10)									
18 Cr-8 Ni	8	Smls. Pp.	SA-376	TP304H	(1)									
18 Cr-8 Ni	8	Cast. Pp.	SA-452	TP304H	(1)									
18 Cr-8 Ni	8	Forg.	SA-182	F304	(1)(10)									
18 Cr-8 Ni	8	Forg.	SA-182	F304H	(1)									
18 Cr-8 Ni	8	Bar.	SA-479	304	(1)(10)(13)									
18 Cr-8 Ni	8	Plate	SA-240	304	(10)(13)	30.0	75.0	18.7	15.6	14.0	12.9	12.1	11.4	11.2
18 Cr-8 Ni	8	Smls. Tb.	SA-213	TP304	(10)									
18 Cr-8 Ni	8	Smls. Tb.	SA-213	TP304H	...									
18 Cr-8 Ni	8	Smls. Pp.	SA-312	TP304	(10)									
18 Cr-8 Ni	8	Smls. Pp.	SA-312	TP304H	...									
18 Cr-8 Ni	8	Smls. Pp.	SA-376	TP304	(10)									
18 Cr-8 Ni	8	Smls. Pp.	SA-376	TP304H	...									
18 Cr-8 Ni	8	Cast. Pp.	SA-452	TP304H	...									
18 Cr-8 Ni	8	Forg.	SA-182	F304	(10)									
18 Cr-8 Ni	8	Forg.	SA-182	F304H	...									
18 Cr-8 Ni	8	Bar.	SA-479	304	(10)(13)									
18 Cr-8 Ni	8	Wld. Tb.	SA-249	TP304	(1)(4)(10)	30.0	75.0	15.9	15.1	14.1	13.7	13.5	13.5	13.5
18 Cr-8 Ni	8	Wld. Tb.	SA-249	TP304H	(1)(4)									
18 Cr-8 Ni	8	Wld. Tb.	SA-312	TP304	(1)(4)(10)									
18 Cr-8 Ni	8	Wld. Tb.	SA-312	TP304H	(1)(4)									
18 Cr-8 Ni	8	Wld. Tb.	SA-249	TP304	(4)(10)	30.0	75.0	15.9	13.3	11.9	11.0	10.3	9.7	9.5
18 Cr-8 Ni	8	Wld. Tb.	SA-249	TP304H	(4)									
18 Cr-8 Ni	8	Wld. Tb.	SA-312	TP304	(4)(10)									
18 Cr-8 Ni	8	Wld. Tb.	SA-312	TP304H	(4)									
18 Cr-8 Ni	...	Bolt.	SA-193	B8	(5)(7) (10)(13)	30.0	75.0	15.0	13.3	12.0	10.9	10.0	9.3	8.9
18 Cr-8 Ni	...	Bolt.	SA-320	B8	(5)(7)(8)	30.0	75.0	15.0	...	...	...	...	...	...
18 Cr-8 Ni-S	...	Bolt.	SA-320	B8F-S	(5)(7)(8)									
18 Cr-8 Ni-Se	...	Bolt.	SA-320	B8F-Se	(5)(7)(8)									
18 Cr-8 Ni	8	Cast.	SA-351	CF3A	(1)(6)	35.0	77.5	19.3	17.1	16.0	15.4	15.0	14.8	14.7
18 Cr-8 Ni	8	Cast.	SA-351	CF3A	(6)	35.0	77.5	19.3	17.1	16.0	14.3	13.2	12.6	12.4

TABLE UHA-23 (CONT'D)
MAXIMUM ALLOWABLE STRESS VALUES IN TENSION FOR HIGH-ALLOY STEEL,
IN KIPS/SQ. IN. (MULTIPLY BY 1000 TO OBTAIN PSI)
(See UW-12(c) for vessels constructed under Part UW that include welded joints that are neither fully radiographed nor spot radiographically examined)

For Metal Temperatures Not Exceeding Deg F: 700	750	800	850	900	950	1000	1050	1100	1150	1200	1250	1300	1350	1400	1450	1500	Specification Number	Grade
14.8	14.7	14.6	14.4	14.1	13.8	13.3	12.0	9.7	7.7	6.0	4.7	3.7	2.9	2.3	1.8	1.4	SA-430	FP304
																	SA-430	FP304H
																	SA-182	F304
																	SA-182	F304H
																	SA-336	F8
11.0	10.8	10.5	10.3	10.1	9.9	9.7	9.5	8.8	7.7	6.0	4.7	3.7	2.9	2.3	1.8	1.4	SA-430	FP304
																	SA-430	FP304H
																	SA-182	F304
																	SA-182	F304H
																	SA-336	F8
15.9	15.5	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	SA-240	302
																	SA-479	302
11.0	10.8	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	SA-240	302
																	SA-479	302
15.9	15.5	15.1	14.9	14.6	14.3	13.7	12.1	9.7	7.7	6.0	4.7	3.7	2.9	2.3	1.8	1.4	SA-240	304
																	SA-213	TP304
																	SA-213	TP304H
																	SA-312	TP304
																	SA-312	TP304H
																	SA-376	TP304
																	SA-376	TP304H
																	SA-452	TP304H
																	SA-182	F304
																	SA-182	F304H
																	SA-479	304
11.0	10.8	10.5	10.3	10.1	9.9	9.7	9.5	8.8	7.7	6.0	4.7	3.7	2.9	2.3	1.8	1.4	SA-240	304
																	SA-213	TP304
																	SA-213	TP304H
																	SA-312	TP304
																	SA-312	TP304H
																	SA-376	TP304
																	SA-376	TP304H
																	SA-452	TP304H
																	SA-182	F304
																	SA-182	F304H
																	SA-479	304
13.6	13.2	12.9	12.6	12.4	12.2	11.7	10.3	8.3	6.5	5.1	4.0	3.1	2.4	1.9	1.5	1.2	SA-249	TP304
																	SA-249	TP304H
																	SA-312	TP304
																	SA-312	TP304H
9.4	9.2	8.9	8.8	8.6	8.4	8.3	8.0	7.5	6.5	5.1	4.0	3.1	2.4	1.9	1.5	1.2	SA-249	TP304
																	SA-249	TP304H
																	SA-312	TP304
																	SA-312	TP304H
8.6	8.3	8.0	7.7	7.5	7.2	7.0	6.8	6.3	5.7	4.5	3.2	2.4	1.8	1.4	1.0	0.75	SA-193	B8
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	SA-320	B8
																	SA-320	B8F-S
																	SA-320	B8F-Se
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	SA-351	CF3A
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	SA-351	CF3A

TABLE UHA-23 (CONT'D)
MAXIMUM ALLOWABLE STRESS VALUES IN TENSION FOR HIGH-ALLOY STEEL, IN KIPS/SQ IN. (MULTIPLY BY 1000 TO OBTAIN PSI)
(See UW-12(c) for vessels constructed under Part UW that include welded joints that are neither fully radiographed nor spot radiographically examined)

Nominal Composition	P-Number	Product Form	Specification Number	Grade	Notes	Specified Minimum Yield	Specified Minimum Tensile	For Metal Temperatures Not Exceeding Deg F: −20 to 100	200	300	400	500	600	650
18 Cr-13 Ni-3 Mo	8	Plate	SA-240	317L	(1)	30.0	75.0	18.7	18.7	18.3	18.0	17.9	17.0	16.6
18 Cr-13 Ni-3 Mo	8	Plate	SA-240	317L	...	30.0	75.0	18.7	16.1	14.6	13.3	12.4	11.8	11.5
16 Cr-12 Ni-2 Mo	8	Wld. Tb.	SA-249	TP316	(1)(4)(10)	30.0	75.0	15.9	15.9	15.6	15.3	15.2	14.4	14.1
16 Cr-12 Ni-2 Mo	8	Wld. Tb.	SA-249	TP316H	(1)(4)									
18 Cr-13 Ni-3 Mo	8	Wld. Tb.	SA-249	TP317	(1)(4)(10)									
16 Cr-12 Ni-2 Mo	8	Wld. Pp.	SA-312	TP316	(1)(4)(10)									
16 Cr-12 Ni-2 Mo	8	Wld. Pp.	SA-312	TP316H	(1)(4)									
18 Cr-13 Ni-3 Mo	8	Wld. Pp.	SA-312	TP317	(1)(4)(10)									
16 Cr-12 Ni-2 Mo	8	Wld. Tb.	SA-249	TP316	(4)(10)	30.0	75.0	15.9	13.7	12.4	11.3	10.6	10.0	9.8
16 Cr-12 Ni-2 Mo	8	Wld. Tb.	SA-249	TP316H	(4)									
18 Cr-13 Ni-3 Mo	8	Wld. Tb.	SA-249	TP317	(4)(10)									
16 Cr-12 Ni-2 Mo	8	Wld. Pp.	SA-312	TP316	(4)(10)									
16 Cr-12 Ni-2 Mo	8	Wld. Pp.	SA-312	TP316H	(4)									
18 Cr-13 Ni-3 Mo	8	Wld. Pp.	SA-312	TP317	(4)(10)									
16 Cr-12 Ni-2 Mo	...	Bolt.	SA-193	B8M	(5)(7)(10)(13)	30.0	75.0	15.0	15.0	13.6	12.6	12.2	11.9	11.8
16 Cr-12 Ni-2 Mo	...	Bolt.	SA-320	B8M	(5)(7)(8)	30.0	75.0	15.0	...	...	...	...	...	...
18 Cr-10 Ni-Ti	8	Smls. Pp.	SA-430	FP321	(1)(10)(13)	30.0	70.0	17.5	17.1	16.1	16.0	16.0	16.0	16.0
18 Cr-10 Ni-Ti	8	Forg.	SA-182	F321	(1)(10)(12)									
18 Cr-10 Ni-Ti	8	Forg.	SA-336	F8t	(1)(10)(13)									
18 Cr-10 Ni-Ti	8	Smls. Pp.	SA-430	FP321H	(1)	30.0	70.0	17.5	17.1	16.1	16.0	16.0	16.0	16.0
18 Cr-10 Ni-Ti	8	Forg.	SA-182	F321H	(1)(12)									
18 Cr-10 Ni-Ti	8	Smls. Pp.	SA-430	FP321	(10)(13)	30.0	70.0	17.5	15.9	14.1	12.9	12.0	11.3	11.1
18 Cr-10 Ni-Ti	8	Forg.	SA-182	F321	(10)(12)									
18 Cr-10 Ni-Ti	8	Forg.	SA-336	F8t	(10)(13)									
18 Cr-10 Ni-Ti	8	Smls. Pp.	SA-430	FP321H	...	30.0	70.0	17.5	15.9	14.1	12.9	12.0	11.3	11.1
18 Cr-10 Ni-Ti	8	Forg.	SA-182	F321H	(12)									
18 Cr-10 Ni-Ti	8	Plate	SA-240	321	(1)(10)(13)	30.0	75.0	18.7	18.3	17.3	17.1	17.1	16.3	16.0
18 Cr-10 Ni-Ti	8	Smls. Tb.	SA-213	TP321	(1)(10)									
18 Cr-10 Ni-Ti	8	Smls. Pp.	SA-312	TP321	(1)(10)									
18 Cr-10 Ni-Ti	8	Smls. Pp.	SA-376	TP321	(1)(10)									
18 Cr-10 Ni-Ti	8	Forg.	SA-182	F321	(1)(10)									
18 Cr-10 Ni-Ti	8	Bar.	SA-479	321	(1)(10)(13)									
18 Cr-10 Ni-Ti	8	Smls. Tb.	SA-213	TP321H	(1)	30.0	75.0	18.7	18.3	17.3	17.1	17.1	16.3	16.0
18 Cr-10 Ni-Ti	8	Smls. Pp.	SA-312	TP321H	(1)									
18 Cr-10 Ni-Ti	8	Smls. Pp.	SA-376	TP321H	(1)									
18 Cr-10 Ni-Ti	8	Forg.	SA-182	TP321H	(1)									
18 Cr-10 Ni-Ti	8	Plate	SA-240	321	(10)(13)	30.0	75.0	18.7	15.9	14.1	12.9	12.0	11.3	11.1
18 Cr-10 Ni-Ti	8	Smls. Tb.	SA-213	TP321	(10)									
18 Cr-10 Ni-Ti	8	Smls. Pp.	SA-312	TP321	(10)									
18 Cr-10 Ni-Ti	8	Smls. Pp.	SA-376	TP321	(10)									
18 Cr-10 Ni-Ti	8	Forg.	SA-182	F321	(10)									
18 Cr-10 Ni-Ti	8	Bar.	SA-479	321	(10)(13)									
18 Cr-10 Ni-Ti	8	Smls. Tb.	SA-213	321H	...	30.0	75.0	18.7	15.9	14.1	12.9	12.0	11.3	11.1
18 Cr-10 Ni-Ti	8	Smls. Pp.	SA-312	TP321H	...									
18 Cr-10 Ni-Ti	8	Smls. Pp.	SA-376	TP321H	...									
18 Cr-10 Ni-Ti	8	Forg.	SA-182	TP321H	...									
18 Cr-10 Ni-Ti	8	Wld. Tb.	SA-249	TP321	(1)(4)(10)	30.0	75.0	15.9	15.6	14.7	14.5	14.5	13.9	13.6
18 Cr-10 Ni-Ti	8	Wld. Pp.	SA-312	TP321	(1)(4)(10)									

TABLE UHA-23 (CONT'D)
MAXIMUM ALLOWABLE STRESS VALUES IN TENSION FOR HIGH-ALLOY STEEL, IN KIPS/SQ IN. (MULTIPLY BY 1000 TO OBTAIN PSI)
(See UW-12(c) for vessels constructed under Part UW that include welded joints that are neither fully radiographed nor spot radiographically examined)

For Metal Temperatures Not Exceeding Deg F: 700	750	800	850	900	950	1000	1050	1100	1150	1200	1250	1300	1350	1400	1450	1500	Specification Number	Grade
16.3	16.0	15.8	15.7	...	...	...	...	...	...	...	...	...	...	...	...	...	SA-240	317L
11.3	11.1	11.0	10.9	...	...	...	...	...	...	...	...	...	...	...	...	...	SA-240	317L
13.8	13.6	13.4	13.3	13.2	13.1	13.0	12.3	10.5	8.3	6.3	4.6	3.5	2.6	1.9	1.4	1.0	SA-249 SA-249 SA-249 SA-312 SA-312 SA-312	TP316 TP316H TP317 TP316 TP316H TP317
9.6	9.5	9.3	9.2	9.2	9.1	9.0	8.9	8.7	7.9	6.3	4.6	3.5	2.6	1.9	1.4	1.0	SA-249 SA-249 SA-249 SA-312 SA-312 SA-312	TP316 TP316H TP317 TP316 TP316H TP317
11.8	11.7	11.6	11.4	11.3	11.1	10.8	10.5	10.0	8.5	6.8	5.3	4.0	3.0	2.3	1.8	1.0	SA-193	B8M
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	SA-320	B8M
15.8	15.6	15.4	15.3	15.2	15.1	13.8	9.6	6.9	5.0	3.6	2.5	1.7	1.1	0.7	0.5	0.3	SA-430 SA-182 SA-336	FP321 F321 F8t
15.8	15.6	15.4	15.3	15.2	15.1	14.0	11.7	9.0	6.9	5.3	4.1	3.1	2.4	1.8	1.4	1.1	SA-430 SA-182	FP321H F321H
10.9	10.8	10.7	10.6	10.6	10.5	10.4	9.2	6.9	5.0	3.6	2.5	1.7	1.1	0.7	0.5	0.3	SA-430 SA-182 SA-336	FP321 F321 F8t
10.9	10.8	10.7	10.6	10.6	10.5	10.4	10.1	8.8	6.9	5.3	4.1	3.1	2.4	1.8	1.4	1.1	SA-430 SA-182	FP321H F321H
15.8	15.6	15.4	15.3	15.2	15.1	13.8	9.6	6.9	5.0	3.6	2.5	1.7	1.1	0.7	0.5	0.3	SA-240 SA-213 SA-312 SA-376 SA-182 SA-479	321 TP321 TP321 TP321 F321 321
15.8	15.6	15.4	15.3	15.2	15.1	14.0	11.7	9.0	6.9	5.3	4.1	3.1	2.4	1.8	1.4	1.1	SA-213 SA-312 SA-376 SA-182	TP321H TP321H TP321H TP321H
10.9	10.8	10.7	10.6	10.6	10.5	10.4	9.2	6.9	5.0	3.6	2.5	1.7	1.1	0.7	0.5	0.3	SA-240 SA-213 SA-312 SA-376 SA-182 SA-479	321 TP321 TP321 TP321 F321 321
10.9	10.8	10.7	10.6	10.6	10.5	10.4	10.1	8.8	6.9	5.3	4.1	3.1	2.4	1.8	1.4	1.1	SA-213 SA-312 SA-376 SA-182	321H TP321H TP321H TP321H
13.4	13.3	13.1	13.0	12.9	12.9	11.7	8.1	5.8	4.2	3.0	2.1	1.4	0.9	0.6	0.4	0.2	SA-249 SA-312	TP321 TP321

TABLE UHA-23 (CONT'D)
MAXIMUM ALLOWABLE STRESS VALUES IN TENSION FOR HIGH-ALLOY STEEL, IN KIPS/SQ IN. (MULTIPLY BY 1000 TO OBTAIN PSI)
(See UW-12(c) for vessels constructed under Part UW that include welded joints that are neither fully radiographed nor spot radiographically examined)

Nominal Composition	P-Number	Product Form	Specification Number	Grade	Notes	Specified Minimum Yield	Specified Minimum Tensile	For Metal Temperatures Not Exceeding Deg F: −20 to 100	200	300	400	500	600	650
18 Cr-13 Ni-3 Mo	8	Plate	SA-240	317L	(1)	30.0	75.0	18.7	18.7	18.3	18.0	17.9	17.0	16.6
18 Cr-13 Ni-3 Mo	8	Plate	SA-240	317L	...	30.0	75.0	18.7	16.1	14.6	13.3	12.4	11.8	11.5
16 Cr-12 Ni-2 Mo	8	Wld. Tb.	SA-249	TP316	(1)(4)(10)	30.0	75.0	15.9	15.9	15.6	15.3	15.2	14.4	14.1
16 Cr-12 Ni-2 Mo	8	Wld. Tb.	SA-249	TP316H	(1)(4)									
18 Cr-13 Ni-3 Mo	8	Wld. Tb.	SA-249	TP317	(1)(4)(10)									
16 Cr-12 Ni-2 Mo	8	Wld. Pp.	SA-312	TP316	(1)(4)(10)									
16 Cr-12 Ni-2 Mo	8	Wld. Pp.	SA-312	TP316H	(1)(4)									
18 Cr-13 Ni-3 Mo	8	Wld. Pp.	SA-312	TP317	(1)(4)(10)									
16 Cr-12 Ni-2 Mo	8	Wld. Tb.	SA-249	TP316	(4)(10)	30.0	75.0	15.9	13.7	12.4	11.3	10.6	10.0	9.8
16 Cr-12 Ni-2 Mo	8	Wld. Tb.	SA-249	TP316H	(4)									
18 Cr-13 Ni-3 Mo	8	Wld. Tb.	SA-249	TP317	(4)(10)									
16 Cr-12 Ni-2 Mo	8	Wld. Pp.	SA-312	TP316	(4)(10)									
16 Cr-12 Ni-2 Mo	8	Wld. Pp.	SA-312	TP316H	(4)									
18 Cr-13 Ni-3 Mo	8	Wld. Pp.	SA-312	TP317	(4)(10)									
16 Cr-12 Ni-2 Mo	...	Bolt.	SA-193	B8M	(5)(7)(10)(13)	30.0	75.0	15.0	15.0	13.6	12.6	12.2	11.9	11.8
16 Cr-12 Ni-2 Mo	...	Bolt.	SA-320	B8M	(5)(7)(8)	30.0	75.0	15.0	...	...	...	...	...	...
18 Cr-10 Ni-Ti	8	Smls. Pp.	SA-430	FP321	(1)(10)(13)	30.0	70.0	17.5	17.1	16.1	16.0	16.0	16.0	16.0
18 Cr-10 Ni-Ti	8	Forg.	SA-182	F321	(1)(10)(12)									
18 Cr-10 Ni-Ti	8	Forg.	SA-336	F8t	(1)(10)(13)									
18 Cr-10 Ni-Ti	8	Smls. Pp.	SA-430	FP321H	(1)	30.0	70.0	17.5	17.1	16.1	16.0	16.0	16.0	16.0
18 Cr-10 Ni-Ti	8	Forg.	SA-182	F321H	(1)(12)									
18 Cr-10 Ni-Ti	8	Smls. Pp.	SA-430	FP321	(10)(13)	30.0	70.0	17.5	15.9	14.1	12.9	12.0	11.3	11.1
18 Cr-10 Ni-Ti	8	Forg.	SA-182	F321	(10)(12)									
18 Cr-10 Ni-Ti	8	Forg.	SA-336	F8t	(10)(13)									
18 Cr-10 Ni-Ti	8	Smls. Pp.	SA-430	FP321H	...	30.0	70.0	17.5	15.9	14.1	12.9	12.0	11.3	11.1
18 Cr-10 Ni-Ti	8	Forg.	SA-182	F321H	(12)									
18 Cr-10 Ni-Ti	8	Plate	SA-240	321	(1)(10)(13)	30.0	75.0	18.7	18.3	17.3	17.1	17.1	16.3	16.0
18 Cr-10 Ni-Ti	8	Smls. Tb.	SA-213	TP321	(1)(10)									
18 Cr-10 Ni-Ti	8	Smls. Pp.	SA-312	TP321	(1)(10)									
18 Cr-10 Ni-Ti	8	Smls. Pp.	SA-376	TP321	(1)(10)									
18 Cr-10 Ni-Ti	8	Forg.	SA-182	F321	(1)(10)									
18 Cr-10 Ni-Ti	8	Bar.	SA-479	321	(1)(10)(13)									
18 Cr-10 Ni-Ti	8	Smls. Tb.	SA-213	TP321H	(1)	30.0	75.0	18.7	18.3	17.3	17.1	17.1	16.3	16.0
18 Cr-10 Ni-Ti	8	Smls. Pp.	SA-312	TP321H	(1)									
18 Cr-10 Ni-Ti	8	Smls. Pp.	SA-376	TP321H	(1)									
18 Cr-10 Ni-Ti	8	Forg.	SA-182	TP321H	(1)									
18 Cr-10 Ni-Ti	8	Plate	SA-240	321	(10)(13)	30.0	75.0	18.7	15.9	14.1	12.9	12.0	11.3	11.1
18 Cr-10 Ni-Ti	8	Smls. Tb.	SA-213	TP321	(10)									
18 Cr-10 Ni-Ti	8	Smls. Pp.	SA-312	TP321	(10)									
18 Cr-10 Ni-Ti	8	Smls. Pp.	SA-376	TP321	(10)									
18 Cr-10 Ni-Ti	8	Forg.	SA-182	F321	(10)									
18 Cr-10 Ni-Ti	8	Bar.	SA-479	321	(10)(13)									
18 Cr-10 Ni-Ti	8	Smls. Tb.	SA-213	321H	...	30.0	75.0	18.7	15.9	14.1	12.9	12.0	11.3	11.1
18 Cr-10 Ni-Ti	8	Smls. Pp.	SA-312	TP321H	...									
18 Cr-10 Ni-Ti	8	Smls. Pp.	SA-376	TP321H	...									
18 Cr-10 Ni-Ti	8	Forg.	SA-182	TP321H	...									
18 Cr-10 Ni-Ti	8	Wld. Tb.	SA-249	TP321	(1)(4)(10)	30.0	75.0	15.9	15.6	14.7	14.5	14.5	13.9	13.6
18 Cr-10 Ni-Ti	8	Wld. Pp.	SA-312	TP321	(1)(4)(10)									

TABLE UHA-23 (CONT'D)
MAXIMUM ALLOWABLE STRESS VALUES IN TENSION FOR HIGH-ALLOY STEEL, IN KIPS/SQ IN. (MULTIPLY BY 1000 TO OBTAIN PSI)
(See UW-12(c) for vessels constructed under Part UW that include welded joints that are neither fully radiographed nor spot radiographically examined)

For Metal Temperatures Not Exceeding Deg F: 700	750	800	850	900	950	1000	1050	1100	1150	1200	1250	1300	1350	1400	1450	1500	Specification Number	Grade
16.3	16.0	15.8	15.7	...	...	...	...	...	...	...	...	...	...	...	...	...	SA-240	317L
11.3	11.1	11.0	10.9	...	...	...	...	...	...	...	...	...	...	...	...	...	SA-240	317L
13.8	13.6	13.4	13.3	13.2	13.1	13.0	12.3	10.5	8.3	6.3	4.6	3.5	2.6	1.9	1.4	1.0	SA-249	TP316
																	SA-249	TP316H
																	SA-249	TP317
																	SA-312	TP316
																	SA-312	TP316H
																	SA-312	TP317
9.6	9.5	9.3	9.2	9.2	9.1	9.0	8.9	8.7	7.9	6.3	4.6	3.5	2.6	1.9	1.4	1.0	SA-249	TP316
																	SA-249	TP316H
																	SA-249	TP317
																	SA-312	TP316
																	SA-312	TP316H
																	SA-312	TP317
11.8	11.7	11.6	11.4	11.3	11.1	10.8	10.5	10.0	8.5	6.8	5.3	4.0	3.0	2.3	1.8	1.0	SA-193	B8M
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	SA-320	B8M
15.8	15.6	15.4	15.3	15.2	15.1	13.8	9.6	6.9	5.0	3.6	2.5	1.7	1.1	0.7	0.5	0.3	SA-430	FP321
																	SA-182	F321
																	SA-336	F8t
15.8	15.6	15.4	15.3	15.2	15.1	14.0	11.7	9.0	6.9	5.3	4.1	3.1	2.4	1.8	1.4	1.1	SA-430	FP321H
																	SA-182	F321H
10.9	10.8	10.7	10.6	10.6	10.5	10.4	9.2	6.9	5.0	3.6	2.5	1.7	1.1	0.7	0.5	0.3	SA-430	FP321
																	SA-182	F321
																	SA-336	F8t
10.9	10.8	10.7	10.6	10.6	10.5	10.4	10.1	8.8	6.9	5.3	4.1	3.1	2.4	1.8	1.4	1.1	SA-430	FP321H
																	SA-182	F321H
15.8	15.6	15.4	15.3	15.2	15.1	13.8	9.6	6.9	5.0	3.6	2.5	1.7	1.1	0.7	0.5	0.3	SA-240	321
																	SA-213	TP321
																	SA-312	TP321
																	SA-376	TP321
																	SA-182	F321
																	SA-479	321
15.8	15.6	15.4	15.3	15.2	15.1	14.0	11.7	9.0	6.9	5.3	4.1	3.1	2.4	1.8	1.4	1.1	SA-213	TP321H
																	SA-312	TP321H
																	SA-376	TP321H
																	SA-182	TP321H
10.9	10.8	10.7	10.6	10.6	10.5	10.4	9.2	6.9	5.0	3.6	2.5	1.7	1.1	0.7	0.5	0.3	SA-240	321
																	SA-213	TP321
																	SA-312	TP321
																	SA-376	TP321
																	SA-182	F321
																	SA-479	321
10.9	10.8	10.7	10.6	10.6	10.5	10.4	10.1	8.8	6.9	5.3	4.1	3.1	2.4	1.8	1.4	1.1	SA-213	321H
																	SA-312	TP321H
																	SA-376	TP321H
																	SA-182	TP321H
13.4	13.3	13.1	13.0	12.9	12.9	11.7	8.1	5.8	4.2	3.0	2.1	1.4	0.9	0.6	0.4	0.2	SA-249	TP321
																	SA-312	TP321

TABLE UHA-23 (CONT'D)
MAXIMUM ALLOWABLE STRESS VALUES IN TENSION FOR HIGH-ALLOY STEEL, IN KIPS/SQ IN. (MULTIPLY BY 1000 TO OBTAIN PSI)
(See UW-12(c) for vessels constructed under Part UW that include welded joints that are neither fully radiographed nor spot radiographically examined)

Nominal Composition	P-Number	Product Form	Specification Number	Grade	Notes	Specified Minimum Yield	Specified Minimum Tensile	For Metal Temperatures Not Exceeding Deg F: −20 to 100	200	300	400	500	600	650
18 Cr-10 Ni-Ti	8	Wld. Tb.	SA-249	TP321H	(1)(4)	30.0	75.0	15.9	15.6	14.7	14.5	14.5	13.9	13.6
18 Cr-10 Ni-Ti	8	Wld. Pp.	SA-312	TP321H	(1)(4)									
18 Cr-10 Ni-Ti	8	Wld. Tb.	SA-249	TP321	(4)(10)	30.0	75.0	15.9	13.5	12.0	10.9	10.2	9.6	9.5
18 Cr-10 Ni-Ti	8	Wld. Pp.	SA-312	TP321	(4)(10)									
18 Cr-10 Ni-Ti	8	Wld. Tb.	SA-249	TP321H	(4)	30.0	75.0	15.9	13.5	12.0	10.9	10.2	9.6	9.5
18 Cr-10 Ni-Ti	8	Wld. Pp.	SA-312	TP321H	(4)									
18 Cr-10 Ni-Ti	...	Bolt.	SA-193	B8T	(5)(7)(10)(13)	30.0	75.0	15.0	15.0	13.6	12.6	12.2	11.9	11.8
18 Cr-10 Ni-Ti	...	Bolt.	SA-320	B8T	(5)(7)(8)	30.0	75.0	15.0	...	...	...	...	...	...
18 Cr-10 Ni-Cb	8	Smls. Pp.	SA-430	FP347	(1)(10)(13)	30.0	70.0	18.7	17.8	16.4	15.4	14.9	14.7	14.6
18 Cr-10 Ni-Cb	8	Smls. Pp.	SA-430	FP347H	(1)	30.0	70.0	18.7	17.8	16.4	15.4	14.9	14.7	14.6
18 Cr-10 Ni-Cb	8	Smls. Pp.	SA-430	FP347	(10)(13)	30.0	70.0	18.7	17.2	16.0	15.0	14.0	13.4	13.1
18 Cr-10 Ni-Cb	8	Smls. Pp.	SA-430	FP347H	...	30.0	70.0	18.7	17.2	16.0	15.0	14.0	13.4	13.1
18 Cr-10 Ni-Cb	8	Forg.	SA-182	F347	(1)(10)(12)	30.0	70.0	17.5	16.6	15.3	14.4	13.9	13.7	13.7
18 Cr-10 Ni-Cb	8	Forg.	SA-182	F348	(1)(10)(12)									
18 Cr-10 Ni-Cb	8	Forg.	SA-336	F8c	(1)(10)(13)									
18 Cr-10 Ni-Cb	8	Forg.	SA-182	F347	(10)(12)	30.0	70.0	17.5	16.6	15.3	14.4	13.9	13.4	13.1
18 Cr-10 Ni-Cb	8	Forg.	SA-182	F348	(10)(12)									
18 Cr-10 Ni-Cb	8	Forg.	SA-336	F8c	(10)(13)									
18 Cr-10 Ni-Cb	8	Forg.	SA-182	F347H	(1)(12)	30.0	70.0	17.5	16.6	15.3	14.4	13.9	13.7	13.7
18 Cr-10 Ni-Cb	8	Forg.	SA-182	F348H	(1)(12)									
18 Cr-10 Ni-Cb	8	Forg.	SA-182	F347H	(12)	30.0	70.0	17.5	16.6	15.3	14.4	13.9	13.4	13.1
18 Cr-10 Ni-Cb	8	Forg.	SA-182	F348H	(12)									
18 Cr-10 Ni-Cb	8	Cast.	SA-351	CF8c	(1)(6)(10)	30.0	70.0	17.5	15.7	14.8	14.3	14.1	14.1	14.1
18 Cr-10 Ni-Cb	8	Cast.	SA-351	CF8c	(6)(10)	30.0	70.0	17.5	15.7	14.8	14.3	13.5	12.8	12.5
18 Cr-10 Ni-Cb	8	Plate	SA-240	347	(1)(10)(13)	30.0	75.0	18.7	17.8	16.4	15.4	14.9	14.7	14.6
18 Cr-10 Ni-Cb	8	Plate	SA-240	348	(1)(10)(13)									
18 Cr-10 Ni-Cb	8	Smls. Tb.	SA-213	TP347	(1)(10)									
18 Cr-10 Ni-Cb	8	Smls. Tb.	SA-213	TP348	(1)(10)									
18 Cr-10 Ni-Cb	8	Smls. Pp.	SA-312	TP347	(1)(10)									
18 Cr-10 Ni-Cb	8	Smls. Pp.	SA-312	TP348	(1)(10)									
18 Cr-10 Ni-Cb	8	Smls. Pp.	SA-376	TP347	(1)(10)									
18 Cr-10 Ni-Cb	8	Smls. Pp.	SA-376	TP348	(1)(10)									
18 Cr-10 Ni-Cb	8	Forg.	SA-182	F347	(1)(10)									
18 Cr-10 Ni-Cb	8	Forg.	SA-182	F348	(1)(10)									
18 Cr-10 Ni-Cb	8	Bar.	SA-479	347	(1)(10)(13)									
18 Cr-10 Ni-Cb	8	Bar.	SA-479	348	(1)(10)(13)									
18 Cr-10 Ni-Cb	8	Smls. Tb.	SA-213	TP347H	(1)	30.0	75.0	18.7	17.8	16.4	15.4	14.9	14.7	14.6
18 Cr-10 Ni-Cb	8	Smls. Tb.	SA-213	TP348H	(1)									
18 Cr-10 Ni-Cb	8	Smls. Pp.	SA-312	TP347H	(1)									
18 Cr-10 Ni-Cb	8	Smls. Pp.	SA-312	TP348H	(1)									
18 Cr-10 Ni-Cb	8	Smls. Pp.	SA-376	TP347H	(1)									
18 Cr-10 Ni-Cb	8	Smls. Pp.	SA-376	TP348H	(1)									
18 Cr-10 Ni-Cb	8	Forg.	SA-182	F347H	(1)									
18 Cr-10 Ni-Cb	8	Forg.	SA-182	F348H	(1)									

TABLE UHA-23 (CONT'D)
MAXIMUM ALLOWABLE STRESS VALUES IN TENSION FOR HIGH-ALLOY STEEL, IN KIPS/SQ IN. (MULTIPLY BY 1000 TO OBTAIN PSI)
(See UW-12(c) for vessels constructed under Part UW that include welded joints that are neither fully radiographed nor spot radiographically examined)

For Metal Temperatures Not Exceeding Deg F: 700	750	800	850	900	950	1000	1050	1100	1150	1200	1250	1300	1350	1400	1450	1500	Specification Number	Grade
13.4	13.3	13.1	13.0	12.9	12.9	11.9	9.9	7.7	5.8	4.5	3.5	2.7	2.1	1.5	1.2	0.9	SA-249	TP321H
																	SA-312	TP321H
9.3	9.2	9.1	9.0	9.0	8.9	8.8	7.8	5.8	4.2	3.0	2.1	1.4	0.9	0.6	0.4	0.2	SA-249	TP321
																	SA-312	TP321
9.3	9.2	9.1	9.0	9.0	8.9	8.9	8.6	7.5	5.8	4.5	3.5	2.7	2.1	1.5	1.2	0.9	SA-249	TP321H
																	SA-312	TP321H
11.8	11.7	11.6	11.4	11.3	11.1	10.8	10.5	10.0	8.0	5.0	3.6	2.7	2.0	1.5	1.2	1.0	SA-193	B8T
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	SA-320	B8T
14.6	14.6	14.6	14.6	14.6	14.5	14.0	12.1	9.1	6.1	4.4	3.3	2.2	1.5	1.2	0.9	0.7	SA-430	FP347
14.6	14.6	14.6	14.6	14.6	14.5	14.4	14.1	13.0	10.5	7.9	5.9	4.3	3.2	2.4	1.8	1.3	SA-430	FP347H
12.9	12.8	12.7	12.6	12.6	12.5	12.5	11.9	9.1	6.1	4.4	3.3	2.2	1.5	1.2	0.9	0.7	SA-430	FP347
12.9	12.8	12.7	12.6	12.6	12.5	12.5	12.5	12.1	10.5	7.9	5.9	4.3	3.2	2.4	1.8	1.3	SA-430	FP347H
13.7	13.7	13.7	13.7	13.7	13.5	13.2	12.0	9.1	6.1	4.4	3.3	2.2	1.5	1.2	0.9	0.7	SA-182	F347
																	SA-182	F348
																	SA-336	F8c
12.9	12.8	12.7	12.6	12.6	12.5	12.5	11.9	9.1	6.1	4.4	3.3	2.2	1.5	1.2	0.9	0.7	SA-182	F347
																	SA-182	F348
																	SA-336	F8C
13.7	13.7	13.7	13.7	13.7	13.5	13.4	13.1	12.5	10.5	7.9	5.9	4.3	3.2	2.4	1.8	1.3	SA-182	F347H
																	SA-182	F348H
12.9	12.8	12.7	12.6	12.6	12.5	12.5	12.5	12.1	10.5	7.9	5.9	4.3	3.2	2.4	1.8	1.3	SA-182	F347H
																	SA-182	F348H
14.1	14.1	14.1	14.0	13.9	13.8	13.5	13.0	10.8	8.0	5.0	3.6	2.7	2.0	1.5	1.2	1.0	SA-351	CF8c
12.2	12.0	11.9	11.6	11.3	11.2	11.0	10.6	10.4	8.0	5.0	3.6	2.7	2.0	1.5	1.2	1.0	SA-351	CF8c
14.6	14.6	14.6	14.6	14.6	14.5	14.0	12.1	9.1	6.1	4.4	3.3	2.2	1.5	1.2	0.9	0.7	SA-240	347
																	SA-240	348
																	SA-213	TP347
																	SA-213	TP348
																	SA-312	TP347
																	SA-312	TP348
																	SA-376	TP347
																	SA-376	TP348
																	SA-182	F347
																	SA-182	F348
																	SA-479	347
																	SA-479	348
14.6	14.6	14.6	14.6	14.6	14.5	14.4	14.1	13.0	10.5	7.9	5.9	4.3	3.2	2.4	1.8	1.3	SA-213	TP347H
																	SA-213	TP348H
																	SA-312	TP347H
																	SA-312	TP348H
																	SA-376	TP347H
																	SA-376	TP348H
																	SA-182	F347H
																	SA-182	F348H

TABLE UHA-23 (CONT'D)
MAXIMUM ALLOWABLE STRESS VALUES IN TENSION FOR HIGH-ALLOY STEEL, IN KIPS/SQ In. (MULTIPLY BY 1000 TO OBTAIN PSI)
(See UW-12(c) for vessels constructed under Part UW that include welded joints that are neither fully radiographed nor spot radiographically examined)

Nominal Composition	P-Number	Product Form	Specification Number	Grade	Notes	Specified Minimum Yield	Specified Minimum Tensile	For Metal Temperatures Not Exceeding Deg F: −20 to 100	200	300	400	500	600	650
18 Cr-10 Ni-Cb	8	Plate	SA-240	347	(10)(13)	30.0	75.0	18.7	17.2	16.0	15.0	14.0	13.4	13.1
18 Cr-10 Ni-Cb	8	Plate	SA-240	348	(10)(13)									
18 Cr-10 Ni-Cb	8	Smls. Tb.	SA-213	TP347	(10)									
18 Cr-10 Ni-Cb	8	Smls. Tb.	SA-213	TP348	(10)									
18 Cr-10 Ni-Cb	8	Smls. Pp.	SA-312	TP347	(10)									
18 Cr-10 Ni-Cb	8	Smls. Pp.	SA-312	TP348	(10)									
18 Cr-10 Ni-Cb	8	Smls. Pp.	SA-376	TP347	(10)									
18 Cr-10 Ni-Cb	8	Smls. Pp.	SA-376	TP348	(10)									
18 Cr-10 Ni-Cb	8	Forg.	SA-182	F347	(10)									
18 Cr-10 Ni-Cb	8	Forg.	SA-182	F348	(10)									
18 Cr-10 Ni-Cb	8	Bar.	SA-479	347	(10)(13)									
18 Cr-10 Ni-Cb	8	Bar.	SA-479	348	(10)(13)									
18 Cr-10 Ni-Cb	8	Smls. Tb.	SA-213	TP347H	...	30.0	75.0	18.7	17.2	16.0	15.0	14.0	13.4	13.1
18 Cr-10 Ni-Cb	8	Smls. Tb.	SA-213	TP348H	...									
18 Cr-10 Ni-Cb	8	Smls. Pp.	SA-312	TP347H	...									
18 Cr-10 Ni-Cb	8	Smls. Pp.	SA-312	TP348H	...									
18 Cr-10 Ni-Cb	8	Smls. Pp.	SA-376	TP347H	...									
18 Cr-10 Ni-Cb	8	Smls. Pp.	SA-376	TP348H	...									
18 Cr-10 Ni-Cb	8	Forg.	SA-182	F347H	...									
18 Cr-10 Ni-Cb	8	Forg.	SA-182	F348H	...									
18 Cr-10 Ni-Cb	8	Cast. Pp.	SA-452	TP347H	(1)	30.0	75.0	18.7	17.8	16.4	15.4	14.9	14.7	14.6
18 Cr-10 Ni-Cb	8	Cast Pp.	SA-452	TP347H	...	30.0	75.0	18.7	17.2	16.0	15.0	14.0	13.4	13.1
18 Cr-10 Ni-Cb	8	Wld. Tb.	SA-249	TP347	(1)(4)(10)	30.0	75.0	15.9	15.1	13.9	13.1	12.6	12.5	12.4
18 Cr-10 Ni-Cb	8	Wld. Tb.	SA-249	TP348	(1)(4)(10)									
18 Cr-10 Ni-Cb	8	Wld. Pp.	SA-312	TP347	(1)(4)(10)									
18 Cr-10 Ni-Cb	8	Wld. Pp.	SA-312	TP348	(1)(4)(10)									
18 Cr-10 Ni-Cb	8	Wld. Tb.	SA-249	TP347H	(1)(4)	30.0	75.0	15.9	15.1	13.9	13.1	12.6	12.5	12.4
18 Cr-10 Ni-Cb	8	Wld. Tb.	SA-249	TP348H	(1)(4)									
18 Cr-10 Ni-Cb	8	Wld. Pp.	SA-312	TP347H	(1)(4)									
18 Cr-10 Ni-Cb	8	Wld. Pp.	SA-312	TP348H	(1)(4)									
18 Cr-10 Ni-Cb	8	Wld. Tb.	SA-249	TP347	(4)(10)	30.0	75.0	15.9	14.6	13.6	12.7	11.9	11.4	11.2
18 Cr-10 Ni-Cb	8	Wld. Tb.	SA-249	TP348	(4)(10)									
18 Cr-10 Ni-Cb	8	Wld. Pp.	SA-312	TP347	(4)(10)									
18 Cr-10 Ni-Cb	8	Wld. Pp.	SA-312	TP348	(4)(10)									
18 Cr-10 Ni-Cb	8	Wld. Tb.	SA-249	TP347H	(4)	30.0	75.0	15.9	14.6	13.6	12.7	11.9	11.4	11.2
18 Cr-10 Ni-Cb	8	Wld. Tb.	SA-249	TP348H	(4)									
18 Cr-10 Ni-Cb	8	Wld. Pp.	SA-312	TP347H	(4)									
18 Cr-10 Ni-Cb	8	Wld. Pp.	SA-312	TP348H	(4)									
18 Cr-10 Ni-Cb	...	Bolt.	SA-193	B8c	(5)(7)(10)(13)	30.0	75.0	15.0	15.0	13.6	12.6	12.2	11.9	11.8
18 Cr-10 Ni-Cb	...	Bolt.	SA-320	B8c	(5)(7)(8)	30.0	75.0	15.0	...	...	...	...	...	...
25 Cr-12 Ni	8	Cast.	SA-351	CH8	(1)(6)(10)	28.0	65.0	16.2	14.9	14.2	13.7	13.4	13.2	13.1
25 Cr-12 Ni	8	Cast.	SA-351	CH8	(6)(10)	28.0	65.0	16.2	14.9	14.2	13.7	13.1	12.5	12.1
25 Cr-20 Ni	8	Cast.	SA-351	CK20	(1)(6)(10)	28.0	65.0	16.2	14.9	14.2	13.7	13.4	13.2	13.1
25 Cr-20 Ni	8	Cast.	SA-351	CK20	(6)(10)	28.0	65.0	16.2	14.9	14.2	13.7	13.1	12.5	12.2
25 Cr-12 Ni	8	Cast.	SA-351	CH20	(1)(6)(10)	30.0	70.0	17.5	16.0	15.3	14.8	14.5	14.2	14.1
25 Cr-12 Ni	8	Cast.	SA-351	CH20	(6)(10)	30.0	70.0	17.5	16.0	15.3	14.8	14.1	13.3	13.0

TABLE UHA-23 (CONT'D)
MAXIMUM ALLOWABLE STRESS VALUES IN TENSION FOR HIGH-ALLOY STEEL, IN KIPS/SQ IN. (MULTIPLY BY 1000 TO OBTAIN PSI)
(See UW-12(c) for vessels constructed under Part UW that include welded joints that are neither fully radiographed nor spot radiographically examined)

For Metal Temperature Not Exceeding Deg F: 700	750	800	850	900	950	1000	1050	1100	1150	1200	1250	1300	1350	1400	1450	1500	Specification Number	Grade
12.9	12.8	12.7	12.6	12.6	12.5	12.5	11.9	9.1	6.1	4.4	3.3	2.2	1.5	1.2	0.9	0.7	SA-240	347
																	SA-240	348
																	SA-213	TP347
																	SA-213	TP348
																	SA-312	TP347
																	SA-312	TP348
																	SA-376	TP347
																	SA-376	TP348
																	SA-182	F347
																	SA-182	F348
																	SA-479	347
																	SA-479	348
12.9	12.8	12.7	12.6	12.6	12.5	12.5	12.5	12.1	10.5	7.9	5.9	4.3	3.2	2.4	1.8	1.3	SA-213	TP347H
																	SA-213	TP348H
																	SA-312	TP347H
																	SA-312	TP348H
																	SA-376	TP347H
																	SA-376	TP348H
																	SA-182	F347H
																	SA-182	F348H
14.6	14.6	14.6	14.6	14.6	14.5	14.4	...	...	...	...	...	...	...	...	...	...	SA-452	TP347H
12.9	12.8	12.7	12.6	12.6	12.5	12.5	...	...	...	...	...	...	...	...	...	...	SA-452	TP347H
12.4	12.4	12.4	12.4	12.4	12.3	11.9	10.3	7.7	5.2	3.7	2.8	1.8	1.2	1.0	0.7	0.6	SA-249	TP347
																	SA-249	TP348
																	SA-312	TP347
																	SA-312	TP348
12.4	12.4	12.4	12.4	12.4	12.3	12.2	12.0	11.0	8.9	6.7	5.0	3.7	2.7	2.1	1.5	1.1	SA-249	TP347H
																	SA-249	TP348H
																	SA-312	TP347H
																	SA-312	TP348H
10.9	10.9	10.8	10.7	10.7	10.6	10.6	10.1	7.7	5.2	3.7	2.8	1.8	1.2	1.0	0.7	0.6	SA-249	TP347
																	SA-249	TP348
																	SA-312	TP347
																	SA-312	TP348
10.9	10.9	10.8	10.7	10.7	10.6	10.6	10.6	10.3	8.9	6.7	5.0	3.7	2.7	2.1	1.5	1.1	SA-249	TP347H
																	SA-249	TP348H
																	SA-312	TP347H
																	SA-312	TP348H
11.8	11.7	11.6	11.4	11.3	11.1	10.8	10.5	10.0	8.0	5.0	3.6	2.7	2.0	1.5	1.2	1.0	SA-193	B8c
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	SA-320	B8c
13.0	13.0	12.9	12.8	12.5	11.8	10.5	8.5	6.5	5.0	3.8	2.9	2.3	1.7	1.3	0.9	0.7	SA-351	CH8
11.8	11.7	11.3	11.1	10.8	10.5	9.8	8.5	6.5	5.0	3.8	2.9	2.3	1.7	1.3	0.9	0.7	SA-351	CH8
13.0	13.0	12.9	12.8	12.5	11.9	11.0	9.7	8.5	7.2	6.0	4.7	3.5	2.3	1.6	1.1	0.7	SA-351	CK20
11.8	11.7	11.3	11.1	10.8	10.6	10.2	9.7	8.5	7.2	6.0	4.7	3.5	2.3	1.6	1.1	0.7	SA-351	CK20
14.0	14.0	13.9	13.7	13.3	12.5	10.5	8.5	6.5	5.0	3.8	2.9	2.3	1.7	1.3	0.9	0.7	SA-351	CH20
12.7	12.5	12.1	11.9	11.6	11.1	10.1	8.5	6.5	5.0	3.8	2.9	2.3	1.7	1.3	0.9	0.7	SA-351	CH20

TABLE UHA-23 (CONT'D)
MAXIMUM ALLOWABLE STRESS VALUES IN TENSION FOR HIGH-ALLOY STEEL, IN KIPS/SQ IN. (MULTIPLY BY 1000 TO OBTAIN PSI)
(See UW-12(c) for vessels constructed under Part UW that include welded joints that are neither fully radiographed nor spot radiographically examined)

Nominal Composition	P-Number	Product Form	Specification Number	Grade	Notes	Specified Minimum Yield	Specified Minimum Tensile	For Metal Temperatures Not Exceeding Deg F: -20 to 100	200	300	400	500	600	650
23 Cr-12 Ni	8	Plate	SA-240	309S	(1)(10)	30.0	75.0	18.7	17.2	16.4	15.8	15.5	15.3	15.2
23 Cr-12 Ni	8	Smls. Pp.	SA-312	TP309	(1)(10)									
23 Cr-12 Ni	8	Plate	SA-240	309S	(10)	30.0	75.0	18.7	16.9	15.8	14.9	14.1	13.3	13.0
23 Cr-12 Ni	8	Smls. Pp.	SA-312	TP309	(10)									
25 Cr-20 Ni	8	Plate	SA-240	310S	(1)(2)(10)	30.0	75.0	18.7	17.2	16.4	15.8	15.5	15.3	15.2
25 Cr-20 Ni	8	Smls. Tb.	SA-213	TP310	(1)(2)(10)									
25 Cr-20 Ni	8	Smls. Pp.	SA-312	TP310	(1)(2)(10)									
25 Cr-20 Ni	8	Forg.	SA-182	F310	(1)(2)(10)									
25 Cr-20 Ni	8	Forg.	SA-336	F25	(1)(2)(10)									
25 Cr-20 Ni	8	Plate	SA-240	310S	(2)(10)	30.0	75.0	18.7	16.9	15.8	14.9	14.1	13.3	13.0
25 Cr-20 Ni	8	Smls. Tb.	SA-213	TP310	(2)(10)									
25 Cr-20 Ni	8	Smls. Pp.	SA-312	TP310	(2)(10)									
25 Cr-20 Ni	8	Forg.	SA-182	F310	(2)(10)									
25 Cr-20 Ni	8	Forg.	SA-336	F25	(2)(10)									
25 Cr-20 Ni	8	Plate	SA-240	310S	(1)(3)(10)	30.0	75.0	18.7	17.2	16.4	15.8	15.5	15.3	15.2
25 Cr-20 Ni	8	Smls. Tb.	SA-213	TP310	(1)(3)(10)									
25 Cr-20 Ni	8	Smls. Pp.	SA-312	TP310	(1)(3)(10)									
25 Cr-20 Ni	8	Forg.	SA-182	F310	(1)(3)(10)									
25 Cr-20 Ni	8	Forg.	SA-336	F25	(1)(3)(10)									
25 Cr-20 Ni	8	Plate	SA-240	310S	(3)(10)	30.0	75.0	18.7	16.9	15.8	14.9	14.1	13.3	13.0
25 Cr-20 Ni	8	Smls. Tb.	SA-213	TP310	(3)(10)									
25 Cr-20 Ni	8	Smls. Pp.	SA-312	TP310	(3)(10)									
25 Cr-20 Ni	8	Forg.	SA-182	F310	(3)(10)									
25 Cr-20 Ni	8	Forg.	SA-336	F25	(3)(10)									
25 Cr-20 Ni	8	Bar.	SA-479	310S	(1)(2)(10)	30.0	75.0	18.7	17.2	16.4	15.8	15.5	15.3	15.2
25 Cr-20 Ni	8	Bar.	SA-479	310S	(1)(3)(10)									
25 Cr-20 Ni	8	Bar.	SA-479	310S	(2)(10)	30.0	75.0	18.7	16.9	15.8	14.9	14.1	13.3	13.0
25 Cr-20 Ni	8	Bar.	SA-479	310S	(3)(10)	30.0	75.0	18.7	16.9	15.8	14.9	14.1	13.3	13.0
23 Cr-12 Ni	8	Wld. Tb.	SA-249	TP309	(1)(4)(10)	30.0	75.0	15.9	14.6	13.9	13.4	13.1	13.0	12.9
23 Cr-12 Ni	8	Wld. Pp.	SA-312	TP309	(1)(4)(10)									
23 Cr-12 Ni	8	Wld. Tb.	SA-249	TP309	(4)(10)	30.0	75.0	15.9	14.3	13.4	12.6	12.0	11.3	11.1
23 Cr-12 Ni	8	Wld. Pp.	SA-312	TP309	(4)(10)									
25 Cr-20 Ni	8	Wld. Tb.	SA-249	TP310	(1)(2)(4)(10)	30.0	75.0	15.9	14.6	13.9	13.4	13.1	13.0	12.9
25 Cr-20 Ni	8	Wld. Pp.	SA-312	TP310	(1)(2)(4)(10)									
25 Cr-20 Ni	8	Wld. Tb.	SA-249	TP310	(2)(4)(10)	30.0	75.0	15.9	14.3	13.4	12.6	12.0	11.3	11.1
25 Cr-20 Ni	8	Wld. Pp.	SA-312	TP310	(2)(4)(10)									
25 Cr-20 Ni	8	Wld. Tb.	SA-249	TP310	(1)(3)(4)(10)	30.0	75.0	15.9	14.6	13.9	13.4	13.1	13.0	12.9
25 Cr-20-Ni	8	Wld. Pp.	SA-312	TP310	(1)(3)(4)(10)									
25 Cr-20 Ni	8	Wld. Tb.	SA-249	TP310	(3)(4)(10)	30.0	75.0	15.9	14.3	13.4	12.6	12.0	11.3	11.1
25 Cr-20 Ni	8	Wld. Pp.	SA-312	TP310	(3)(4)(10)									
19 Cr-9 Ni-Mo-W-Ti-Cb-Cu	...	Bolt.	SA-453	651 Class B ≤ 3″	(5)	60.0	95.0	15.0	13.7	12.7	12.0	11.5	10.9	10.6

TABLE UHA-23 (CONT'D)
MAXIMUM ALLOWABLE STRESS VALUES IN TENSION FOR HIGH-ALLOY STEEL, IN KIPS/SQ IN. (MULTIPLY BY 1000 TO OBTAIN PSI)
(See UW-12(c) for vessels constructed under Part UW that include welded joints that are neither fully radiographed nor spot radiographically examined)

For Metal Temperatures Not Exceeding Deg F: 700	750	800	850	900	950	1000	1050	1100	1150	1200	1250	1300	1350	1400	1450	1500	Specification Number	Grade
15.1	15.0	14.9	14.6	13.8	12.5	10.5	8.5	6.5	5.0	3.8	2.9	2.3	1.7	1.3	0.9	0.7	SA-240 SA-312	309S TP309
12.7	12.5	12.1	11.9	11.6	11.1	10.1	8.5	6.5	5.0	3.8	2.9	2.3	1.7	1.3	0.9	0.7	SA-240 SA-312	309S TP309
15.1	15.0	14.9	14.6	13.8	12.5	11.0	9.7	8.5	7.2	6.0	4.7	3.5	2.3	1.6	1.1	0.7	SA-240 SA-213 SA-312 SA-182 SA-336	310S TP310 TP310 F310 F25
12.7	12.5	12.1	11.9	11.6	11.3	10.8	9.7	8.5	7.2	6.0	4.7	3.5	2.3	1.6	1.1	0.7	SA-240 SA-213 SA-312 SA-182 SA-336	310S TP310 TP310 F310 F25
15.1	15.0	14.9	14.6	13.8	12.5	11.0	7.1	5.0	3.6	2.5	1.4	0.7	0.4	0.3	0.2	0.2	SA-240 SA-213 SA-312 SA-182 SA-336	310S TP310 TP310 F310 F25
12.7	12.5	12.1	11.9	11.6	11.1	9.8	7.1	5.0	3.6	2.5	1.4	0.7	0.4	0.3	0.2	0.2	SA-240 SA-213 SA-312 SA-182 SA-336	310S TP310 TP310 F310 F25
15.1	15.0	14.9	14.6	13.8	12.5	11.0	...	...	...	...	...	...	...	...	...	...	SA-479 SA-479	310S 310S
12.7	12.5	12.1	11.9	11.6	11.3	10.8	...	...	...	...	...	...	...	...	...	...	SA-479	310S
12.7	12.5	12.1	11.9	11.6	11.1	9.8	...	...	...	...	...	...	...	...	...	...	SA-479	310S
12.8	12.7	12.6	12.4	11.7	10.6	8.9	7.2	5.5	4.2	3.2	2.4	1.9	1.5	1.1	0.7	0.6	SA-249 SA-312	TP309 TP309
10.8	10.6	10.3	10.1	9.9	9.6	8.6	7.2	5.5	4.2	3.2	2.4	1.9	1.5	1.1	0.7	0.6	SA-249 SA-312	TP309 TP309
12.8	12.7	12.6	12.4	11.7	10.6	9.3	8.3	7.2	6.1	5.1	4.0	2.9	2.0	1.3	0.9	0.6	SA-249 SA-312	TP310 TP310
10.8	10.6	10.3	10.1	9.9	9.6	9.2	8.3	7.2	6.1	5.1	4.0	2.9	2.0	1.3	0.9	0.6	SA-249 SA-312	TP310 TP310
12.8	12.7	12.6	12.4	11.7	10.6	9.3	6.0	4.2	3.0	2.1	1.2	0.6	0.4	0.3	0.2	0.1	SA-249 SA-312	TP310 TP310
10.8	10.6	10.3	10.1	9.9	9.4	8.3	6.0	4.2	3.0	2.1	1.2	0.6	0.4	0.3	0.2	0.1	SA-249 SA-312	TP310 TP310
10.4	10.1	9.9	9.7	9.5	9.4	9.1	...	...	...	...	...	...	...	...	...	...	SA-453	651 Class B ≤ 3″

TABLE UHA-23 (CONT'D)
MAXIMUM ALLOWABLE STRESS VALUES IN TENSION FOR HIGH-ALLOY STEEL, IN KIPS/SQ IN. (MULTIPLY BY 1000 TO OBTAIN PSI)
(See UW-12(c) for vessels constructed under Part UW that include welded joints that are neither fully radiographed nor spot radiographically examined)

Nominal Composition	P-Number	Product Form	Specification Number	Grade	Notes	Specified Minimum Yield	Specified Minimum Tensile	For Metal Temperatures Not Exceeding Deg F: −20 to 100	200	300	400	500	600	650
19 Cr-9 Ni-Mo-W-Ti-Cb-Cu	...	Bolt	SA-453	651 Class B >3"	(5)	50.0	95.0	12.5	11.4	10.6	10.0	9.5	9.0	8.8
19 Cr-9 Ni-Mo-W-Ti-Cb-Cu	...	Bolt	SA-453	651 Class A ≤ 3"	(5)	70.0	100.0	17.5	16.0	14.8	14.0	13.4	12.7	12.4
19 Cr-9 Ni-Mo-W-Ti-Cb-Cu	...	Bolt	SA-453	651 Class A > 3"	(5)	60.0	100.0	15.0	13.7	12.7	12.0	11.5	10.9	10.6
15 Cr-25 Ni-Mo Ti-V-B	...	Bolt	SA-453	660 Classes A and B	(5)	85.0	130.0	21.2	20.7	20.5	20.3	20.2	20.2	20.1

NOTES:

The stress values in this table may be interpolated to determine values for intermediate temperatures.

Stress values in restricted shear such as dowel bolts, rivets, or similar construction in which the shearing member is so restricted that the section under consideration would fail without reduction of area shall be 0.80 times the values in the above table.

Stress values in bearing shall be 1.60 times the values in the above table.

(1) Due to the relatively low yield strength of these materials, these higher stress values were established at temperatures where the short time tensile properties govern to permit the use of these alloys where slightly greater deformation is acceptable. These higher stress values exceed 62½ percent but do not exceed 90 percent of the yield strength at temperature. Use of these stress may result in dimensional changes due to permanent strain. These stress values are not recommended for the flanges of gasketed joints or other applications where slight amounts of distortion can cause leakage or malfunction.

(2) These stress values at temperatures of 1050 F and above should be used only when assurance is provided that the steel has a predominant grain size not finer than ASTM No. 6.

(3) These stress values shall be considered basic values to be used when no effort is made to control or check the grain size of the steel.

TABLE UHA-23 (CONT'D)
MAXIMUM ALLOWABLE STRESS VALUES IN TENSION FOR HIGH-ALLOY STEEL, IN KIPS/SQ IN. (MULTIPLY BY 1000 TO OBTAIN PSI)
(See UW-12(c) for vessels constructed under Part UW that include welded joints that are neither fully radiographed nor spot radiographically examined)

For Metal Temperatures Not Exceeding Deg F: 700	750	800	850	900	950	1000	1050	1100	1150	1200	1250	1300	1350	1400	1450	1500	Specification Number	Grade
8.6	8.4	8.3	8.1	8.0	7.8	7.6	...	...	...	...	...	...	...	...	...	...	SA-453	651 Class B ≤ 3"
12.1	11.8	11.6	11.4	11.1	10.9	10.7	...	...	...	...	...	...	...	...	...	...	SA-453	651 Class A ≤ 3"
10.4	10.1	9.9	9.7	9.5	9.4	9.1	...	...	...	...	...	...	...	...	...	...	SA-453	651 Class A > 3"
20.1	20.0	19.9	19.9	19.8	19.8	19.7	...	...	...	...	...	...	...	...	...	...	SA-453	660 Classes A and B

(4) These stress values are the basic values multiplied by a joint efficiency factor of 0.85.

(5) These stress values are established from a consideration of strength only and will be satisfactory for average service. For bolted joints where freedom from leakage over a long period of time without retightening is required, lower stress values may be necessary as determined from the flexibility of the flange and bolts and corresponding relaxation properties.

(6) To these stress values a quality factor as specified in UG-24 shall be applied for castings.

(7) These stress values permitted for material that has been carbide-solution treated.

(8) For temperatures below 100 F, stress values equal to 20 percent of the specified minimum tensile strength will be permitted.

(9) This steel may be expected to develop embrittlement at room temperature after service at temperatures above 700 F; consequently, its use at higher temperatures is not recommended unless due caution is observed.

(10) At temperatures over 1000 F, these stress values apply only when the carbon is 0.04 percent or higher.

(11) For temperatures above 800 F, the stress values apply only when the carbon content is 0.04 percent and above.

(12) These stress values shall be applicable to forgings over 5 in. in thickness.

(13) For temperatures above 1000 F, these stress values may be used only if the material is heat treated by heating it to a minimum temperature of 1900 F and quenching in water or rapidly cooling by other means.

(14) Filler metal shall not be used in the manufacture of welded pipe or tubing.

number of materials that have approximately the same range of chemical composition. To supply such a uniform system of reference, Table UHA-23 gives opposite each grade the AISI type number which has approximately the same range of chemical composition. These type numbers are used in the rules of Part UHA whenever reference is made to materials of approximately the same chemical composition that are furnished under more than one approved specification or in more than one product form.

DESIGN

UHA-20 General

(*a*) The rules in the following paragraphs apply specifically to the design of pressure vessels and vessel parts that are constructed of high-alloy steel and shall be used in conjunction with the general requirements for *Design* in Subsection A, and with the specific requirements for *Design* in Subsection B that pertain to the method of fabrication used.

(*b*) *Minimum Thickness of Plate.* The minimum thickness after forming of any plate subject to pressure shall be $^3/_{32}$ in. except that for high-alloy materials in noncorrosive service, the minimum thickness shall be $^1/_{16}$ in. (see UG-16(c) for permissible undertolerance).

UHA-21 Welded Joints

When radiographic examination is required for butt-welded joints by UHA-33, joints of Categories A and B (see UW-3) shall be of Type No. (1) and No. (2) of Table UW-12.

UHA-23 Maximum Allowable Stress Values

(*a*) Table UHA-23 gives the maximum allowable stress values at the temperatures indicated for the materials conforming to the specifications listed therein. Values may be interpolated for intermediate temperatures (see UG-23).

(*b*) For vessels designed to operate at a temperature below —20F, the allowable stress values to be used in design shall not exceed those given in Table UHA-23 for temperatures of —20 F to 100 F.

UHA-28 Thickness of Shells Under External Pressure

Cylindrical and spherical shells under external pressure shall be designed by the rules in UG-28, using the Figures for High Alloy Steels or Fig. UCS-28.2 in Appendix V. Examples illustrating the application of this paragraph are given in Appendix L.

UHA-29 Stiffening Rings for Shells Under External Pressures

Rules covering the design of stiffening rings are given in UG-29. An example illustrating the use of these rules is given in Appendix L.

UHA-30 Attachment of Stiffening Rings to Shell

Rules covering the attachment of stiffening rings are given in UG-30.

UHA-31 Formed Heads, Pressure on Convex Side

Ellipsoidal, torispherical, hemispherical, and conical heads, having pressure on the convex side (minus heads), shall be designed by the rules of UG-33, using the Figures for High-Alloy Steels or Fig. UCS-28.2 in Appendix V. Examples illustrating the application of this paragraph are given in Appendix L.

UHA-32 Requirements for Postweld Heat Treatment

(*a*) Before applying the detailed requirements and exemptions in these paragraphs, satisfactory weld procedure qualifications of the procedures to be used shall be performed in accordance with all the essential variables of Section IX of the Code including conditions of postweld heat treatment or lack of postweld heat treatment and including other restrictions listed below. All welded pressure vessels or pressure vessel parts shall be given a postweld heat treatment at a temperature not less than specified in Table UHA-32 when the nominal thickness, including corrosion allowance, of any welded joint in the vessel or vessel part exceeds the limits in the notes to Table UHA-32. The exemptions provided for in the notes to Table UHA-32 are not permitted when postweld heat treatment is a service requirement as set forth in UHA-51 and UW-2. The materials in Table UHA-32 are listed in accordance with the Section IX P-number material groupings of Table Q-11.2 and are also listed in Table UHA-23.

(*b*) Holding temperatures and/or holding times in excess of the minimum values given in Table UHA-32 may be used.

(*c*) When pressure parts of two different P-number groups are joined by welding, the postweld heat treatment shall be that specified in Table UHA-32 with applicable notes for the material requiring the higher postweld temperature. When nonpressure parts are welded to pressure parts, the postweld heat treatment temperature of the pressure part shall control. Ferritic steel parts, when used in conjunction with austenitic chromium-nickel stainless steel vessels, shall not be subjected to the solution heat treatment described in UHA-105(b).

TABLE UHA-32
REQUIREMENTS FOR POSTWELD HEAT TREATMENT

Material	Notes	Minimum Holding Temperature F	Minimum Holding Time Temperature, hr per in. of thickness (Note 1)
P-6	(2), (4)	1400	1
P-7	(2), (5)	1350	1
P-8	(3)		
P-10E*	(5)	1250	1

*For SA-268 Grade TP446 only.

NOTES:
(1) The minimum holding time at temperature for material under $^1/_4$ in. in thickness shall be $^1/_4$ hr.
(2) Postweld heat treatment is not required for vessels constructed of Type 405 material or of Type 410 material with carbon content not to exceed 0.08 percent, welded with electrodes that produce an austenitic chromium nickel weld deposit or a non-air hardening nickel-chromium-iron weld deposit, provided the plate thickness at the welded joint does not exceed ⅜ in., and for thicknesses over ⅜ in. to 1½ in. provided a preheat of 450 F is maintained during welding and the joints are completely radiographed.
(3) Postweld heat treatment is neither required nor prohibited for joints between austenitic stainless steels of the P-8 Group. See Nonmandatory Appendix HA, UHA 100 to 108 inclusive.
(4) Postweld heat treatment shall be performed as prescribed in UW-40 and UCS-56(e).
(5) Postweld heat treatment shall be performed as prescribed in UW-40 and UCS-56(e) except that the cooling rate shall be a maximum of 100 F per hour in the range above 1200 F after which the cooling rate shall be sufficiently rapid to prevent embrittlement.

(*d*) When the welded joint connects parts that are of different thickness, the thickness to be used in applying the requirements for postweld heat treatment in (a) shall be the following:

(*1*) The thinner of two adjacent butt-welded plates including head to shell connections;

(*2*) The thicker of the shell or head plate in connections to intermediate heads of the type shown in Fig. UW-13.1(f);

(*3*) The thickness of the shell in connections to tube sheets, flat heads, covers, or similar constructions;

(*4*) The thickness of the shell or head plate in nozzle attachment welds;

(*5*) The thickness of the nozzle neck in nozzle neck to flange connections;

(*6*) The thickness of the pressure part, at the point of attachment, where a nonpressure part is welded to a pressure part.

(*e*) The operation of postweld heat treatment shall be carried out by one of the procedures given in UW-40 in accordance with the requirements of UCS-56(e) except as modified by the notes to Table UHA-32.

(*f*) Vessels or parts of vessels that have been postweld heat treated in accordance with the requirements of this paragraph shall again be postweld heat treated after repairs or alterations have been made if the welds made in such alterations or repairs require postweld treatment under the requirements given in (a).

UHA-33 Radiographic Examination

(*a*) The requirements for radiographing prescribed in UW-11, UW-51, and UW-52 shall apply in high-alloy vessels, except as provided in (b). (See Par. UHA-21.)

(*b*) Butt-welded joints in vessels constructed of materials conforming to Type 405 welded with straight chromium electrodes, and to Types 410 and 430 welded with any electrode, shall be radiographed in all thicknesses. Butt-welded joints in vessels constructed of Type 405 material or of Type 410 with carbon content not to exceed 0.08 percent, welded with electrodes that produce an austenitic chromium-nickel weld deposit or a non-air hardening nickel-chromium-iron deposit shall be radiographed when the thinner of the plate or vessel wall thickness at the welded joint exceeds 1½ in. The final radiographs of all straight chromium ferritic welds including major repairs to these welds shall be made after postweld heat treatment has been performed.

(*c*) Butt-welded joints in vessels constructed of austenitic chromium-nickel stainless steels which are radiographed because of the thickness requirements of UW-11, or for lesser thicknesses where the joint efficiency reflects the credit for radiographic

examination of Table UW-12, shall be radiographed following post heating if such is performed.

UHA-34 Liquid Penetrant Examination

All austenitic chromium-nickel alloy steel welds, both butt and fillet, in vessels whose shell thickness exceeds $^3/_4$ in. shall be examined for the detection of cracks by the liquid penetrant method. This examination shall be made following heat-treatment if heat treatment is performed. All cracks shall be eliminated.

FABRICATION

UHA-40 General

The rules in the following paragraphs apply specifically to the fabrication of pressure vessels and vessel parts that are constructed of high-alloy steel and shall be used in conjunction with the general requirements for *Fabrication* in Subsection A, and with the specific requirements for *Fabrication*, in Subsection B that pertain to the method of fabrication used.

UHA-41 Marking

(*a*) The specification number, grade or type number, test identification number, and the name of the manufacturer shall be legibly marked on each plate not less than 12 in. from the edges. Die stamping may be harmful for some conditions of service.

(*b*) The plate manufacturer shall describe on the mill test reports any heat treatments carried out by him.

UHA-42 Weld Metal Composition

Welds that are exposed to the corrosive action of the contents of the vessel should have a resistance to corrosion that is not substantially less than that of the base metal. The use of filler metal that will deposit weld metal with practically the same composition as the material joined is recommended. When the manufacturer is of the opinion that a physically better joint can be made by departure from these limits, filler metal of a different composition may be used provided the strength of the weld metal at the operating temperature is not appreciably less than that of the high-alloy material to be welded, and the user is satisfied that its resistance to corrosion is satisfactory for the intended service. The columbium content of weld metal shall not exceed 1.00 percent.

INSPECTION AND TESTS

UHA-50 General

The rules in the following paragraphs apply specifically to the inspection and testing of pressure vessels and vessel parts that are constructed of high-alloy steel and shall be used in conjunction with the general requirements for *Inspection and Tests* in Subsection A, and with the specific requirements for *Inspection and Tests* in Subsection B that pertain to the method of fabrication used.

UHA-51 Impact Tests

Impact tests as prescribed in UG-84 shall be made for the following combinations of materials and operating temperatures.

(*a*) For Types 304, 304L and 347 at operating temperatures below —425 F and all other materials below —325 F.

(*b*) For the following materials operating at a metal temperature below —20 F except when the minimum thickness is the greater of those determined under the most severe condition of coincident pressure (external or internal) and temperature in accordance with UG-21 for temperatures of (a) —20 F and above, and (b) below —20 F in which case the coincident pressure (internal if above atmospheric and external if below atmospheric) shall be multiplied by $2^1/_2$.

(*1*) Ferritic chromium stainless steels.

(*2*) Austenitic chromium-nickel stainless steels with carbon in excess of 0.10 percent.

(*3*) Austenitic chromium-nickel stainless steels that have a nickel or a chromium content in excess of the AISI standard analysis range of the specified type number and product form.

(*4*) Materials in casting form.

(*5*) Material in the form of deposited weld metal.

(*c*) For the following materials at all values of operating temperature:

Type 309, 310, 316, 309Cb, 310Cb, or 316Cb material that is postweld heat treated at temperatures below 1650 F. The tests shall include the weld metal and shall be made at room temperature, or at operating temperature if lower.

UHA-52 Welded Test Plates

(*a*) For welded vessels constructed of Type 405 material which are not postweld heat treated, welded test plates shall be made to include material from each melt of plate steel used in the vessel. Plates from two different melts may be welded together and be represented by a single test plate.

(*b*) From each welded test plate there shall be taken two face-bend test specimens as prescribed in Q-7(2) of Section IX; these shall meet the requirements of Q-8, Section IX.

STAMPING AND REPORTS

UHA-60 General

The provisions for stamping and reports in UG-115 through UG-120 shall apply without supplement to vessels constructed of high-alloy steels.

PRESSURE RELIEF DEVICES

UHA-65 General

The provisions for pressure-relief devices given in UG-125 through UG-134 shall apply without supplement to vessels constructed of high-alloy steels.

APPENDIX HA

SUGGESTIONS ON THE SELECTION AND TREATMENT OF AUSTENITIC CHROMIUM-NICKEL STEELS

(Informative and Nonmandatory)

UHA-100 General

The selection of the proper metal composition to resist a given corrosive medium and the choice of the proper heat treatment and surface preparation of the material selected are not within the scope of this Division. This Appendix discusses some of the factors that should be considered in arriving at a proper selection.

UHA-101 Structure

The composition, mechanical working, heat treatment cycle, and the solidification rate in castings and weld metal largely determine the degree to which ferrite, carbide, and sigma phases are formed in austenitic stainless steels. The type of structure and the thermal and mechanical treatment it receives are determining factors in its resistance to intergranular corrosion, stress corrosion cracking, and crack susceptibility, and in its ductility and toughness.

UHA-102 Intergranular Corrosion

When austenitic steels are held for a sufficient time between 800 F and 1600 F, chromium carbide tends to precipitate preferentially at austenite grain boundaries. This type of precipitation is referred to as sensitization. Intergranular corrosion takes place when a sensitized material is exposed to a sufficiently strong corrosive medium for a long enough time.

Methods for combating intergranular corrosion include the following:

(*1*) An anneal at 1850 F to 2050 F followed by rapid cooling through the sensitization range. Subsequent operation of a vessel in the sensitization range may resensitize the material.

(*2*) Stabilizing with columbium, titanium, or tantalum. These elements have a strong affinity for carbon and, in sufficient quantities, prevent the precipitation of chromium carbides.

(*3*) Use of types of steel having a low enough carbon content that the chromium depletion at the grain boundaries is kept within safe limits.

UHA-103 Stress Corrosion Cracking

Austenitic chromium-nickel steels that are highly stressed in tension may develop transcrystalline or interorystalline cracks when exposed to certain corrosive media. The stresses may be produced by external loads, welding or cold forming operations, or by uneven cooling. Methods of reducing susceptibility to stress corrosion cracking include the selection of a composition that will have a stable austenite structure in the operating range and heat treatment to reduce the magnitude of the residual stresses.

UHA-104 Formation of Sigma Phase

The existence of the sigma phase in an austenitic stainless steel may materially reduce its ductility and toughness. Under favorable conditions, the sigma phase is formed relatively slowly in the temperature range between 1050 F and 1700 F. Factors contributing to the formation of sigma phase include the presence of ferrite, prior cold working, variation in composition due to progressive solidification, and the presence of ferritizers, particularly molybdenum, columbium, and titanium. Formation of sigma phase may be minimized or prevented by a proper selection of composition. Or the sigma may be transformed

into austenite and ferrite by suitable heating and quenching.

UHA-105 Heat Treatment of Austenitic Chromium-Nickel Steels

(*a*) In recognition of controversial opinion relative to the effects of postweld heat treatment of austenitic stainless steels, mandatory requirements for such have been omitted. Service experience is too limited to permit comparison between the relative safety of as-welded and postweld heat treated austenitic steel weldments, particularly in thick sections. It is recognized that the stability of austenitic steels and their optimum behavior in service are influenced by the mechanical and thermal treatment they have received; however, it is a basic principle that the Code rules are intended to provide minimum safety requirements for new construction, not to cover deterioration which may occur in service as a result of corrosion, instability of the material, or unusual operating conditions such as fatigue or shock loading.

(*b*) Where maximum corrosion resistance is required it is advisable to heat treat in such a fashion as to place all chromium carbides in solution. For such service it is recommended that the following procedure be followed.

(*1*) Hold the vessel within the prescribed temperature range for not less than one hour per inch of thickness. Quench all parts of the vessel uniformly and as rapidly as possible. Material not stabilized with columbium or titanium should be cooled through the range from 1700 F to 1000 F in not more than three minutes. The rapid cooling should be continued to below 800 F. Slower cooling rates may be just as satisfactory for some compositions of the material and conditions of service.

TABLE UHA-105
RECOMMENDED TEMPERATURE RANGES FOR HEAT TREATMENT

Type Number of Material	Heat Treatment Procedure
301, 302, 304, 308, 309, 310	1850–2000 F
321, 347	1850–2000 F
316	1850–2050 F
309Cb, 310Cb, 316Cb	1850–1950 F

UHA-106 Restricted Composition

For constructions involving heat treatment within the sigma-formation range, a more restricted chemical composition is recommended for Type 316Cb, as follows:

Carbon	0.07 max	
Manganese	1.50 min	
Phosphorus	0.030 max	
Sulfur	0.030 max	
Silicon	0.75 max	
Nickel	13.00 to 15.00	
Chromium	17.50 to 19.00	
Molybdenum	2.00 to 2.50	(2.25 preferred)
Columbium or Columbium plus Tantalum	0.90 max	Min not less than 9 times the carbon content.

UHA-107 Dissimilar Weld Metal

The difference between the coefficients of expansion of the base material and the weld should receive careful consideration before undertaking the welding of ferritic type stainless steels with austenitic electrodes for services involving severe temperature conditions, particularly those of a cyclic nature.

UHA-108 Fabrication

It is recommended that the user of austenitic chromium-nickel steel vessels in corrosive service consider the following additional fabrication test.

A welded guided-bend test specimen should be made as prescribed in Q-7(2) of Section IX from one of the heats of material used in the shell. The test plate should be welded by the procedure used in the longitudinal joints of the vessel and should be heat treated using the same temperature cycle as used for the vessel. The operations on the test plate should be such as to duplicate as closely as possible the physical conditions of the material in the vessel itself.

Grind and polish the specimen and immerse it for not less than 72 hr in a boiling solution consisting of 47cc concentrated sulfuric acid and 13 g of crystalline copper sulfate ($CuSO_4 \cdot 5H_2O$) per liter of water. Then bend the specimen so as to produce an elongation of not less than 20 percent at a section in the base metal 1/4 in. from the edge of the weld. The metal shall show no sign of disintegration after bending.

PART UCI

REQUIREMENTS FOR PRESSURE VESSELS CONSTRUCTED OF CAST IRON

GENERAL

UCI-1 Scope

The rules in Part UCI are applicable to pressure vessels and vessel parts that are constructed of cast iron, or of cast nodular iron having an elongation of less than 15 percent in 2 in., except standard pressure parts covered by UG-11(b), and shall be used in conjunction with the general requirements in Subsection A and with the specific requirements in Part UR of Subsection B, *Requirements for Pressure Vessels Fabricated by Riveting*, insofar as these requirements are applicable to cast material.

UCI-2 Service Restrictions

Cast iron vessels shall not be used to contain lethal[1] or flammable substances, either liquid or gaseous.

UCI-3 Pressure-Temperature Limitations

(*a*) The design pressure for vessels and vessel parts constructed of any of the classes of cast iron listed in Table UCI-23 shall not exceed the following values except as provided in (b).

(*1*) 160 psi at temperatures not greater than 450 F for vessels containing gases, steam, or other vapors;

(*2*) 160 psi at temperatures not greater than 375 F for vessels containing liquids;

(*3*) 250 psi for liquids at temperatures less than their boiling point at design pressure, but in no case at temperatures exceeding 120 F;

(*4*) 300 psi at temperatures not greater than 450 F for bolted heads, covers, or closures that do not form a major component of the pressure vessel.

[1]By "lethal substances" are meant poisonous gases or liquids of such a nature that a very small amount of the gas or vapor of the liquid mixed or unmixed with air is dangerous to life, when inhaled. For purposes of the Code this class includes substances of this nature which are stored under pressure or may generate a pressure if stored in a closed vessel. Some such substances are hydrocyanic acid, carbonyl chloride, cyanogen, mustard gas, and xylyl bromide. For design purposes under this Code, chlorine, ammonia, natural or manufactured gas, any liquefied petroleum gas (such as propane, butane, butadiene), and vapors of any other petroleum products are not classified as lethal substances.

(*b*) Vessels and vessel parts constructed of stress relief annealed material conforming to Classes 40, 50, and 60 of Specification SA-278 may be used for design pressures up to 250 psi at temperatures up to 650 F, provided the distribution of metal in the pressure containing walls of the casting is shown to be approximately uniform.

(*c*) Cast iron flanges and flanged fittings conforming to ANSI B16.1-1967, Cast Iron Pipe Flanges and Flanged Fittings, Class 125 and Class 250 may be used in whole or in part of a pressure vessel for pressures not exceeding the American National Standard ratings at temperatures not exceeding 450 F.

MATERIALS

UCI-5 General

All cast iron material subject to stress due to pressure shall conform to one of the specifications given in Section II of the Code and shall be limited to those listed in Table UCI-23 except as otherwise provided in UG-11.

UCI-12 Bolt and Rivet Materials

The requirements for bolts, rivet material, nuts, and washers shall be the same as for carbon and low-alloy steels in UCS-10 and UCS-11.

DESIGN

UCI-16 General

The rules in the following paragraphs apply specifically to the design of pressure vessels and vessel parts of cast iron and shall be used in conjunction with the general requirements for *Design* in Subsection A, and with the specific requirements for *Design* in Part UR, insofar as these requirements are applicable to cast materials.

UCI-23 Maximum Allowable Stress Values

(*a*) Table UCI-23 gives the maximum allowable stress values in tension at the temperatures indicated

for castings conforming to the specifications listed therein.

(*b*) The maximum allowable stress value in bending shall be $1^1/_2$ times that permitted in tension, and the maximum allowable stress value in compression shall be 2 times that permitted in tension.

UCI-28 Thickness of Shells Under External Pressure

(*a*) Cylindrical and spherical shells under external pressure shall be designed by the rules in UG-28, using Fig. UCI-28.

(*b*) Examples illustrating the use of charts similar to Fig. UCI-28 are given in Appendix L.

UCI-32 Head With Pressure on Concave Side

Heads with pressure on the concave side (plus heads) shall be designed in accordance with the formulas in UG-32 using the maximum allowable stress value in tension.

TABLE UCI-23
MAXIMUM ALLOWABLE STRESS VALUES IN TENSION FOR CAST IRON, IN POUNDS PER SQUARE INCH

Specification Number	Class	Spec Min Tensile Strength	For Metal Temperatures Not Exceeding Degrees F	
			Subzero to 450	650
SA-278	20	20,000	2000	....
SA-278	25	25,000	2500	....
SA-278	30	30,000	3000	....
SA-278	35	35,000	3500	....
SA-278	40	40,000	4000	4000
SA-278	50	50,000	5000	5000
SA-278	60	60,000	6000	6000
SA-476	80	80,000	8000	....

UCI-33 Heads With Pressure on Convex Side

The thickness of heads with pressure on the convex side (minus heads) shall not be less than the thickness required in UCI-32 for plus heads under the same pressure nor less than 0.01 times the inside diameter of the head skirt.

UCI-35 Spherically Shaped Covers (Heads)

(*a*) Circular cast iron spherically shaped heads with bolting flanges, similar to Fig. UA-6(b), (c), and (d), shall be designed in accordance with the provisions in UA-6, except as otherwise provided in this paragraph.

(*b*) Circular cast iron spherically shaped heads with bolting flanges shall be designed in accordance with the following requirements.

(*1*) The head thickness shall be determined in accordance with the requirements in UG-32.

(*2*) The spherical and knuckle radii shall conform to the requirements in UG-32.

(*3*) Cast iron flanges and flanged fittings conforming to ANSI B16.1-1967, Cast Iron Pipe Flanges and Flanged Fittings, Class 125 and Class 250 may be used in whole or in part of a pressure vessel for pressures not exceeding American National Standard ratings at temperatures not exceeding 450 F. Other flanges may be designed in accordance with the provisions of Appendix II using the allowable stress values in bending.

Alternatively, the maximum allowable working pressure of cast iron dished covers with bolting flanges, with or without nozzles or internal ribs, may be established in accordance with the provisions of UCI-101.

UCI-36 Openings and Reinforcements

(*a*) The dimensional requirements in UG-36 through UG-46 are applicable to cast iron and shall be used in the design of openings and reinforcements in vessels and vessel parts except that in no case shall the thickness of the reinforcement exceed twice the thickness of the vessel wall.

(*b*) Cast iron flanges, nozzles, and opening reinforcements which enter into the design calculations of the completed vessel or vessel part, shall be cast integrally with the vessel or vessel part.

(*c*) Cast iron flanges, nozzles, and opening reinforcements, when attached to steel or nonferrous vessels, shall not be considered as contributing to the strength of the vessels.

UCI-37 Corners and Fillets

A liberal radius shall be provided at projecting edges and reentrant corners in accordance with good foundry practice. Abrupt changes in surface contour and in wall thickness at junctures shall be avoided. Fillets and transition sections between adjacent main pressure containment walls or integral attachment thereto, such as nozzles, lugs, supports, flanges, and bosses, shall have radii or the equivalent not less than one-half of the thickness of the thinner of the sections being joined. Basic design, grade of iron, and other factors entering into the production of castings may require increased filleting or ... minimum specified in order to provi... soundness of material.

FABRICATION

UCI-75 General

The rules in the following paragraphs apply specifically to the fabrication of pressure vessels and vessel parts of cast iron and shall be used in conjunction with the general requirements for *Fabrication* in Subsection A and with the specific requirements for *Fabrication* in Part UR, insofar as these requirements are applicable to cast materials.

UCI-78 Repair of Defects in Materials

(*a*) Surface imperfections in vessels and pressure parts that are to operate within the limitations given in UCI-3(a)(1), (2), and (4) may be repaired by plugging provided the depth of the plug is not greater than 20 percent of the thickness of the section and the diameter of the plug is not greater than its thickness. Except as limited in (c), repair by welding is not permitted.

(*b*) Seepage around chaplets in vessels and pressure parts that are to operate within the limitations given in UCI-3(a)(1), (2), and (4) may be repaired by plugging, provided the following requirements are met:

(*1*) No welding is performed;

(*2*) The diameter of the plug is not greater than its thickness;

(*3*) The metal surrounding the defect is shown to be sound by radiographic examination;

(*4*) The part after repair meets the standard hydrostatic test prescribed in UCI-99.

(*c*) Surface imperfections and defects in materials in vessels and pressure parts that are to operate within the limitations given in UCI-3(a)(3) may be repaired using methods and procedures that are consistent with safe practice. Where welding is used, the weld and the metal adjacent to it must be free of cracks when examined by the magnetic particle or liquid penetrant examination method of testing for cracks.

INSPECTION AND TESTS

UCI-90 General

The rules in the following paragraphs apply specifically to the inspection and testing of pressure vessels and vessel parts of cast iron and shall be used in conjunction with the general requirements for *Inspection and Tests* in Subsection A and the specific requirements for *Inspection and Tests* in Part UR, insofar as these requirements are applicable to cast material.

UCI-99 Standard Hydrostatic Test

Cast iron pressure vessels shall be hydrostatically tested by the method prescribed in UG-99 except that the test pressure shall be 2 times the maximum allowable working pressure to be marked on the vessel for maximum allowable working pressures greater than 30 psi and $2^1/_2$ times the maximum allowable working pressure but not to exceed 60 psi for maximum allowable working pressure under 30 psi.

UCI-101 Hydrostatic Test to Destruction

(*a*) The maximum allowable working pressure of identical cast iron vessels or vessel parts, based on testing one of them to destruction, limited to the service conditions specified in UCI-3 and in accordance with UG-101(m) shall be:

$$P_R = \frac{P_B}{6.67} \times \frac{\text{(Specified minimum tensile strength)}}{\left(\begin{array}{c}\text{Minimum tensile strength of}\\ \text{associated arbitration bar}\end{array}\right)}$$

where

P_R = maximum allowable working pressure at operating temperatures listed in Table UCI-23 in pounds per square inch

P_B = destruction test pressure in pounds per square inch

The principle of UG-101(c) shall be followed.

NOTE: It is assumed that failure will occur in bending.

(*b*) All vessels or vessel parts of the same material, design, and construction, whose maximum allowable working pressure is based on a test to destruction of a sample vessel in accordance with (a) above, shall be considered to have a design pressure equal to the maximum allowable working pressure thus determined, except as limited by the rules of UCI-3, and shall be subjected to a hydrostatic test pressure in conformity with the rules of UCI-99.

STAMPING AND REPORTS

UCI-115 General

The provisions for stamping and reports in UG-115 through UG-120 shall apply without supplement to vessels constructed of cast iron.

PRESSURE RELIEF DEVICES

UCI-125 General

The provisions for pressure relief devices in UG-125 through UG-134 shall apply without supplement to vessels constructed of cast iron.

PART UCL

REQUIREMENTS FOR WELDED PRESSURE VESSELS CONSTRUCTED OF INTEGRALLY CLAD PLATE OR WITH APPLIED CORROSION RESISTANT LININGS

GENERAL

UCL-1 Scope

The rules in Part UCL are applicable to pressure vessels or vessel parts that are constructed of integrally clad plate, and to vessels and vessel parts that are fully or partially lined inside or outside with corrosion resistant plate, sheet, or strip, attached by welding to the base plates before or after forming or to the shell, heads, and other parts during or after assembly into the completed vessel.[1] These rules shall be used in conjunction with the general requirements in Subsection A and with the specific requirements in the applicable Parts of Subsection B.

UCL-2 Methods of Fabrication

Vessels and vessel parts of integrally clad construction shall be fabricated by welding. Corrosion resistant linings may be attached by welding to vessels fabricated by any method of construction permitted under the rules of this section.

UCL-3
Conditions of Service

Specific chemical compositions, heat treatment procedures, fabrication requirements, and supplementary tests may be required to assure that the vessel will be suitable for the intended service. This is particularly true for vessels subject to severe corrosive conditions, and also those vessels operating in a cyclic temperature service. These rules do not indicate the selection of an alloy suitable for the intended service or the amount of the corrosion allowance to be provided.

It is recommended that users assure themselves by appropriate tests, or otherwise, that the alloy material selected and its heat treatment during fabrication will be suitable for the intended service. Where service data are not available, it is recommended that service inspection be made at frequent intervals until the nature and rate of corrosion and extent of metal distortion or other forms of deterioration in service can be definitely established. The data thus secured should determine the subsequent intervals between service inspection and the probable safe operating life of the vessel.

NOTE: Attention is called to the difficulties that have been experienced in welding materials differing greatly in chemical composition. Mixtures of uncertain chemical composition and physical properties are produced at the line of fusion. Some of these mixtures are brittle and may give rise to cracks during solidification or afterwards. To avoid weld embrittlement, special care is required in the selection of lining material and welding electrodes, and in the application of controls over the welding process and other fabrication procedures.

MATERIALS

UCL-10 General

The base plate and other base materials used in the construction of vessels of integrally clad plate and of those having applied corrosion linings shall comply with the requirements for materials given in UCS-5, UHA-11, or UNF-5.

[1]See UA-60—*Definitions.*

UCL-11 Clad Plate

(*a*) Clad plate used in constructions in which the design calculations are based on the total thickness including cladding (see UCL-23(c)) shall conform to one of the following specifications:

SA-263 Specification for Corrosion-Resisting Chromium-Steel Clad Plate, Sheet and Strip

SA-264 Specifications for Corrosion-Resisting Chromium-Nickel Steel Clad Plate, Sheet and Strip

SA-265 Specification for Nickel and Nickel-Base Alloy Clad Steel Plate.

(*b*) Clad plate used in constructions in which the design calculations are based on the clad-plate thickness, exclusive of the thickness of the cladding material, may consist of any base-plate material satisfying the requirements of UCL-10 and any metallic cladding material of weldable quality that in the judgment of the user is suitable for the intended service.

(*c*) Integrally clad steel plates in which any part of the cladding is included in the design calculations, as permitted in UCL-23(c), shall show a minimum shear strength of 20,000 psi when tested in the manner described in the plate specification. One shear test shall be made on each such clad plate as rolled and the results shall be reported by the mill.

(*d*) When any part of the cladding thickness is specified as an allowance for corrosion, such added thickness shall be removed before mill tension tests are made. When corrosion of the cladding is not expected, no part of the cladding need be removed before testing, even though excess thickness seems to have been provided or is available as corrosion allowance.

UCL-12 Lining

Material used for applied corrosion resistant lining may be any metallic material or weldable quality that in the judgment of the user is suitable for the intended purpose.

DESIGN

UCL-20 General

(*a*) The rules in the following paragraphs apply specifically to pressure vessels and vessel parts constructed of integrally clad plate and those having applied corrosion resistant linings and shall be used in conjunction with the general requirements for *Design* in Subsection A, and with the specific requirements for *Design* in Subsection B that pertain to the method of fabrication used.

(*b*) *Minimum Thickness of Plate.* The minimum thickness specified in UCS-16(b) shall be the total thickness for clad construction and the base-plate thickness for applied-lining construction.

UCL-23 Maximum Allowable Stress Values

(*a*) *Applied Corrosion Resistant Linings.* The thickness of material used for applied lining shall not be included in the computation for the required wall thickness of any lined vessel. The maximum allowable stress value shall be that given for the base material in Table UCS-23, UHA-23, or UNF-23.

(*b*) *Integrally Clad Plate Without Credit for Full Cladding Thickness.* Except as permitted in (c), design calculations shall be based on the total thickness of the clad plate less the specified nominal minimum thickness of cladding. A reasonable excess thickness either of the actual cladding or of the same thickness of corrosion resistant weld metal may be included in the design calculations as an equal thickness of base plate. The maximum allowable stress value shall be that given for the base-plate material in Table UCS-23, UHA-23, or UNF-23.

(*c*) *Integrally Clad Plate With Credit for Cladding Thickness.* When clad plate conforms to one of the specifications listed in UCL-11(a), and the joints are completed by depositing corrosion resisting weld metal over the weld in the base plate to restore the cladding, the design calculations may be based on a thickness equal to the nominal thickness of the base plate plus S_c/S_b times the nominal thickness of the cladding after any allowance provided for corrosion has been deducted:

where

S_c = maximum allowable stress value for the cladding at the design temperature, pounds per square inch

S_b = maximum allowable stress value for the base plate at the design temperature, pounds per square inch

Where S_c is greater than S_b, the multiplier S_c/S_b shall be taken equal to unity. The maximum allowable stress value shall be that given for the base-plate material in Table UCS-23. Vessels in which the cladding is included in the computation of wall thickness shall not be constructed for internal

pressure under the provisions of Table UW-12, column (c).

UCL-24 Maximum Allowable Working Temperature

(*a*) When the design calculations are based on the thickness of base plate exclusive of lining or cladding thickness, the maximum service metal temperature of the vessel shall be that allowed for the base-plate material.

(*b*) When the design calculations are based on the full thickness of clad plate as permitted in UCL-23(c), the maximum service metal temperature shall be the lower of the values allowed for the base-plate material in Table UCS-23 and the cladding material in Tables UHA-23 or UNF-23.

(*c*) The use of cladding or lining material of chromium-alloy stainless steel with a chromium content of over 14 percent is not recommended for service metal temperatures above 800 F.

UCL-25 Corrosion of Cladding or Lining Material

(*a*) When corrosion or erosion of the cladding or lining material is expected, the cladding or lining thickness shall be increased by an amount that in the judgment of the user will provide the service life that he desires.

(*b*) *Telltale Holes.* When telltale holes are used in clad or lined vessels, they shall have a depth not less than 80 percent of the thickness required for a seamless shell of like dimensions, or they may extend to the cladding or lining.

UCL-26 Thickness of Shells and Heads Under External Pressure

The requirements for the thickness of shells under external pressure in UCS-28, UHA-28, or UNF-28 and of heads under external pressure in UCS-33, UHA-31, or UNF-33 shall apply to pressure vessels of clad or lined plate. The cladding may be included in the design calculations for clad plate to the extent provided in UCL-23(b) and (c).

UCL-27 Low Temperature Operations

The base materials used in the construction of vessels to operate below —20 F shall satisfy the requirements of UCS-66, UCS-67, UHA-51, or UNF-65.

FABRICATION

UCL-30 General

The rules in the following paragraphs apply specifically to pressure vessels and vessel parts constructed of integrally clad plate and those having applied corrosion resistant linings and shall be used in conjunction with the general requirements for *Fabrication* in Subsection A, and with the specific requirements for *Fabrication* in Subsection B that pertain to the method of fabrication used.

UCL-31 Joints in Cladding and Applied Linings

The types of joints and welding procedure used shall be such as to minimize the formation of brittle weld composition by the mixture of metals of corrosion resistant alloy and the base material.

NOTE: Because of the different thermal coefficients of expansion of dissimilar metals, caution should be exercised in design and construction under the provisions of these paragraphs in order to avoid difficulties in service under extreme temperature conditions, or with unusual restraint of parts such as may occur at points of stress concentration.

UCL-32 Weld Metal Composition

Welds that are exposed to the corrosive action of the contents of the vessel should have a resistance to corrosion that is not substantially less than that of the corrosion resistant cladding or lining. The use of filler metal that will deposit weld metal with practically the same composition as the material joined is recommended. Weld metal of different composition may be used provided it has better mechanical properties in the opinion of the manufacturer, and the user is satisfied that its resistance to corrosion is satisfactory for the intended service. The columbium content of columbium-stabilized austenitic stainless-steel weld metal shall not exceed 1.00 percent, except when a higher columbium content is permitted in the material being welded.

UCL-33 Inserted Strips in Clad Material

The thickness of inserted strips used to restore cladding at joints shall be equal to that of the nominal minimum thickness of cladding specified for the plates backed, if necessary, with corrosion resistant weld metal deposited in the groove to bring the insert flush with the surface of the adjacent cladding.

UCL-34 Postweld Heat Treatment[1]

(*a*) Vessels or parts of vessels constructed of integrally clad or applied corrosion resistant lining material shall be postweld heat treated when the base plate is required to be postweld heat treated. In applying these rules the determining thickness shall be the total thickness of integrally clad plate and the base plate thickness of plate having applied corrosion resistant lining.

(*b*) Vessels or parts of vessels constructed of chromium-alloy stainless-steel clad plate and those lined with chromium-alloy stainless-steel applied linings shall be postweld heat treated in all thicknesses, except vessels that are clad or lined with Type 405 or Type 410S and welded with an austenitic electrode or non-air hardening nickel-chromium-iron electrode need not be postweld heat treated unless required by (a).

UCL-35 Radiographic Examination

(*a*) *General.* Vessels or parts of vessels constructed of clad plate and those having applied corrosion resistant linings shall be radiographed when required by the rules in UW-11(a), UCS-57, and UCL-36. The plate thickness specified under these rules shall be the total plate thickness for clad construction and the base plate thickness for applied-lining construction.

(*b*) *Base-Plate Weld Protected by a Strip Covering.* When the base-plate weld in clad or lined construction is protected by a covering strip or sheet of corrosion resistant material applied over the weld in the base plate to complete the cladding or lining, any radiographic examination required by the rules of UW-11(a) and UCS-57 may be made on the completed weld in the base plate before the covering is attached.

(*c*) *Base-Plate Weld Protected by an Alloy Weld.* The radiographic examination required by the rules in UW-11(a) and UCS-57 shall be made after the joint, including the corrosion resistant layer, is complete, except that the radiographic examination may be made on the weld in the base plate before the alloy cover weld is deposited, provided the following requirements are met:

(*1*) The thickness of the base plate at the welded joint is not less than that required by the design calculation.

(*2*) The corrosion resistant alloy weld deposit is non-air hardening.

(*3*) The completed alloy weld deposit is spot examined by any method that will detect cracks.

[1]CAUTION: Postweld heat treatment may be in the carbide-precipitation range for unstabilized austenitic chromium-nickel steels, as well as within the range where a sigma phase may form, and if used indiscriminately could result in material of inferior physical properties and inferior corrosion resistance, which ultimately could result in failure of the vessel.

UCL-36 Examination of Chrome-Alloy Cladding or Lining

The alloy weld joints between the edges of adjacent chromium-alloy cladding layers or liner sheets shall be examined for cracks as follows:

(*1*) Joints welded with straight chromium-alloy filler metal shall be examined throughout their full length. The examination shall be by radiographic methods when the chromium-alloy welds are in continuous contact with the welds in the base metal. Liner welds that are attached to the base metal, but merely cross the seams in the base metal, may be examined by any method that will disclose surface cracks.

(*2*) Joints welded with austenitic chromium-nickel steel filler metal or non-air hardening nickel-chromium-iron filler metal shall be given a radiographic spot examination in accordance with UW-52. For lined construction, at least one spot examination shall include a portion of the liner weld that contacts weld metal in the base plate.

UCL-40 Qualification of Welding Procedure

(*a*) The specification of the welding procedure that is proposed to be followed in clad or lined construction shall be recorded in detail.

(*b*) The procedure shall be qualified in accordance with the provisions of Section IX of the Code except as these provisions are modified in the following paragraphs. This qualified procedure specification shall be followed in construction.

UCL-41 Groove Welds in Clad Plate

(*a*) The requirements in Section IX for procedure qualification shall be modified as follows for groove welds in clad plate.

(*1*) The requirements in Items V1 and V2 of Q-11 and QN-11 shall apply separately to the base plate and to the cladding.

(*2*) The thicknesses specified in Q-13 and Table Q-13 shall apply to the total thickness of clad plate.

(*3*) For material not included in Table Q-11.1, the material used in the test plate shall be within the range of chemical composition of that to be used in construction.

(*b*) The welding procedure for groove welds in integrally clad plate shall be qualified as provided in (a) when any part of the cladding thickness of the clad plate is included in the design calculations in accordance with UCL-23(c). When the cladding thickness is not included in the design calculations, the procedure for groove welds may be qualified as in (a), or the weld in the base-plate joint may be qualified by itself in accordance with the rules in Section IX and the weld in the cladding joint by itself in accordance with UCL-43.

UCL-42 Alloy Welds in Base Metal

Groove joints in base-metal plates and parts may be made with corrosion resistant alloy-steel filler metal, or groove joints may be made between corrosion resistant alloy steel and carbon or low-alloy steel, provided the welding procedure and the welders have been qualified in accordance with the requirements of Section IX for the combination of materials used. Some applications of this rule are base metal welded with alloy-steel electrodes, and alloy nozzles welded to steel shells.

UCL-43 Corrosion Resistant Weld Deposits

Construction in which deposits of corrosion resistant alloy weld metal are applied as a protective covering on the surface of base-metal plates and parts and over welded base-metal joints, whether adjacent or not to the edges of lining sheets or cladding material, shall be qualified in accordance with the following rules:

(*1*) The qualification test plate shall consist of a base plate not less than 6 in. long, 3 in. wide, and $^1/_4$ in. thick, to which are clamped or bonded two strips of lining or cladding material separated by a gap left in the lining or a groove cut in the cladding. The gap or groove shall run lengthwise of the test plate, approximately midway of the plate width. The nominal thickness of the lining or cladding shall be within 20 percent plus or minus of the thickness to be used in construction.

(*2*) The requirements in Items V1 and V2 of Q-11 and QN-11 shall apply separately to the base plate and the lining or cladding. For material not included in Table Q-11.1, the material used in the test plate shall be within the range of chemical composition of that to be used in construction.

(*3*) The width of gap shall not be less than twice the nominal thickness of the lining or cladding and not less than the maximum gap to be used in construction but need not be greater than $^3/_4$ in. in order to qualify welding procedures in which corrosion resistant weld metal is deposited in contact with base metal and adjacent lining or cladding material on two sides of a gap, as in welding the joints in liner sheets or clad plates.

(*4*) The width of gap shall be not less than $^3/_4$ in. in order to qualify welding procedures in which corrosion resistant weld metal is deposited in contact with base metal with lining or cladding material on one side only, as in layering corrosion resistant weld metal on flange facings, or in making fillet welds.

(*5*) The weld joint shall be made between the edges of the lining or cladding material by the procedure to be used in construction. The cooling of the test plate and any subsequent heat treatment shall follow the procedure to be used in construction.

(*6*) The tests to qualify the welding procedure shall be performed on two longitudinal bend test specimens that conform to the dimensions and other requirements of Q-7 and Fig. Q-7.3 of Section IX. The specimens shall be tested in accordance with, and meet the requirements of Q-8.

UCL-44 Attachment of Applied Linings

(*a*) Applied linings may be attached to the base plate and other parts by any methods and processes of welding that are not excluded by the rules of this Division. The welding procedure to be used in attaching applied linings to base plates and the method of determining the security of the attachment shall be a matter for agreement between the user and the manufacturer.

(*b*) Each welding procedure to be used for attaching lining material to the base plate shall be qualified on lining-attachment welds made in the form and arrangement to be used in construction and with materials that are within the range of chemical composition of the material to be used, respectively, for the base plate, the linings, and the weld metal. Welds shall be made in each of the positions defined in Q-3 that are to be used in construction. One specimen from each position to be qualified shall be sectioned, polished, and etched to show clearly the demarcation between the fusion zone and the base metal. For the procedure to qualify, the specimen shall show, under visual examination without magnification, complete fusion in the fusion zone and complete freedom from cracks in the fusion zone, and in the heat affected metal.

UCL-45 Performance Qualification of Welders

(*a*) *General.* A welder who has passed a test on composite welds in clad plate as provided in (b) or as part of a procedure qualification test as provided in UCL-41(a), is qualified for welding base metal and lining or cladding material separately. Likewise, a welder who has qualified on base metal and lining or cladding material separately is qualified to make composite welds. Qualification on both base plate and lining or cladding material is required only of welders who weld both materials.

(*b*) *Composite Welds.* Performance qualification tests shall be made in accordance with Section IX by preparing test plates from clad material having the same P-numbers in Table Q-11.1 as that of the base plate and cladding material to be used in construction, and having the same F-number in Table Q-22 as the filler metal that will be used in construction. When the cladding material is not listed in Table Q-11.1, qualification shall be made on the same grade as used in the vessel. Heat treatment is not required but is permitted if the welder's work on construction is to be heat treated.

(*c*) *Corrosion Resistant Welds.* Performance qualification tests for welding corrosion resistant materials shall be the same as the procedure qualification tests described in UCL-40.

UCL-46 Fillet Welds

Fillet welds of corrosion resistant metal deposited in contact with two materials of dissimilar composition may be used for shell joints under the limitations of UW-12, for connection attachments under the limitations of UW-15 and UW-16, and for any other uses permitted by this Division. The qualification of the welding procedures and welders to be used on fillet welds for a given combination of materials and alloy weld metal shall be made in accordance with UCL-43, or alternatively by the rules prescribed in Section IX.

INSPECTION AND TESTS

UCL-50 General

The rules in the following paragraphs apply specifically to the inspection and testing of pressure vessels and vessel parts constructed of integrally clad plate and those having applied corrosion resistant linings and shall be used in conjunction with the general requirements for *Inspection and Tests* in Subsection A, and with the specific requirements for *Inspection and Tests* in Subsection B that pertain to the method of fabrication used.

UCL-51 Tightness of Applied Lining

A test for tightness of the applied lining that will be appropriate for the intended service is recommended, but the details of the test shall be a matter for agreement between the user and the manufacturer. The test should be such as to assure freedom from damage to the load carrying base plate. When rapid corrosion of the base plate is to be expected from contact with the contents of the vessel, particular care should be taken in devising and executing the tightness test.

Following the hydrostatic pressure test, the interior of the vessel shall be inspected to determine if there is any seepage of the test fluid through the lining. Seepage of the test fluid behind the applied lining may cause serious damage to the liner when the vessel is put in service. When seepage occurs, UA-173 shall be considered and the lining shall be repaired by welding. Repetition of the radiography, and heat treatment, or the hydrostatic test of the vessel after lining repairs, is not required except when there is reason to suspect that the repair welds may have defects that penetrate into the base plate, in which case the Inspector shall decide which one or more shall be repeated.

UCL-52 Hydrostatic Test

The requirements for standard hydrostatic test in UG-99 shall apply to pressure vessels fabricated in accordance with the rules of Part UCL.

STAMPING AND REPORTS

UCL-55 General

The provisions for stamping and reports in UG-115 through UG-120 shall apply to vessels that are constructed of integrally clad plates and those having applied corrosion resistant linings, with the following supplements to the data reports.

(*a*) Include specification and type of lining material.

(*b*) Include applicable paragraph in UCL-23 under which the shell and heads were designed.

PRESSURE RELIEF DEVICES

UCL-60 General

The provisions for pressure relief devices given in UG-125 through UG-134 shall apply without supplement to welded vessels that are constructed of integrally clad plate and those having applied corrosion resistant linings.

PART UCD

REQUIREMENTS FOR PRESSURE VESSELS CONSTRUCTED OF CAST DUCTILE IRON

GENERAL

UCD-1 Scope

The rules in Part UCD are applicable to pressure vessels and pressure vessel parts that are constructed of cast ductile iron,[1] and shall be used in conjunction with the general requirements in Subsection A and with the specific requirements in Part UR of Subsection B, *Requirements for Pressure Vessels Fabricated by Riveting,* insofar as these requirements are applicable to cast material.

UCD-2 Service Restrictions

Cast ductile iron pressure vessels or pressure vessel parts shall not be used to contain lethal[2] substances, either liquids or gases.

UCD-3 Pressure-Temperature Limitations

(*a*) The design pressure for pressure vessels and pressure vessel parts constructed of cast ductile iron of the type listed in Table UCD-23 shall not exceed 1000 psi nor shall the material be subjected to operating temperatures higher than 650 F nor less than —20 F.

(*b*) Cast ductile iron flanges and fittings conforming in dimension to the several American National Standards for carbon steel pipe flanges and flanged fittings given in ANSI B16.5-1968 may be used in whole or as a part of a pressure vessel for pressures not exceeding 80 percent of the American National Standard pressure ratings for carbon steel at their listed temperatures provided the temperature is not less than —20 F nor greater than 650 F and provided that the adjusted service pressure does not exceed 1000 psi.

NOTE: Cast ductile iron flanges and fittings conforming in dimension to the 125 and 250 pound American National Standard for cast iron flanges and fittings may be used in whole or as a part of a pressure vessel for pressures not exceeding 80 percent of the American National Standard pressure ratings for 150 and 300 pound carbon steel flanges and fittings respectively at their listed temperature provided the temperature is not less than —20 F nor greater than 650 F, except that the $3^1/_2$ in. and smaller screwed and lapped flanges conforming in dimensions to the 125 lb ANSI B16.1-1967 for cast iron flanged fittings, shall have identical ratings specified in ANSI B16.1-1967.

MATERIALS

UCD-5 General

All cast ductile iron material subject to stress due to pressure shall conform to the specifications given in Section II of the Code and shall be limited to the stress values listed in Table UCN-23 except as otherwise provided in UG-11.

UCD-12 Bolt and Rivet Materials

The requirements for bolts, rivet materials, nuts, and washers shall be the same as for carbon and low-alloy steels in UCS-10 and UCS-11.

DESIGN

UCD-16 General

The rules in the following paragraphs apply specifically to the design of pressure vessels and pressure vessel parts of cast ductile iron and shall be used in conjunction with the general requirements for *Design* in Subsection A and with the specific requirements for *Design* in Part UR, insofar as these requirements are applicable to cast materials.

UCD-23 Maximum Allowable Stress Values

Table UCD-23 gives the maximum allowable stress values at the temperatures indicated for castings conforming to the specification listed therein. These stress values shall be limited to the stress values in Table UCD-23 multiplied by the applicable casting quality factor given in UG-24.

[1]It is the intent that cast ductile irons with an elongation of less than 15 percent in 2 in. be treated as cast iron and that vessels or pressure parts of such material be designed and fabricated in accordance with the rules in Part UCI.

[2]By "lethal substances" are meant poisonous gases or liquids of such a nature that a very small amount of the gas or of the vapor of the liquid mixed or unmixed with air is dangerous to life when inhaled. For purposes of the Code this class includes substances of this nature which are stored under pressure or may generate a pressure if stored in a closed vessel. Some such substances are hydrocyanic acid, carbonyl chloride, cyanogen, mustard gas, and xylyl bromide. For design purposes under this Code, chlorine, ammonia, natural or manufactured gas, any liquefied petroleum gas (such as propane, butane, butadiene), and vapors of any other petroleum products are not classified as lethal substances.

UCD-28 Thickness of Shells Under External Pressure

(*a*) Cylindrical and spherical shells under external pressure shall be designed by the rules in UG-28 using Fig. UCD-28.

(*b*) Examples illustrating the use of charts similar to Fig. UCD-28 are given in Appendix L.

TABLE UCD-23
MAXIMUM ALLOWABLE STRESS VALUES IN TENSION FOR CAST DUCTILE IRON, PSI

Spec No.	Class	Note	Spec Min Tensile Strength[a]	For Metal Temp Not Exceeding Deg F −20 to 650
SA-395	....	(1)	60,000	12,000

[a] The yield stresses in compression and tension for cast ductile iron are not sufficiently different to justify an increase in the allowable stress for bending except as permitted in UA-50(a).

NOTES: (1) To these stress values, a quality factor as specified in UG-24 shall be applied.

UCD-32 Heads With Pressure on Concave Side

Heads with pressure on the concave side (plus heads) shall be designed in accordance with the formulas in UG-32.

UCD-33 Heads With Pressure on Convex Side

The thickness of heads with pressure on the convex side (minus heads) shall not be less than the thickness required in UG-33.

UCD-35 Spherically Shaped Covers (Heads)

(*a*) Circular cast ductile iron spherically shaped heads with bolting flanges, similar to Fig. UA-6(b), (c), and (d) shall be designed in accordance with the provisions in UA-6, except that corners and fillets shall comply with the requirements of UCD-37.

(*b*) Circular cast ductile iron spherically shaped heads with bolting flanges other than those described in (a) shall be designed in accordance with the following requirements:

(*1*) The head thickness shall be determined in accordance with the requirements in UG-32.

(*2*) The spherical and knuckle radii shall conform to the requirements in UG-32.

(*3*) Flanges made of cast ductile iron in compliance with SA-395 and conforming in dimensions to American National Standard for carbon steel given in ANSI B16.5-1968 may be used at pressures not exceeding 80 percent of the pressures permitted in those standards at their listed temperatures provided the temperature is not less than —20 F nor greater than 650 F and provided that the adjusted service pressure does not exceed 1000 psi.

NOTE: Cast ductile iron flanges conforming in dimension to the 125- and 250-lb American National Standard for cast iron flanges may be used for pressures not exceeding 80 percent of the American National Standard pressure ratings for 150- and 300-lb carbon steel flanges, respectively, at their listed temperatures provided the temperature is not less than —20 F nor greater than 650 F, except as in note to UCD-3(b).

UCD-36 Openings and Reinforcements

(*a*) The dimensional requirements in UG-36 through UG-46 are applicable to cast ductile iron and shall be used in the design of openings and reinforcements in pressure vessels and pressure vessel parts which are cast integrally with the vessel or vessel part. In no case shall the thickness of the reinforcement, including the actual thickness of the vessel wall, exceed twice the acutal thickness of the vessel wall.

(*b*) Cast ductile iron flanges, nozzles, and opening reinforcements may be attached to steel or nonferrous pressure vessels or pressure parts by the use of mechanical fastenings and may be considered to contribute strength to the vessel in compliance with UR-23, UR-24, and UR-25. They shall not be attached by welding or brazing.

(*c*) Cast ductile iron flanges, nozzles, and other pressure parts may be attached to cast iron pressure vessels or pressure vessel parts by the use of mechanical fastenings in compliance with UR-23, UR-24, and UR-25. They shall not be considered to contribute strength to the pressure vessel or pressure vessel part nor shall they be attached by welding or brazing.

UCD-37 Corners and Fillets

A liberal radius shall be provided at projecting edges and in reentrant corners in accordance with good foundry practice. Abrupt changes in surface contour and in wall thickness at junctures shall be avoided. Fillets shall conform to the following:

(*1*) Fillets forming the transition between the pressure containing walls and integral attachments such as brackets, lugs, supports, nozzles, flanges, and bosses shall have a radius not less than one-

half the thickness of the pressure containing wall adjacent to the attachment.

(2) Transitions between pressure containing walls of different contours shall have a radius not less than 3 times the thickness of the thinner wall.

FABRICATION

UCD-75 General

The rules in the following paragraphs apply specifically to the fabrication of pressure vessels and pressure vessel parts of cast ductile iron and shall be used in conjunction with the general requirements for *Fabrication* in Subsection A and with the specific requirements for *Fabrication* in Part UR, insofar as these requirements are applicable to cast materials.

UCD-78 Repair of Defects in Materials

(*a*) Imperfections in pressure vessels and pressure vessel parts that are to operate within the limitations of UCD-3(a) may be repaired by plugging, providing the following requirements are met:

(1) No welding is performed.

(2) The diameter of the plug shall not exceed the diameter of a standard 2 in. IPS pipe plug.

(3) The plugs where practical shall conform in all dimensions to standard IPS pipe plugs, and in addition they shall have full thread engagement corresponding to the thickness of the repaired section. Where a tapered plug is impractical because of excess wall thickness in terms of plug diameter and coincident thread engagement, other types of plugs may be used provided both full thread engagement and effective sealing against pressure are obtained. Where possible the ends of the plug should be ground smooth after installation to conform to the inside and outside contours of the walls of the pressure vessel or pressure part.

(4) The material from which the plug is manufactured shall conform in all respects to the materials specification which applies to the pressure vessel or pressure vessel part.

(5) The machined surface of the drilled or bored hole shall be free from visual defects and the adjacent metal shown to be sound by radiographic examination.

(6) The thickness of any repaired section in relation to the size of plug used shall not be less than that given in Table UCD-78.1.

(7) The minimum radius of curvature of repaired sections of cylinders or cones in relation to the size of plug used shall not be less than that given in Table UCD-78.2.

(8) A repaired area may consist of a maximum of three plugs with a spacing such that the ligaments between adjacent plugs shall not be less than listed in Table UCD-78.3. Other defective areas may also be repaired by plugging in the same manner provided the minimum ligament between plugs in adjacent areas is not less than twice the values listed in Table UCD-78.3.

TABLE UCD-78.1

IPS Plug or Equivalent, in.	Min. Thickness of Repaired Section, in.
1/8	11/32
1/4	7/16
3/8	1/2
1/2	21/32
3/4	3/4
1	13/16
1 1/4	7/8
1 1/2	15/16
2	1

(9) Surface imperfections in pressure vessels and pressure vessel parts that are to operate within the limitations given in UCD-3(a) may be repaired by plugging provided the depth of the plug is not greater than 20 percent of the thickness of the section and provided the diameter of the plug is not greater than its engaged length.

TABLE UCD-78.2

IPS Plug or Equivalent, In.	Minimum Radius of Curvature of Cylinder or Cone, in.
1/8	9/16
1/4	11/16
3/8	1 1/16
1/2	1 1/4
3/4	2
1	2 1/2
1 1/4	4
1 1/2	5 1/4
2	8 1/8

(10) The pressure vessel or pressure vessel part meets the standard hydrostatic test prescribed in UCD-99.

INSPECTION AND TESTS

UCD-90 General

The rules in the following paragraphs apply specifically to the inspection and testing of pressure vessels and pressure vessel parts of cast ductile iron and shall be used in conjunction with the general requirements of *Inspection and Tests* in Subsection A and the specific requirements for *Inspection and Tests* in Part UR, insofar as these requirements are applicable to cast material.

UCD-99 Standard Hydrostatic Test

Cast ductile iron pressure vessels and pressure vessel parts shall be hydrostatically tested by the method prescribed in UG-99 except that the test pressure shall be 2 times the maximum allowable working pressure.

UCD-101 Hydrostatic Test to Destruction

(*a*) The maximum allowable working pressure of identical cast ductile iron vessels, based on testing one of them to destruction in accordance with UG-101(m), shall be

$$P_R = \left(\frac{P_B f}{5}\right)\left(\frac{\text{Specified min. tensile strength}}{\text{Min. tensile str. of associated arbitration bar}}\right)$$

where

P_R = maximum allowable working pressure in pounds per square inch

P_B = destruction test pressure in pounds per square inch

f = casting quality factor as defined in UG-24

The principle of UG-101(c) shall be followed.

(*b*) All pressure vessels or pressure vessel parts of the same material, design, and construction, whose maximum allowable working pressure is based on the destruction test of a sample vessel or part, shall be subjected to a hydrostatic test pressure of not less than twice the maximum allowable working pressure determined by the application of the rules in (a).

TABLE UCD-78.3
MINIMUM LIGAMENT BETWEEN PLUGS[a]

IPS Plug or Equivalent, In.	1/8, 1/4, 3/8	1/2, 3/4	1, 1 1/4	1 1/2, 2
1/8, 1/4, 3/8	2 5/8	4 1/8	6 5/8	9 1/2
1/2, 3/4	4 1/8	4 1/8	6 5/8	9 1/2
1, 1 1/4	6 5/8	6 5/8	6 5/8	9 1/2
1 1/2, 2	9 1/2	9 1/2	9 1/2	9 1/2

[a] Based on a minimum efficiency of 80 percent.

STAMPING AND REPORTS

UCD-115 General

The provisions for stamping and preparing reports in UG-115 through UG-120 shall apply without supplement to vessels constructed in cast ductile iron.

PRESSURE RELIEF DEVICES

UCD-125 General

The provisions for the application of pressure-relief devices in UG-125 through UG-134 shall apply without supplement to vessels constructed of cast ductile iron.

PART UHT

REQUIREMENTS FOR PRESSURE VESSELS CONSTRUCTED OF FERRITIC STEELS WITH TENSILE PROPERTIES ENHANCED BY HEAT TREATMENT

GENERAL

UHT-1 Scope

The rules in Part UHT are applicable to pressure vessels and vessel parts that are constructed of ferritic steels suitable for welding, whose tensile properties have been enhanced by heat treatment, and shall be used in conjunction with the general requirements in Subsection A, and with the specific requirements in Part UW of Subsection B. The heat treatment may be applied to the individual parts of a vessel prior to assembly by welding, to partially fabricated components, or to an entire vessel after completion of welding. This part is not intended to apply to those steels approved for use under the rules of Part UCS but which are furnished in such thicknesses that heat treatment involving the use of accelerated cooling, including liquid quenching, is used to attain structures comparable to those attained by normalizing thinner sections. Integrally forged vessels, quenched and tempered, which do not contain welded seams, are not intended to be covered by the rules of this Part.

MATERIALS

UHT-5 General

(*a*) Steels covered by this Part subject to stress due to pressure shall conform to one of the specifications given in Section II and shall be limited to those listed in Table UHT-23.

The thickness limitations of the material specifications shall not be exceeded.

(*b*) Steels listed in Table UHT-23 may be used for the entire vessel or for individual components which are joined to other grades listed in that Table or to other steels conforming to specifications listed in Parts UCS or UHA of this Division when specifically permitted in this Part.

(*c*) All steels listed in Table UHT-23 shall be tested for notch ductility, as required by UHT-6. These ductility tests shall be conducted at the lowest temperature at which pressure will be applied to the vessel, or the design temperature, whichever is lower. For materials to be used in vessels containing fluids at temperatures governed by atmospheric conditions only and whose vapor pressure reduces with decreasing temperature, the impact tests may be made at the temperature corresponding with the vapor pressure obtained by dividing the vessel design pressure by $2^1/_2$. In no case shall the test temperature be higher than 32 F.

(*d*) All test specimens shall be prepared from the material in its final heat treated condition or from full-thickness samples of the same heat similarly and simultaneously treated. Test samples shall be of such size that the prepared test specimens are free from any change in properties due to edge effects.

(*e*) Where the vessel or vessel parts are to be hot formed or postweld heat treated (stress relieved), this identical heat treatment shall be applied to the test specimens required by the material specifications including the cooling rate specified by the fabricator which shall in no case be slower than that specified in Table UHT-56.

UHT-6 Test Requirements

(*a*) (*1*) A Charpy V-notch test (three specimens) shall be made for each plate as it is heat treated, and from each heat of bars, pipe, tubing, rolled sections, forged parts, or castings included in any one heat treatment lot.

(*2*) The location and orientation of the specimens shall be the same as required by UG-84, and, as applicably by Section II, Material Specifications, covering materials of the applicable product form for low temperature service except that the specimen shall be oriented as follows for the given product form:

Plates—transverse to final direction of rolling.
Circular Forgings—parallel to the circumference.
Pipe and Tube—longitudinal.

(*3*) Where the geometry permits, the Charpy tests shall be made on full-size specimens (10 × 10 mm) in accordance with Fig. UG-84. Where the geometry does not permit full size specimens to be taken, reduced-size specimens shall be used in which the dimension along the notch shall be largest possible of the following widths:

Fractional Width of Full-Size Specimens	Width, mm	Width, in.
$^3/_4$	7.50	0.296
$^2/_3$	6.67	0.263
$^1/_2$	5.00	0.197
$^1/_3$	3.33	0.131

(*4*) Each of the three specimens tested shall have a lateral expansion opposite the notch not less than 0.015 in. (15 mils).

The values of absorbed energy in foot pounds and of fracture appearance in percentage shear shall be recorded for information and these values shall be retained for a period of at least two years.

(*5*) If the value of lateral expansion for one specimen is below 0.015 in., but not below 0.010 in., a retest of three additional specimens may be made, each of which must equal or exceed the specified minimum value of 0.015 in. Such a retest shall be permitted only when the average value of the three specimens equals or exceeds 0.015 in. If the required values are not obtained in the retest or if the values in the initial test are below the minimum required for retest, the material may be reheat treated. After reheat treatment, a set of three specimens shall be made, each of which must equal or exceed the specified minimum value of 0.015 in.

(*b*) Materials conforming to Specification SA-517 and which are to be designed for minimum allowable temperature below −20 F shall have, in addition to the Charpy tests required under UHT-6(a), drop-weight tests as defined by ASTM E208-63T, Tentative Method for Conducting Drop-Weight Tests to Determine Nil Ductility Transition Temperatures of Ferritic Steels, made as follows:

(*1*) For plates $^5/_8$ in. thick and over, one drop-weight test (two specimens) shall be made for each plate as heat treated.

(*2*) For forgings and castings of all thicknesses one drop-weight test (two specimens) shall be made for each heat in any one heat treatment lot using the procedure in SA-350 for forgings and in SA-352 for castings.

(*3*) Each of the two test specimens shall meet the "no-break" criterion, as defined by ASTM E208-63T, at test temperature.

DESIGN

UHT-16 General

(*a*) The rules in the following paragraphs apply specifically to the design of pressure vessels and vessel parts that are constructed of heat treated steels covered by this Part and shall be used in conjunction with the general requirements for Design in Subsection A and in Subsection B, Part UW.

(*b*) *Thickness.* The minimum thickness after forming of any section subject to pressure shall be $^1/_4$ in., except as permitted by the footnotes in Table UHT-23.

UHT-17 Welded Joints

(*a*) In vessels or vessel parts constructed of heat treated steels covered by this part except as permitted in (b), all joints of categories A,B, and C, as defined in UW-3, and all other welded joints between parts of the pressure containing enclosure which are not defined by the category designation, shall be in accordance with Type No. (1) of Table UW-12. All joints of Category D shall be in accordance with Type No. (1) of Table UW-12 when the shell plate thickness is 2 in. or less (see Fig. UHT-18.1). When the thickness exceeds 2 in. the weld detail may be as permitted for nozzles in UHT-18 and Fig. UHT-18.2.

(*b*) For materials SA-333 Grade 8, SA-334 Grade 8, SA-353, SA-522, and SA-553 the joints of various Categories (see UW-3) shall be as follows:

(*1*) All joints of Category A shall be Type No. (1) of Table UW-12.

(*2*) All joints of Category B shall be Type No. (1) or No. (2) of Table UW-12.

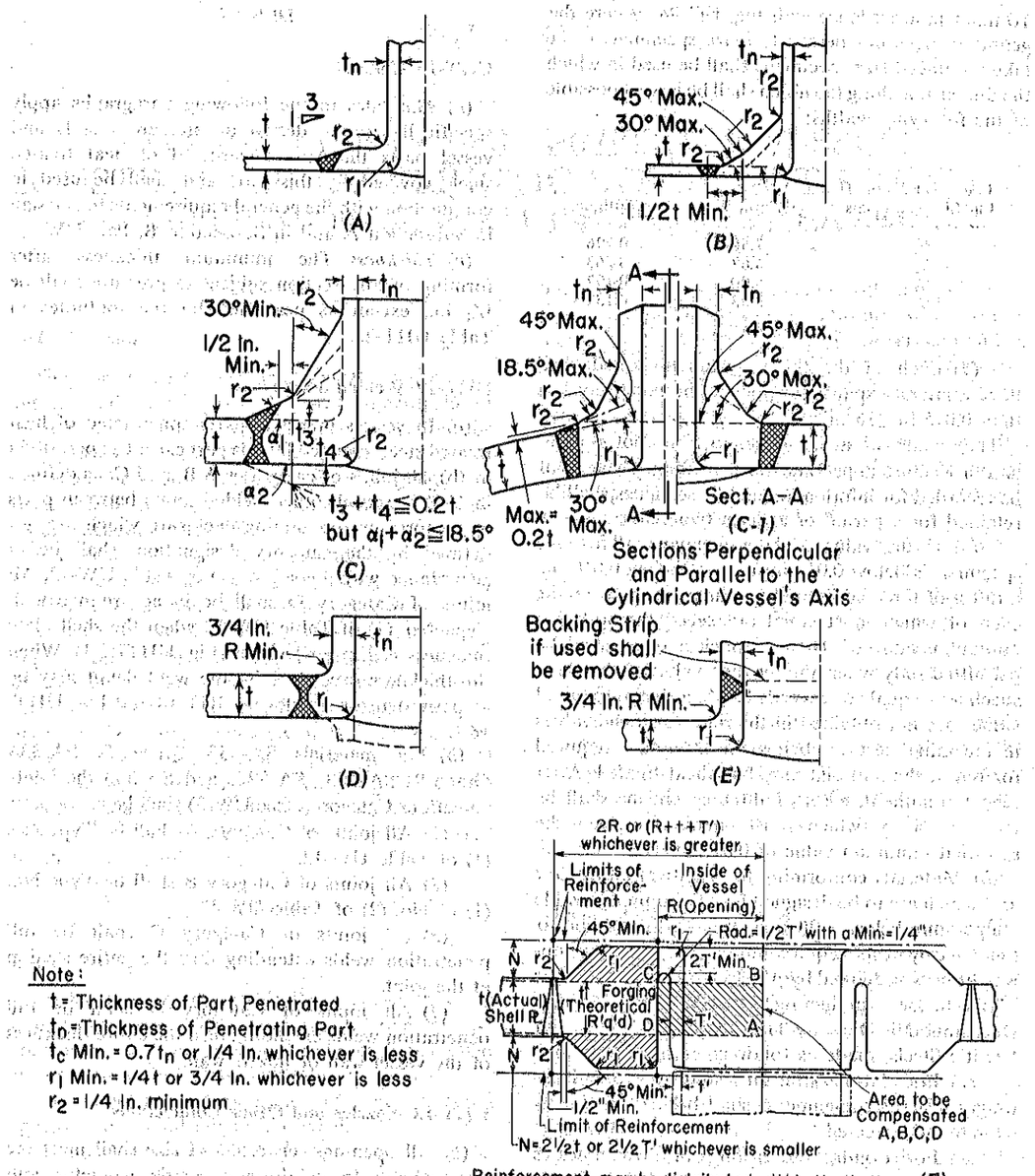
(*3*) All joints of Category C shall be full penetration welds extending thru the entire section at the joint.

(*4*) All joints of Category D shall be full penetration welds extending thru the entire thickness of the vessel wall or nozzle wall.

UHT-18 Nozzles and Other Connections

(*a*) All openings regardless of size shall meet the requirements for reinforcing, nozzle geometry, and nozzle attachments and shall conform to details shown in Figure UHT-18.1 or as shown in 18.2 when permitted by the provisions of UHT-17 or as shown in Figure UW-16.1 when permitted by the provisions of UHT-17(b).

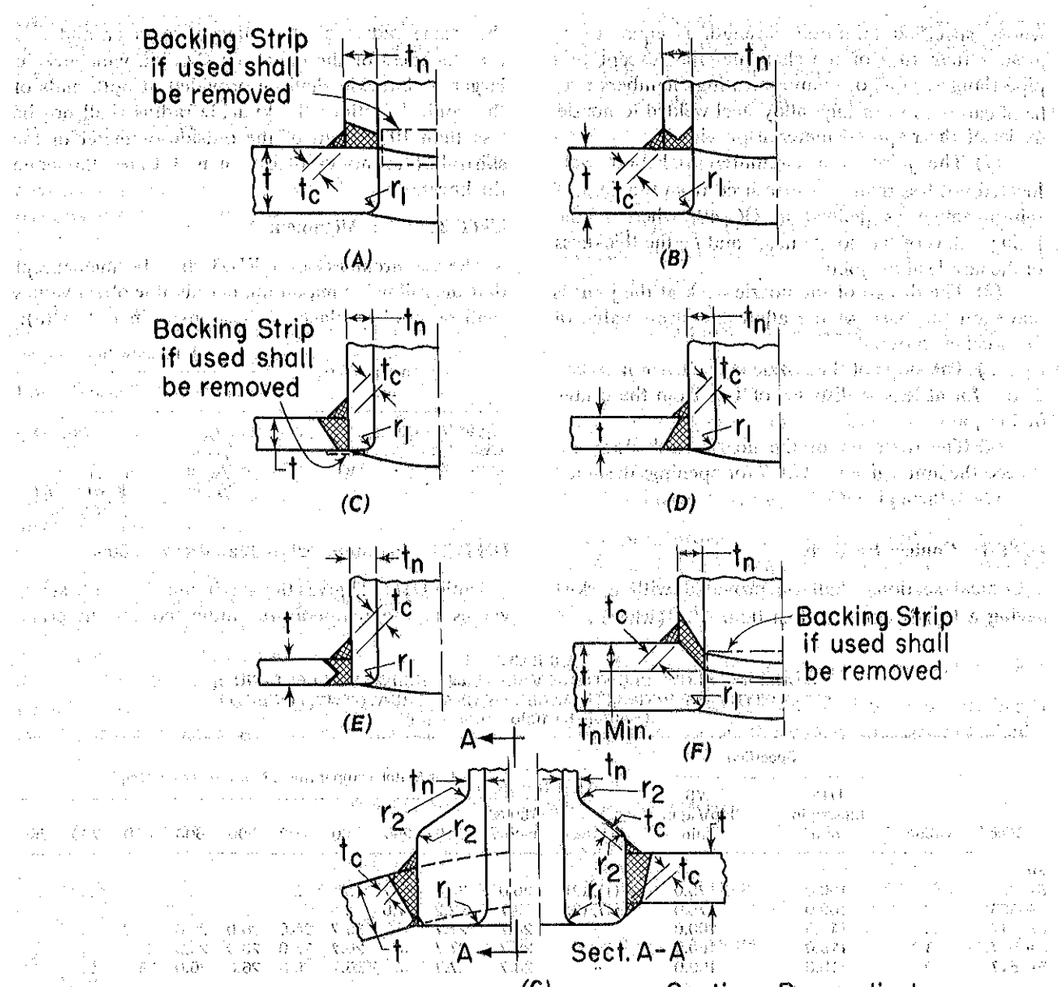
(*b*) All pressure parts shall be made of material



Note:

t = Thickness of Part Penetrated
t_n = Thickness of Penetrating Part
t_c Min. = $0.7t_n$ or 1/4 In. whichever is less
r_1 Min. = 1/4 t or 3/4 In. whichever is less
r_2 = 1/4 In. minimum

FIG. UHT-18.1 ACCEPTABLE WELDED NOZZLE ATTACHMENT READILY RADIOGRAPHED TO CODE STANDARDS



Note:

t = Thickness of Part Penetrated
t_n = Thickness of Penetrating Part
t_c Min. = $0.7t_n$ or 1/4 In. whichever is less
r_1 Min. = 1/4 t or 3/4 In. whichever is less
r_2 = 1/4 In. minimum

FIG. UHT-18.2 ACCEPTABLE FULL PENETRATION WELDED NOZZLE ATTACHMENTS RADIOGRAPHABLE WITH DIFFICULTY AND GENERALLY REQUIRING SPECIAL TECHNIQUES INCLUDING MULTIPLE EXPOSURES TO TAKE CARE OF THICKNESS VARIATIONS

whose specified minimum strength is equal to or greater than that of the shell material, except that pipe flanges, pipe, or communicating chambers may be of carbon, low or high-alloy steel welded to nozzle necks of the required material provided:

(*1*) The joint is a circumferential butt weld located not less than $\sqrt{rt}$ measured from the limit of reinforcement as defined in UG-40, where r=the inside radius of the nozzle neck, and t=the thickness of the nozzle at the joint.

(*2*) The design of the nozzle neck at the joint is made on the basis of the allowable stress value of the weaker material.

(*3*) The slope of the nozzle neck does not exceed 3 to 1 for at least a distance of $1.5t$ from the center of the joint.

(*4*) The diameter of the nozzle neck does not exceed the limits given in UA-7 for openings designed to UG-36 through UG-44.

UHT-19 Conical Sections

Conical sections shall be provided with a skirt having a length not less than $0.50\sqrt{rt}$ (where r is the inside radius of the adjacent cylinder and t is the thickness of the cone), or $1\frac{1}{2}$ in., whichever is larger. A knuckle shall be provided at both ends of the conical section; the knuckle radius shall not be less than 10 percent of the outside diameter of the skirt, but in no case less than 3 times the cone thickness.

UHT-20 Joint Alignment

The requirements of UW-33 shall be met except that the following maximum permissible offset values shall be used in place of those given in UW-33(a):

Section Thickness, in.	Joint Direction	
	Longitudinal	Circumferential
Up to $\frac{1}{2}$, incl.	$.2t$	$.2t$
Over $\frac{1}{2}$ to $\frac{15}{16}$, incl.	$\frac{3}{32}$ in.	$.2t$
Over $\frac{15}{16}$ to $1\frac{1}{2}$ incl.	$\frac{3}{32}$ in.	$\frac{3}{16}$ in.
Over $1\frac{1}{2}$	$\frac{3}{32}$ in.	lesser of $\frac{1}{8}t$ or $\frac{1}{4}$ in.

UHT-23 Maximum Allowable Stress Values

Table UHT-23 gives the maximum allowable stress values at the temperatures indicated for materials conforming to the specifications listed therein. Values may be interpolated for intermediate temperatures (see UG-23).

TABLE UHT-23
MAXIMUM ALLOWABLE STRESS VALUES IN TENSION FOR FERRITIC STEELS WITH PROPERTIES ENHANCED BY HEAT TREATMENT, in Kips/sq in.
(Multiply by 1000 to obtain psi)

Spec	Grade	Specified UTS kips/sq in. min	Specified YS kips/sq in. min	Notes	For Metal Temperatures Not Exceeding Deg F: 150 & below	200	250	300	400	500	600	650	700	750
Plates														
SA-353		100.0	75.0	(1), (2)	25.0	23.4	22.7	...	...	...	...	...	...	...
SA-353		100.0	75.0	(1), (3)	23.7	22.2	21.5	...	...	...	...	...	...	...
SA-517	A	115.0	100.0	...	28.7	27.7	...	26.7	26.0	26.0	26.0	25.0	...	...
SA-517	B	115.0	100.0	...	28.7	27.7	...	26.7	26.0	26.0	26.0	25.0	...	...
SA-517	D	115.0	100.0	...	28.7	27.7	...	26.7	26.0	26.0	26.0	25.0	...	...
SA-517	E	115.0	100.0	...	28.7	27.7	...	26.7	26.0	26.0	26.0	25.0	...	...
SA-517	F	115.0	100.0	...	28.7	27.7	...	26.7	26.0	26.0	26.0	25.0	...	...
SA-517	J	115.0	100.0	...	28.7	27.7	...	26.7	26.0	26.0	26.0	25.0	...	...
SA-553		100.0	85.0	(1), (2)	25.0	23.4	22.7	...	...	...	...	...	...	...
SA-553		100.0	85.0	(1), (3)	23.7	22.2	21.5	...	...	...	...	...	...	...
Pipes and Tubes														
SA-333	8	100.0	75.0	(1), (2)	25.0	23.4	22.7	...	...	...	...	...	...	...
SA-333	8	100.0	75.0	(1), (3)	23.7	22.2	21.5	...	...	...	...	...	...	...
SA-334	8	100.0	75.0	(1), (2)	25.0	23.4	22.7	...	...	...	...	...	...	...
SA-334	8	100.0	75.0	(1), (3)	23.7	22.2	21.5	...	...	...	...	...	...	...
Forgings														
SA-522		100.0	75.0	(2)	25.0	23.4	22.7	...	...	...	...	...	...	...
SA-522		100.0	75.0	(3)	23.7	22.2	21.5	...	...	...	...	...	...	...
SA-592	A	115.0	100.0	...	28.7	27.7	...	26.7	26.0	26.0	26.0	25.0	...	...
SA-592	E	115.0	100.0	...	28.7	27.7	...	26.7	26.0	26.0	26.0	25.0	...	...
SA-592	F	115.0	100.0	...	28.7	27.7	...	26.7	26.0	26.0	26.0	25.0	...	...

Notes: (1) Minimum thickness after forming any section subject to pressure shall be $\frac{3}{16}$ in.
(2) Nonwelded.
(3) Welded.

UHT-25 Corrosion Allowance

Provision for possible deterioration due to the environment in which the vessel operates is the responsibility of the designer.

UHT-27 Thickness of Shells Under External Pressure

Cylindrical and spherical shells under external pressure shall be designed by the rules in UG-28, using Fig. UHT-28.1 in Appendix V for SA-517 A, B, D, E, and F.

UHT-28 Structural Attachments and Stiffening Rings

(*a*) Except as permitted in (b) all structural attachments and stiffening rings which are welded directly to pressure parts shall be made of materials of specified minimum strength equal to or greater than that of the material to which it is attached.

(*b*) All permanent structural attachments welded directly to shells or heads constructed of materials conforming to SA-333 Grade 8, SA-334 Grade 8, SA-353, SA-522, and SA-553 shall be of the material covered by these specifications or austenitic stainless steel of the type which cannot be hardened by heat treatment. If suitable austenitic stainless steel is used for permanent attachments, consideration should be given to the greater coefficient of expansion of the austenitic stainless steel.

UHT-29 Stiffening Rings for Shells Under External Pressure

Rules covering the design of stiffening rings are given in UG-29. The design shall be based on the appropriate chart in this Division for the material used in the ring.

UHT-30 Attachment of Stiffening Rings to Shells

Rules covering the attachment of stiffening rings are given in UG-30. Attachments shall be made using a welding procedure qualified to Section IX of the Code for vessels constructed to Part UHT.

UHT-32 Formed Heads, Pressure on Concave Side

Except as provided in UG-32(e) and UA-4(c) and (d) formed heads shall be limited to ellipsoidal and/or hemispherical heads designed in accordance with UG-32(d) or (f).

UHT-33 Formed Heads, Pressure on Convex Side

Ellipsoidal, hemispherical, and conical heads having pressure on the convex side (minus heads)

TABLE UHT-56
POSTWELD HEAT TREATMENT REQUIREMENTS

Material	P-Number	Quench (Q) or Normalize (N)	Temper	Thickness Requiring PWHT, in.	Temp.	Holding Time hrs/in.	Holding Time min. hrs.	Cool Rate
SA-333 Gr8 or SA-334 Gr8	11A SG-1	1625-1700(N) plus 1425-1500(N)	1050-1125	Over 2	1025-1085	1	2	Note (1), (2)
SA-333 Gr8 or SA-334 Gr8	11A SG-1	1450-1525(Q)	1050-1125	Over 2	1025-1085	1	2	Note (1), (2)
SA-353	11A SG-1	1625-1700(N) 1425-1500(N)	1050-1125	Over 2	1025-1085	1	2	Note (1), (2)
SA-517 GrA or SA-592 GrA	11B SG-1	1650-1725(Q)	1150 min	Over 0.58	1000-1100	1	¼	Note (1)
SA-517 GrE or SA-592 GrE	11B SG-2	1650-1725(Q)	1150 min	Over 0.58	1000-1100	1	¼	Note (1)
SA-517 GrF or SA-592 GrF	11B SG-3	1650-1725(Q)	1150 min	Over 0.58	1000-1100	1	¼	Note (1)
SA-517 GrB	11B SG-4	1650-1725(Q)	1150 min	Over 0.58	1000-1100	1	¼	Note (1)
SA-517 GrD	11B SG-5	1650-1725(Q)	1150 min	Over 0.58	1000-1100	1	¼	Note (1)
SA-522	11A SG-1	1625-1700(N) 1425-1500(N)	1050-1125	Over 2	1025-1085	1	2	Note (1), (2)
SA-522	11A SG-1	1450-1525(Q)	1050-1125	Over 2	1025-1085	1	2	Note (1), (2)
SA-553 GrA	11A SG-1	1450-1525(Q)	1050-1125	Over 2	1025-1085	1	2	Note (1), (2)

NOTES:
(1) The maximum cooling rate required by UCS-56(e)(5) need not apply.
(2) If postweld heat treatment is used, the cooling rate shall not be less than 300°F per hour down to a temperature of 600°F.

shall be designed by the rules of UG-33, using Fig. UHT-28.1 in Appendix V for SA-517 A, B, D, E, and F.

UHT-34 Hemispherical Heads

When hemispherical heads are used, the head-to-shell transition of Fig. UW-13.1(1) or Fig. UW-13.1(n) shall be used. When the weld is in or adjacent to the tapered section, it shall be finished in a manner that will maintain the required uniform slope for the full length of the tapered section.

UHT-40 Materials Having Different Coefficients of Expansion

When welding materials with austenitic electrodes, the differences between the coefficients of expansion and the strengths of the base material and the weld metal should be carefully considered, particularly for applications involving cyclic stresses.

UHT-56 Postweld Heat Treatment

(*a*) Before applying the detailed requirements and exemptions in these paragraphs, satisfactory weld procedure qualifications of the procedures to be used shall be performed in accordance with all of the essential variables in Section IX of the Code including conditions of postweld heat treatment or lack of postweld heat treatment and including restrictions listed below.

(*b*) Vessels or vessel parts constructed of steels listed in Table UHT-23 shall be postweld heat treated when required in Table UHT-56.

(*c*) Postweld heat treatment shall be performed in accordance with UCS-56 as modified by the requirements of Table UHT-56.

(*d*) All welding of connections and attachments shall be postweld heat treated whenever required by Table UHT-56 based on the greatest thickness of material at the point of attachment of the head or shell (see UHT-56(b) and (c)).

(*e*) When materials of Specifications SA-333 Grade 8, SA-334 Grade 8, SA-353, SA-522, and SA-553 are postweld heat treated, the complete vessel or vessel component being so heat treated shall be maintained within the permissible temperature range defined in Table UHT-56.

UHT-57 Examination

(*a*) *Radiography.* Complete radiographic examination in accordance with the requirements of UW-51 is required for all welded joints of Type No. (1) of Table UW-12.

(*b*) *Nozzle Attachment Welds.* Nozzle attachment welds as provided for in UHT-18, Figs. UHT-18.1 and 18.2, shall be radiographically examined in accordance with the requirements of UW-51, except that Fig. UHT-18.2 type nozzles having an inside diameter of 2 in. or less shall be examined by a magnetic particle or liquid penetrant method. For nozzle attachments illustrated as (a), (b), and (f) of Fig. UHT-18.2 the exposed cross section of the vessel wall at the opening shall be included in the examination.

(*c*) *Magnetic Particle Method.* All welds, including welds for attaching nonpressure parts to heat treated steels covered by this Part, shall be examined by the magnetic particle method after the hydrostatic test, except that those surfaces not accessible after the hydrostatic test shall be examined by the magnetic particle method at the last feasible stage of vessel fabrication. A magnetization method shall be used that will avoid arc strikes. Cracks and cracklike defects shall be repaired or removed.

(*d*) *Liquid Penetrant Method.* As an acceptable alternative to magnetic particle examination or when magnetic particle methods are not feasible because of the nonmagnetic character of the weld deposits, a liquid penetrant method shall be used. Cracks and cracklike defects are unacceptable and shall be repaired or removed.

FABRICATION

UHT-75 General

The rules in the following paragraphs apply specifically to the fabrication of pressure vessels and vessel parts that are constructed of heat treated steels covered by this Part and shall be used in conjunction with the general requirements for fabrication in Subsection A, and, when applicable, with the specific requirements for Fabrication in Subsection B, Part UW.

UHT-79 Forming Shell Sections and Heads

(*a*) The selected thickness of material shall be such that the forming processes will not reduce the thickness of the material at any point below the minimum value required by the rules.

(*1*) Pieces that are formed after heat treatment at a temperature lower than the final tempering shall be postheat treated in accordance with Table UHT-56 when the extreme fiber strain from forming

exceeds 3 percent as determined by the following formula:

$$\text{Percent strain} = \frac{65t}{R_f}\left(1 - \frac{R_f}{R_o}\right)$$

t = plate thickness
R_f = final radius
R_o = original radius (equals infinity for flat plate)

(*2*) Pieces that are formed at temperatures equal to or higher than the original tempering shall be reheat treated in accordance with Table UHT-56 either before or after welding into the vessel.

UHT-80 Heat Treatment

(*a*) *Heating Furnace.* Furnaces for heating, for quenching, for normalizing, and for tempering shall be provided with suitable equipment for the automatic recording of temperatures. The temperature of the vessel or vessel part during the holding period shall be recorded and shall be controlled within plus or minus 25 F.

(*b*) Liquid quenching of flat plates and individual parts shall be done as required by the applicable material specifications.

(*c*) Formed plates for shell sections and heads may be quenched by sprays or immersion.

(*d*) Entire vessels, after completion of all welding operations, may be quenched by sprays or immersion.

(*e*) The design and operation of spray equipment and the size of tanks and provision for forced circulation shall be such as to produce a severity of quench in the quenched item sufficient to meet, in representative test specimens after tempering, the requirements of the materials specifications.

UHT-81 Heat Treatment Verification Tests

(*a*) Tests shall be made to verify that the heat treatments, and subsequent thermal treatments, performed by the fabricator have produced the required properties.

(*b*) One or more test coupons representative of the material and the welding in each vessel or vessel component shall be heat treated with the vessel or vessel component.

The requirements of (c) and (d), below, are to be taken as minimum steps toward these objectives.

(*c*) (*1*) One or more test coupons from each lot of material in each vessel (see UHT-81(d)) shall be quenched with the vessel or vessel component. A lot is defined as material from the same melt, quenched or normalized simultaneously and whose thicknesses are within plus or minus 20 percent or $^1/_2$ in. of nominal thickness, whichever is smaller. The test coupons shall be so proportionated that tensile and impact tests may be taken from the same locations relative to thickness as are required by the applicable material specifications. Weld metal tests shall be taken from the same locations relative to thickness as are required by the materials specifications for plates used in the component to be treated. The gage length of tensile specimens and the middle third of the length of impact specimens must be located at a minimum distance of $1 \times t$ from the quenched edge and/or end of the test coupon, where t is the thickness of the material which the test coupon represents. If desired, the effect of this distance may be achieved by temporary attachment of suitable thermal buffers. The effectiveness of such buffers shall be demonstrated by tests.

(*2*) In cases where the test coupon is not attached to the part being treated, it shall be quenched from the same heat treatment charge and under the conditions as the part which it represents. It shall be so proportioned that test specimens may be taken from the locations prescribed in (1).

(*d*) *Tempering*

(*1*) *Attached Test Coupons.* The test coupons shall remain attached to the vessel or vessel component during tempering, except that any thermal buffers may be removed after quenching. After the tempering operation and after removal from the component, the coupon shall be subjected to the same thermal treatment(s), if any, to which the vessel or vessel component will be later subjected. The holding time at temperature shall not be less than that applied to the vessel or vessel component (except that the total time at each temperature may be applied in one heating cycle) and the cooling rate shall be no faster.

(*2*) *Separate Test Coupons.* Test coupons which are quenched separately as described in (c)(2) shall be tempered similarly and simultaneously with the vessel or component which they represent. The conditions for subjecting the test coupons to subsequent thermal treatment(s) shall be as described in (c)(1).

(*e*) *Number of Tests*

One tensile test and one impact test shall be made on material from coupons representing each lot of material in each vessel or vessel component heat treated. A lot is defined as material from the same melt quenched simultaneously and whose thicknesses are within plus or minus 20 percent, or $^1/_2$ in., of nominal thickness, whichever is smaller.

(*1*) Coupons not containing welds shall meet

the complete tensile requirements of the material specification and impact requirements of this part.

(2) Coupons containing weld metal shall be tested across the weld and shall meet the ultimate tensile strength requirements of the material specifications; in addition, the minimum impact requirements shall be met by samples with notches in the weld metal. The form and dimension of the tensile test specimen shall conform to Fig. Q-6 (c) of Section IX. Yield strength and elongation are not a requirement of this test. Charpy impact testing shall be in accordance with the requirements of UHT-6.

UHT-82 Welding

(a) The qualification of the welding procedure and the welders shall conform to the requirements of Section IX.

(b) Filler metal containing more than 0.08 vanadium shall not be used for weldments subject to post heat treatment.

(c) For welded vessels, the welds of which are not subject to quenching or normalizing followed by tempering, the deposited weld metal and the heat affected zone shall meet the impact test requirements of UC-84 except that the Charpy V-notch tests and requirements of UHT-6(a) shall apply.

UHT-83 Methods of Metal Removal

(a) Plate edges, welding bevels, chamferring and other operations involving the removal of metal shall be by machining, chipping, or grinding except as provided in (b).

(b) When metal removal is accomplished by methods involving melting, such as gas cutting or arc-air gouging, etc., it shall be done with due precautions to avoid cracking. Where the cut surfaces are not to be subsequently eliminated by fusion with weld deposits, they shall be removed by machining or grinding to a depth of at least 1/16 in. followed by inspection by magnetic particle or liquid penetrant methods.

CAUTIONARY NOTE: The properties of the base metal may be adversely affected by excessive local heat inputs.

UHT-84 Weld Finish

The requirements of UW-35(a) and UW-51(b) shall be met except that for SA-517 material the maximum weld reinforcement shall not exceed 10 percent of the plate thickness or 1/8 in., whichever is less. The edge of the weld deposits shall merge smoothly into the base metal without undercuts or abrupt transitions; this requirement shall apply to fillet and groove welds as well as to butt welds.

UHT-85 Structural and Temporary Welds

(a) Welds for pads, lifting lugs and other nonpressure parts, as well as temporary lugs for alignment, shall be made by qualified welders in full compliance with a qualified welding procedure.

(b) Temporary welds shall be removed and the metal surface shall be restored to a smooth contour. The area shall be inspected by magnetic powders or penetrant oil for the detection and elimination of cracks or cracklike defects. If repair welding is required, it shall be in accordance with qualified procedures, and the finished weld surface shall be inspected as required in UHT-57(b) or (c). Temporary welds and repair welds shall be considered the same as all other welds so far as requirements for qualified operators and procedures and for heat treatment are concerned.

UHT-86 Marking on Plates and Other Materials

Any steel stamping shall be done with "low stress" stamps, as commercially available. Steel stamping of all types may be omitted on material below 1/2 in. in thickness. Other markings used in lieu of stamping to identify material shall be legible on the completed vessel until final acceptance by the authorized inspector.

INSPECTION AND TESTS

UHT-90 General

The provisions for inspection and testing in Subsections A and B shall apply to vessels and vessel parts constructed of steels covered by this Part.

STAMPING AND REPORTS

UHT-115 General

The provisions for stamping and reports in UG-115 through UG-120 shall apply to pressure vessels constructed in whole or in part of steels covered

by this Part, except that the use of nameplates is mandatory for shell thicknesses below 1/2 in. Nameplates are perferred on vessels constructed of steels covered by this Part in all thicknesses in preference to stamping. In addition to the required marking the letters UHT shall be applied below the "U" symbol.

PRESSURE RELIEF DEVICES

UHT-125 General

The provisions for pressure relief devices in UG-125 through UG-134 shall apply without supplement to pressure vessels constructed in whole or in part of steels covered by this Part.

MANDATORY APPENDICES

APPENDIX I
SUPPLEMENTARY DESIGN FORMULAS

UA-1 Thickness of Cylindrical and Spherical Shells

(a) The following formulas, in terms of the outside radius, are equivalent to and may be used instead of those given in UG-27(c) and (d):

(1) For cylindrical shells

$$t=\frac{PR_o}{SE+0.4P} \quad \text{or} \quad P=\frac{SEt}{R_o-0.4t}$$

where R_o = outside radius of the shell course under consideration, inches

(2) For spherical shells

$$t=\frac{PR_o}{2SE+0.8P}$$

$$P=\frac{2SEt}{R_o-0.8t}$$

Other symbols are as defined in UG-27.

UA-2 Thick Cylindrical Shells

(a)(1) Circumferential Stress Longitudinal Joints). When the thickness of the cylindrical shell under internal pressure exceeds one-half of the inside radius, or when P exceeds 0.385 SE, the following formulas shall apply:

When P is known and t is desired:

$$t=R(Z^{1/2}-1)=R_o\frac{(Z^{1/2}-1)}{Z^{1/2}}$$

where $Z=\frac{SE+P}{SE-P}$

Where t is known and P is desired:

$$P=SE\left(\frac{Z-1}{Z+1}\right)$$

where $Z=\left(\frac{R+t}{R}\right)^2=\left(\frac{R_o}{R}\right)^2=\left(\frac{R_o}{R_o-t}\right)^2$

(2) Longitudinal Stress (Circumferential Joints). When the thickness of the cylindrical shell under internal pressure exceeds one-half of the inside radius, or when P exceeds 1.25 SE, the following formulas shall apply:

When P is known and t is desired:

$$t=R(Z^{1/2}-1)=R_o\left(\frac{Z^{1/2}-1}{Z^{1/2}}\right)$$

where $Z=\left(\frac{P}{SE}+1\right)$

when t is known and P is desired:

$$P=SE(Z-1)$$

where $Z=\left(\frac{R+t}{R}\right)^2=\left(\frac{R_o}{R}\right)^2=\left(\frac{R_o}{R_o-t}\right)^2$

Symbols are as defined in UG-27 and UA-1.

UA-3 Thick Spherical Shells

When the thickness of the shell of a wholly spherical vessel or of a hemispherical head under internal pressure exceeds 0.356R, or when P exceeds 0.665 SE, the following formulas shall apply:

When P is known and t is desired:

$$t=R(Y^{1/3}-1)=R_o\left(\frac{Y^{1/3}-1}{Y^{1/3}}\right)$$

where $Y=\frac{2(SE+P)}{2SE-P}$

When t is known and P is desired:

$$P=2SE\left(\frac{Y-1}{Y+2}\right)$$

where $Y=\left(\frac{R+t}{R}\right)^3=\left(\frac{R_o}{R_o-t}\right)^3$

Symbols are as defined in UG-27 and UA-1.

UA-4 Formulas for the Design of Formed Heads Under Internal Pressure

(a) The formulas of this paragraph provide for the design of formed heads of proportions other than those given in UG-32, in terms of inside and outside diameter.

(b) The symbols defined below are used in the formulas of this paragraph (see Fig. UA-4):

t = minimum required thickness of head after forming, inches (exclusive of corrosion allowance, see UG-25)

P = design pressure, pounds per square inch (see UG-21) (or maximum allowable working pressure for existing vessels, see UG-98)

D = inside diameter of the head skirt; or inside length of the major axis of an ellipsoidal head; or inside diameter of a cone head at the point under consideration measured perpendicular to the longitudinal axis; inches (measurements to be taken before corrosion allowance is added)

D_o = outside diameter of the head skirt; or outside length of the major axis of an ellipsoidal head; or outside diameter of a cone head at the point under consideration measured perpendicular to the longitudinal axis, inches

S = maximum allowable working stress, as given in Subsection C, pounds per square inch except as limited by Footnote 1 to UA-4(c) and (d)

E = lowest efficiency of any joint in the head (for hemispherical heads this includes head-to-shell joint)

For welded vessels, use the efficiency specified in UW-12

For riveted joints, use the efficiency specified in UR-15

For seamless heads, use $E=1$ except for hemispherical heads furnished without a skirt, in which case the head to shell joint must be considered

r = inside knuckle radius, inches

L = inside spherical or crown radius for torispherical and hemispherical heads, inches

$L=K_1D$ for ellipsoidal heads in which K_1 is obtained from Table UG-37, inches

L_o = outside spherical or crown radius, inches

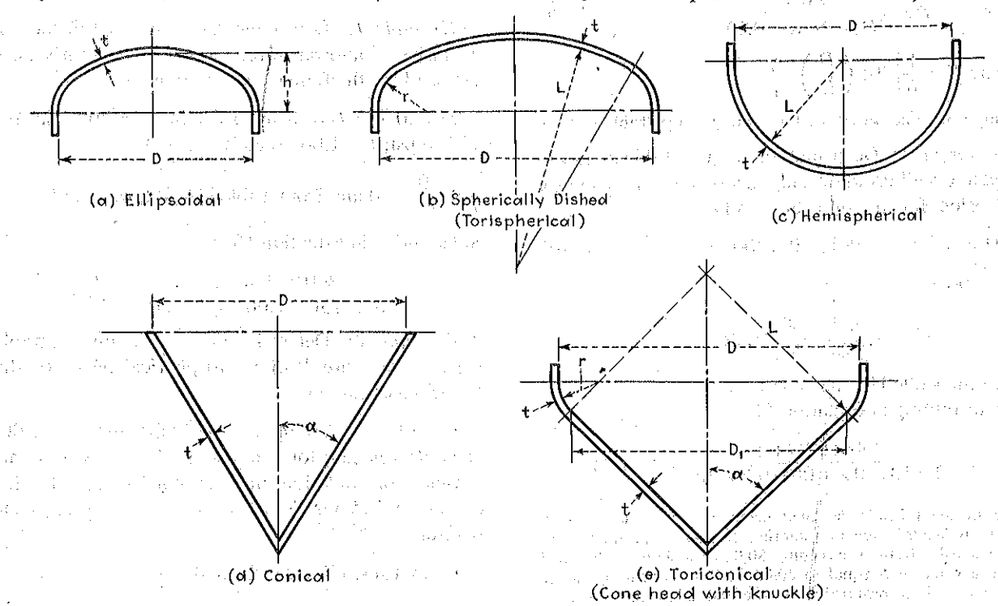


FIG. UA-4 PRINCIPAL DIMENSIONS OF TYPICAL HEADS

$\frac{L}{r}$ = ratio of the inside crown radius to the inside knuckle radius, used in Table UA-4.2

M = a factor in the formulas for torispherical heads depending on the head proportion, L/r

h = one-half of the length of the minor axis of the ellipsoidal head, or the inside depth of the ellipsoidal head measured from the tangent line (head-bend line), inches

K = a factor in the formulas for ellipsoidal heads depending on the head proportion, $D/2h$

$\frac{D}{2h}$ = ratio of the major to the minor axis of ellipsoidal heads, which equals the inside diameter of the skirt of the head divided by twice the inside height of the head, and is used in Table UA-4.1

α = one-half of the included (apex) angle of the cone at the centerline of the head

(c) Ellipsoidal Heads [1]

$$t=\frac{PDK}{2SE-0.2P} \text{ or } P=\frac{2SEt}{KD+0.2t} \quad (1)$$

$$t=\frac{PD_oK}{2SE+2P(K-0.1)} \text{ or}$$

$$P=\frac{2SEt}{KD_o-2t(K-0.1)} \quad (2)$$

where $K=\frac{1}{6}\left[2+\left(\frac{D}{2h}\right)^2\right]$

Numerical values of the factor K are given in Table UA-4.1.

Example 1: Determine the required thickness t of a seamless ellipsoidal head, exclusive of provision for corrosion, for the following conditions:

$D=40$ in; $h=9$ in; $P=200$ psi; $S=13{,}750$ psi; $E=1.00$

$$\frac{D}{2h}=\frac{40}{18}=2.22$$

From Table UA-4.1, $K=1.14$
Substituting in Equation (1)

$$t=\frac{200\times40\times1.14}{2\times13750\times1.00-0.2\times200}=0.33 \text{ in.}$$

[1] Ellipsoidal heads designed using $K>1.0$ and all torispherical heads made of materials having a specified minimum tensile strength exceeding 80,000 psi shall be designed using a value of S equal to 20,000 psi at room temperature and reduced in proportion to the reduction in maximum allowable stress values at temperature for the material as shown in the appropriate table of Subsection C.

Example 2: Determine the maximum allowable working pressure P of a seamless ellipsoidal head for the following conditions:

$D=30$ in.; $h=7.5$ in.; total thickness $=\frac{1}{2}$ in. with no allowance for corrosion; material conforms to Specification SA-285 Grade C; maximum operating temperature $=800$ F; $E=1.00$.

From Table UCS-23, $S=10{,}200$ psi

$$\frac{D}{2h}=\frac{30}{15}=$$

From Table UA-4.1, $K=1.0$
Substituting in Equation (1)

$$P=\frac{2\times10{,}200\times1.0\times0.5}{1\times30+0.2\times0.5}=339 \text{ psi}$$

(d) Torispherical Heads [1]

$$t=\frac{PLM}{2SE-0.2P} \text{ or } P=\frac{2SEt}{LM+0.2t} \quad (3)$$

$$t=\frac{PL_oM}{2SE+P(M-0.2)} \text{ or}$$

$$P=\frac{2SEt}{ML_o-t(M-0.2)} \quad (4)$$

where $M=\frac{1}{4}\left(3+\sqrt{\frac{L}{r}}\right)$

Numerical values of the factor M are given in Table UA-4.2.

Example 1: Determine the required thickness t, exclusive of allowance for corrosion, of a torispherical head for the following conditions:

$D=40$ in.; $L=40$ in.; $r=4$ in.; $P=200$ psi; $S=13750$ psi; $E=1.00$ (seamless head)

$\frac{L}{r}=\frac{40}{4}=10$ and from Table UA-4.2, $M=1.54$

Substituting in Equation (3):

$$t=\frac{200\times40\times1.54}{2\times13750\times1.00-0.2\times200}=0.45 \text{ in.}$$

Example 2: Determine the maximum allowable working pressure P of a torispherical head for the following conditions:

$D=30$ in.; $L=24$ in.; $r=2.00$ in.; $E=1.00$. (Seamless head); total thickness $=0.5$ in. with no allowance for corrosion; material conforms to Specification SA-515 Grade 70; maximum operating temperature $=900$ F.

From Table UCS-23, $S=6500$ psi

$$\frac{L}{r}=\frac{24}{2.00}=12.0$$

TABLE UA-4.1
VALUES OF FACTOR K
(Use nearest value of $D/2h$; interpolation unnecessary)

$\frac{D}{2h}$	3.0	2.9	2.8	2.7	2.6	2.5	2.4	2.3	2.2	2.1	2.0
K	1.83	1.73	1.64	1.55	1.46	1.37	1.29	1.21	1.14	1.07	1.00
$\frac{D}{2h}$	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1.0	
K	0.93	0.87	0.81	0.76	0.71	0.66	0.61	0.57	0.53	0.50	

TABLE UA-4.2
VALUES OF FACTOR M
(Use nearest value of L/r; interpolation unnecessary)

$\frac{L}{r}$	1.0	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00	3.25	3.50
M	1.00	1.03	1.06	1.08	1.10	1.13	1.15	1.17	1.18	1.20	1.22
$\frac{L}{r}$	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0
M	1.25	1.28	1.31	1.34	1.36	1.39	1.41	1.44	1.46	1.48	1.50
$\frac{L}{r}$	9.5	10.00	10.5	11.0	11.5	12.0	13.0	14.0	15.0	16.0	$16\frac{2}{3}$ *
M	1.52	1.54	1.56	1.58	1.60	1.62	1.65	1.69	1.72	1.75	1.77

* Maximum ratio allowed by UG-32(j) when L equals the outside diameter of the skirt of the head.

From Table UA-4.2, $M=1.62$
Substituting in Equation (3):

$$P=\frac{2\times6500\times1.0\times0.5}{24\times1.62+0.2\times0.5}=167 \text{ psi}$$

(e) Conical Heads

$$t=\frac{PD}{2\cos\alpha\,(SE-0.6P)} \text{ or}$$

$$P=\frac{2SEt\cos\alpha}{D+1.2t\cos\alpha} \quad (5)$$

$$t=\frac{PD_o}{2\cos\alpha\,(SE+0.4P)} \text{ or}$$

$$P=\frac{2SEt\cos\alpha}{D_o-0.8t\cos\alpha} \quad (6)$$

UA-5 Rules for Reducer Sections and Conical Heads Under Internal Pressure

(a) The formulas of (b) and (c) provide for the design of reinforcement, if needed, at the cone-to-cylinder junctions for reducer sections and conical heads where all the elements have a common axis and the half-apex angle $\alpha \leqq 30°$. Subparagraph (e) provides for special analysis in the design of cone-to-cylinder intersections with or without reinforcing rings where α is greater than 30 deg.

The symbols defined below are used in the formulas of the following subparagraphs:

t = minimum required thickness of cylinder at cone-to-cylinder junction, exclusive of corrosion allowance (see UG-27(c)), inches

t_s = nominal thickness of cylinder at cone-to-cylinder junction, exclusive of corrosion allowance (see UG-25), inches

t_c = nominal thickness of cone at cone-to-cylinder junction, exclusive of corrosion allowance (see UG-25), inches

t_e = the smaller of (t_s-t) or $[t_c-(t/\cos\alpha)]$, inches

R_s = inside radius of small cylinder, inches

R_L = inside radius of large cylinder, inches

A = required area of reinforcement, square inches

A_e = effective area of reinforcement due to excess metal thickness, square inches

Δ = value to indicate need for reinforcement at

cone-to-cylinder intersection having a half-apex angle $\alpha \leqq 30°$. When $\Delta \geqq \alpha$, no reinforcement at the junction is required (see Tables UA-5.1 and UA-5.2)

m = the smaller of $\left[\frac{t_s}{t}\cos(\alpha-\Delta)\right]$ or $\left[\frac{t_o \cos\alpha \cos(\alpha-\Delta)}{t}\right]$

E = lowest efficiency of the longitudinal joint in the shell or head or of the joint in the reinforcement ring. For the large end of the reducer in compression $E=1$ for butt welds

P, S and α are as defined in UA-4(b)

(b) Reinforcement shall be provided at the junction of the cone with the large cylinder for conical heads and reducers without knuckles when the value of Δ obtained from Table UA-5.1, using the appropriate ratio P/SE, is less than α. Interpolation may be made in the table.

TABLE UA-5.1
VALUES OF Δ FOR JUNCTIONS AT THE LARGE CYLINDER FOR $\alpha \leqq 30$ deg

P/SE	0.001	0.002	0.003	0.004	0.005
Δ, deg	11	15	18	21	23
P/SE	0.006	0.007	0.008	0.009*	
Δ, deg	25	27	28.5	30	

*Δ = 30 deg for greater values of P/SE.

The cross-sectional area of the reinforcement ring shall be at least equal to that indicated by the following formula:

$$A=\frac{PR_L^2}{2SE}\left(1-\frac{\Delta}{\alpha}\right)\tan\alpha \qquad (1)$$

When the thickness, less corrosion allowance, of both the reducer and cylinder exceeds that required by the applicable design formulas, the minimum excess thickness may be considered to contribute to the required reinforcement ring in accordance with the following formula:

$$A_o=4t_o\sqrt{R_L t_s} \qquad (2)$$

Any additional area of reinforcement which is required shall be situated within a distance of $\sqrt{R_L t_s}$ from the junction of the reducer and the cylinder. The centroid of the added area shall be within a distance of $0.5\sqrt{R_L t_s}$ from the junction.

(c) Reinforcement shall be provided at the junction of the conical shell of a reducer without a flare and the small cylinder when the value of Δ obtained from Table UA-5.2, using the appropriate ratio P/SE, is less than α.

TABLE UA-5.2
VALUES OF Δ FOR JUNCTIONS AT THE SMALL CYLINDER FOR $\alpha \leqq 30$ deg

P/SE	0.002	0.005	0.010	0.02
Δ, deg	4	6	9	12.5
P/SE	0.04	0.08	0.10	0.125*
Δ, deg	17.5	24	27	30

*Δ = 30 deg for greater values of P/SE.

The cross-sectional area of the reinforcement ring shall be at least equal to that indicated by the following formula:

$$A=\frac{PR_s^2}{2SE}\left(1-\frac{\Delta}{\alpha}\right)\tan\alpha \qquad (3)$$

When the thickness, less corrosion allowance, of either the reducer or cylinder exceeds that required by the applicable design formula, the excess thickness may be considered to contribute to the required reinforcement ring in accordance with the following formula:

$$A_o=m\sqrt{R_s t}\ \{(t_o-t/\cos\alpha)+(t_s-t)\} \qquad (4)$$

Any additional area of reinforcement which is required shall be situated within a distance of $\sqrt{R_s t_s}$ from the junction, and the centroid of the added area shall be within a distance of $0.5\sqrt{R_s t_s}$ from the junction.

(d) Reducers not described in UG-36(e) (5), such as those made up of two or more conical frustums having different slopes, may be designed in accordance with subsection (e).

(e) When the half-apex angle α is greater than 30 deg, cone-to-cylinder junctions without a knuckle may be used, with or without reinforcing rings, if the design is based on special analysis, such as the beam-on-elastic-foundation analysis of Timoshenko, Hetenyi, or Watts and Lang. See U-2(g). When such an analysis is made, the calculated localized stresses at the discontinuity shall not exceed the following values:

(1) (membrane hoop stress) + (average discontinuity hoop stress) shall not be greater than 1½ SE,

(2) (membrane longitudinal stress) + (discontinuity longitudinal stress due to bending) shall not be greater than $4SE$, where the "average discontinuity hoop stress" is the average hoop stress across the wall thickness due to the discontinuity at the junction, disregarding the effect of Poisson's ratio times the longitudinal stress at the surfaces.

The angle joint (see UA-60(o)) between the cone and cylinder shall be designed equivalent to a double butt-welded joint, and because of the high bending stress, there shall be no weak zones around the angle joint. The thickness of the cylinder may have to be increased to limit the difference in thickness so that the angle joint has a smooth contour.

(f) Example 1: Determine the required thickness of a conical head for the following conditions:

$D=200$ in. (at junction with the cylinder)

$\alpha=30$ deg ($\tan\alpha=0.577$, $\cos\alpha=0.866$)

$P=50$ psi; $S=13750$ psi; $E=0.80$

Substituting in Equation (5), UA-4(e)

$$t=\frac{50\times200}{2\times0.866\ (13750\times0.8-0.6\times50)}=0.526 \text{ in.}$$

Example 2: A compression ring to be used at the junction of conical head and shell of Example 1. Determine the required area of the compression ring. $E=1$ (see UA-5(a)).

$$\frac{P}{SE}=\frac{50}{13750\times1.00}=0.0036$$

Entering Table UA-5.1, we find $\Delta=19.8$. Since α exceeds Δ, a compression ring is required.

Area required in compression ring, from Equation (1):

$$A=\frac{50(100)^2}{2(13750\times1.0)}\left(1-\frac{19.8}{30}\right)0.577=3.55 \text{ sq in.}$$

Example 3: The conical head given in Example 1 is to be attached to the shell with a knuckle having a radius of 20 in. Find the thickness of the knuckle and the cone. (See UG-32(g).)

Required thickness of the knuckle:

The inside diameter of the cone at the point tangent to the knuckle is

$$D_1=200-2\times20\ (1-0.866)=194.64 \text{ in.}$$

$$L=\frac{D_1}{2\cos\alpha}=\frac{194.64}{2\times0.866}=112 \text{ in.}$$

$$\frac{L}{r}=\frac{112}{20}=5.60$$

and from Table UA-4.2, $M=1.34$.

Using Formula (3) in UA-4(d):

$$t=\frac{PLM}{2SE-0.2P}=\frac{50\times112\times1.34}{2\times13750\times0.80-0.2\times50}=0.342 \text{ in.}$$

Required thickness of the cone:

$D=D_1=194.64$ in., $\cos\alpha=0.866$

Using Formula (5) in (e):

$$t=\frac{PD}{2\cos\alpha\ (SE-0.6P)}=\frac{50\times194.64}{2\times0.866\ (13750\times0.80-0.6\times50)}=0.512 \text{ in.}$$

UA-6 Spherically Dished Covers (Bolted Heads)

(a) The symbols used in the formulas of this paragraph are defined as follows:

t = minimum required thickness of head plate after forming, inches

L = inside spherical or crown radius, inches

r = inside knuckle radius, inches

P = design pressure (see UG-21) or maximum allowable working pressure for existing vessels (see UG-98), pounds per square inch

S = maximum allowable stress value as given in Subsection C, pounds per square inch

T = flange thickness, inches

M_o = the total moment, inch pounds, determined as in UA-50 for heads concave to pressure and UA-55 for heads convex to pressure; except that for heads of the type shown in Fig. UA-6(d), H_D and h_D shall be as defined below, and an additional moment $H_r h_r$ (which may add or subtract) shall be included where:

H_r = radial component of the membrane load in the spherical segment = $H_D \cot\beta_1$, pounds, acting at the intersection of the inside of the flange ring with the centerline of the dished cover thickness

h_r = lever arm of force H_r about centroid of flange ring, inches

H_D = axial component of the membrane load in the spherical segment, pounds, acting at the inside of the flange ring = $0.785B^2P$

h_D = radial distance from the bolt circle to the inside of the flange ring, inches

β_1 = angle formed by the tangent to the centerline of the dished cover thickness at its point of intersection with the flange ring, and a line perpen-

dicular to the axis of the dished cover

$$= \arcsin\left(\frac{B}{2L+t}\right)$$

NOTE: Since $H_r h_r$ in some cases will subtract from the total moment, the moment in the flange ring when the internal pressure is zero may be the determining loading for flange design.

A = outside diameter of flange, inches

B = inside diameter of flange, inches

C = bolt circle diameter, inches

(b) Heads Concave to Pressure. Circular spherically dished heads with bolting flanges, concave to the pressure and conforming to the several types illustrated in Fig. UA-6, shall be designed in accordance with the following formulas:

(1) Heads of the type shown in Fig. UA-6(a):

(a) The thickness of the head t, shall be determined by the appropriate formula in UG-32;

(b) The head radius, L, or the knuckle radius r, shall not exceed the limitations given in UG-32;

(c) The flange shall comply at least with the requirements of Fig. UA-48 and shall be designed in accordance with the provisions of UA-45 through UA-51. (Within the range of ANSI B16.5-1968, the flange facings and drillings should conform to those Standards and the thickness specified therein shall be considered as a minimum requirement.)

(2) Heads of the type shown in Fig. UA-6(b) (no joint efficiency factor is required).

(a) Head thickness, $t = \dfrac{5PL}{6S}$

(b) Flange thickness, T:

For ring gasket, $T = \sqrt{\dfrac{M_o}{SB}\left[\dfrac{A+B}{A-B}\right]}$

For full-face gasket,

$$T = 0.6\sqrt{\frac{P}{S}\left[\frac{B(A+B)(C-B)}{A-B}\right]}$$

NOTE: The radial components of the membrane load in the spherical segment are assumed to be resisted by its flange.

(Within the range of ANSI B16.5-1968, the flange facings and drillings should conform to those Standards and the thickness specified therein shall be considered as a minimum requirement.)

(3) Heads of the type shown in Fig. UA-6(c) (no joint efficiency factor is required).

(a) Head thickness, $t = \dfrac{5PL}{6S}$

(b) Flange thickness,

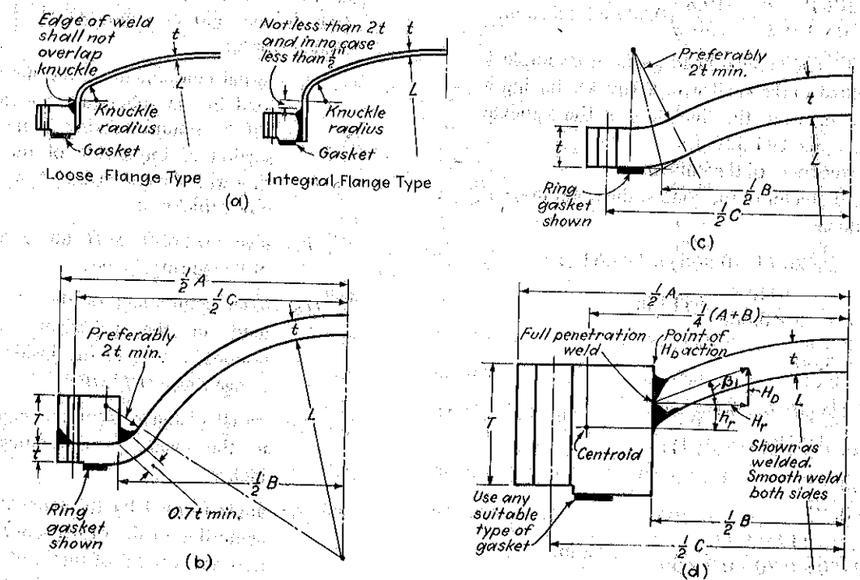


FIG. UA-6 SPHERICALLY DISHED STEEL PLATE COVERS WITH BOLTING FLANGES

For ring gasket, $t = Q\left[1+\sqrt{\dfrac{7.5M_o}{PQBL}}\right]$

For full-face gasket,

$$t = Q\left[1+\sqrt{1+\frac{3(C-B)B}{QL}}\right]$$

where $Q = \dfrac{P}{S}\left(\dfrac{L}{4}\right)\left[\dfrac{1}{1+6\left(\dfrac{C-B}{C+B}\right)}\right]$

for heads with round bolting holes, or where

$$Q = \frac{P}{S}\left(\frac{L}{4}\right)\left[\frac{1}{1+2\left(\frac{C-B}{C+B}\right)}\right]$$

for heads with bolting holes slotted through edge of head.

(c) The larger of the values of t given by (a) and (b) shall be used.

(4) Heads of the type shown in Fig. UA-6(d) (no joint efficiency factor is required).

(a) Head thickness, $t = \dfrac{5PL}{6S}$

(b) Flange thickness, $T = F\left[1+\sqrt{1+\dfrac{J}{F^2}}\right]$

where $F = \dfrac{PB\sqrt{4L^2-B^2}}{8S(A-B)}$

and $J = \left(\dfrac{M_o}{SB}\right)\left(\dfrac{A+B}{A-B}\right)$

NOTE: These formulas are approximate in that they do not take into account continuity between the flange ring and the dished head. A more exact method of analysis which takes this into account may be used if it meets the requirements of U-2. Such a method should parallel the method of analysis and allowable stresses for flange design in Appendix II. The dished portion of a cover designed under this rule may, if welded, require evaluation of any welded joint.

(c) Heads Convex to Pressure. Circular spherically dished heads convex to pressure shall be designed by the formulas in this paragraph and then the spherical segments shall be thickened, if necessary, to meet the requirements of UG-33.

UA-7 Large Openings in Cylindrical Shells

The rules for reinforcement of openings given in UG-36 through UG-44 are intended to apply primarily to openings not exceeding the following:

For vessels 60 in. diameter and less: ½ the vessel diameter, but not to exceed 20 in.

For vessels over 60 in. diameter: ⅓ the vessel diameter, but not to exceed 40 in.

Larger openings should be given special attention and may be reinforced in any suitable manner at least complying with the code rules. It is recommended that the reinforcement provided be distributed close to the juncture. (A provision of about two-thirds of the required reinforcement within a distance of ¼ d on each side of the finished opening is suggested.) It is further recommended that special consideration be given to the fabrication details used and inspection employed on critical openings; reinforcement often may be advantageously obtained by use of heavier shell plate for a vessel course or inserted locally around the opening; welds may be ground to concave contour and the inside corners of the opening rounded to a generous radius to reduce stress concentrations when radiographic examination of welds is not practicable, liquid penetrant examination may be used with nonmagnetic materials and either liquid penetrant or magnetic particle inspection with ferromagnetic materials. If magnetic particle inspection is employed, the prod method is preferred. The degree to which such measures should be used depends on the particular application and the severity of the intended service. Appropriate proof testing may be advisable in extreme cases of large openings approaching full vessel diameter, openings of unusual shape, etc. It is the committee's hope that research work now projected will result in the formulation of extended design rules for large openings.

APPENDIX II

RULES FOR BOLTED FLANGE CONNECTIONS

GENERAL

UA-45 Scope

(a) The rules in Appendix II apply specifically to the design of bolted flange connections for pressure vessels and are to be used in conjunction with the applicable requirements in Subsections A, B, and C of Section VIII. Appendix S provides discussion on Design Considerations for Bolted Flanged Connections.

These rules provide only for hydrostatic end loads and gasket seating. See UA-55 for flanges with ring type gaskets subject to external pressure. Proper allowance shall be made if connections are subject to external loads other than external pressure.

(b) The design of a flange involves the selection of the gasket (material, type, and dimensions), flange facing, bolting, hub proportions, flange width, and flange thickness. (See Note 1, UA-49(b)(1).) Flange dimensions shall be such that the stresses in the flange, calculated in accordance with UA-51 or UA-59, do not exceed the allowable flange stresses specified in UA-52 for Part A or UA-59(c) for Part B flanges. All calculations shall be made on dimensions in the corroded condition.

(c) It is recommended that bolted flange connections conforming to the standards[1] listed in UG-44 be used for connections to external piping. These standards may be used for other bolted flange connections within the limits of size in the standards and the pressure-temperature ratings permitted in UG-44.

(d) Except as otherwise provided in (c), bolted flange connections for unfired pressure vessels shall satisfy the requirements in this Appendix.

(e) The rules of this Appendix should not be construed to prohibit the use of other types of flanged connections provided they are designed in accordance with good engineering practice and the method of design is acceptable to the Inspector. Some examples of flanged connections which might fall in this category are as follows:

(1) Flanged covers as shown in Fig. UA-6.

(2) Bolted flanges using full-face gaskets.

(3) Flanges using means other than bolting to restrain the flange assembly against pressure and other applied loads.

UA-46 Materials

(a) Materials used in the construction of bolted flange connections shall comply with the requirements given in UG-5 through UG-14.

(b) Flanges made from ferritic steel and designed in accordance with this Appendix shall be given a normalizing or full-annealing heat treatment when the thickness of the flange section exceeds 3 in.

(c) Material on which welding is to be performed shall be proved of good weldable quality. Satisfactory qualification of the welding procedure under Section IX of the Code is considered as proof. Welding shall not be performed on steel that has a carbon content greater than 0.35 percent. All welding on flange connections shall comply with the requirements for postweld heat treatment given in this Division.

(d) Hubbed flanges shall not be machined from plate or bar stock material unless the material has been formed into a ring, and further provided that:

(1) In a ring formed from plate, the original plate surfaces are parallel to the axis of the finished flange. (This is not intended to imply that the original plate surface be present in the finished flange.)

(2) The joints in the ring are welded butt-joints that conform to the requirements of this Division.

[1] The ratings in these standards are based on the hub dimensions given or on the minimum specified thickness of flanged fittings of integral construction. Flanges fabricated from rings may be used in place of the hub flanges in these standards provided that their strength, calculated by the rules in this Appendix, is not less than that calculated for the corresponding size of hub flange.

Thickness to be used to determine stress relief and radiography requirements shall be the lesser of:

$$t \text{ or } \frac{(A-B)}{2}$$

where these symbols are as defined in UA-47.

(3) The back of the flange and the outer surface of the hub are inspected by nondestructive methods, such as magnetic particle inspection as per Appendix VI or liquid penetrant inspection to assure that these surfaces are free from defects.

(e) Bolts, studs, nuts, and washers shall comply with the requirements in this Division of Section VIII. It is recommended that bolts and studs have a nominal diameter of not less than ½ in. If bolts or studs smaller than ½ in. are used, ferrous bolting material shall be of alloy steel. Precautions shall be taken to avoid over-stressing small-diameter bolts.

UA-47 Notation

The symbols described below are used in the formulas for the design of flanges (see also Fig. UA-48, and UA-57):

A = outside diameter of flange or, where slotted holes extend to the outside of the flange, the diameter to the bottom of the slots, inches

A_b = actual total cross-sectional area of bolts at root of thread or section of least diameter under stress, square inches

A_m = total required cross-sectional area of bolts, taken as the greater of A_{m1} and A_{m2}, square inches

A_{m1} = total cross-sectional area of bolts at root of thread or section of least diameter under stress, required for the operating conditions, square inches, $= W_{m1}/S_b$

A_{m2} = total cross-sectional area of bolts at root of thread or section of least diameter under stress, required for gasket seating, square inches, $= W_{m2}/S_a$

a = shape factor, for full-face metal-to-metal contact flanges $= (A+C)/2B_1$

B = inside diameter of flange, inches. When B is less than $20g_1$, it will be optional for the designer to substitute B_1 for B in the formula for longitudinal stress, S_H

$B_1 = B + g_1$ for loose-type hub flanges and also for integral type flanges when f is less than 1

$B_1 = B + g_0$ for integral type flanges when f is equal to or greater than 1

b = effective gasket or joint-contact-surface seating width, inches (see Note 1, UA-49 (b)(1))

$2b$ = effective gasket or joint-contact-surface pressure width, inches (see Note 1, UA-49 (b)(1))

b_o = basic gasket seating width, inches (from Table UA-49.2)

C = bolt-circle diameter, inches

c = basic dimension used for the minimum sizing of welds, inches, equal to t_n or t_w, whichever is less

D = diameter of bolt hole, inches

d = factor, for integral type flanges

$$d = \frac{U}{V} h_0 g_0^2$$

for loose type flanges

$$d = \frac{U}{V_L} h_0 g_0^2$$

E = modulus of elasticity of flange material, corrected for operating temperature (see Fig. UF-27)

e = factor, for integral type flanges

$$e = \frac{F}{h_0}$$

for loose type flanges

$$e = \frac{F_L}{h_0}$$

F = factor for integral type flanges (from Fig. UA-51.2)

F_L = factor for loose type flanges (from Fig. UA-51.4)

f = hub stress correction factor for integral flanges from Fig. UA-51.6 (When greater than 1, this is the ratio of the stress in the small end of hub to the stress in the large end.) (For values below limit of figure use $f=1$)

G = diameter at location of gasket load reaction. Except as noted in Sketch 1 of Fig. UA-48, G is defined as follows for Part A flanges (see Table UA-49.2):

When $b_o \leq \frac{1}{4}$ inch, G = mean diameter of gasket contact face, inches

When $b_o > \frac{1}{4}$ inch, G = outside diameter of gasket contact face less $2b$, inches = mean diameter of gasket, inches, for Part B flanges

g_0 = thickness of hub at small end, inches

g_1 = thickness of hub at back of flange, inches

H = total hydrostatic end force, pounds $= 0.785\ G^2P$

H_G = contact force between mating flanges, pounds

H_D = hydrostatic end force on area inside of flange, pounds $= 0.785\ B^2P$

H_G = for Part A flanges only, gasket load (difference between flange design bolt load and total hydrostatic end force), pounds $= W - H$

H_G = for Part B flanges only, gasket load due to seating pressure, plus axial force generated by self-sealing of gasket, pounds

H_p = total joint-contact surface compression load, pounds, $= 2b \times 3.14GmP$

H_T = difference between total hydrostatic end force and the hydrostatic end force on area inside of flange, pounds, $= H - H_D$

h = hub length, inches

h_G = radial distance from bolt circle to flange-spacer or flange-flange bearing circle where the slope of the flange is calculated to be zero, inches

$h_{G\max}$ = radial distance from bolt circle to outer edge of flange or spacer, whichever is less

h_D = radial distance from the bolt circle, to the circle on which H_D acts, as prescribed in Table UA-50, inches

h_G = radial distance from gasket load reaction to the bolt circle, inches, $= \dfrac{C-G}{2}$

h_o = factor $= \sqrt{Bg_0}$, inches

h_T = radial distance from the bolt circle to the circle on which H_T acts as prescribed in Table UA-50, inches

J = ratio factor for hubbed flanges

$$= 0.550\left(\frac{g_0}{t}\right)\sqrt{\frac{B_1}{g_0}}$$

K = ratio of outside diameter of flange to inside diameter of flange $= A/B$

k = ratio factor for hubbed flanges

$$= 2(Z+0.3)/\left(\frac{B_1}{g_0}\right)$$

L = factor $= \dfrac{te+1}{T} + \dfrac{t^3}{d}$

l = calculated strain length of bolt, $= 2t + t_s +$ ½ nominal diameter of bolt for each threaded end

M_D = component of moment due to H_D, inch-pounds. $= H_D h_D$

M_G = component of moment due to H_G, inch-pounds, $= H_G h_G$

M_H = moment acting on end of hub, pipe, or shell, at its junction with back face of flange ring, inch-pounds

M_o = total moment acting upon the flange, for the operating conditions or gasket seating as may apply, inch-pounds (see UA-50) This notation applies to Part A flanges only

M_P = moment due to H_D, H_T, H_G, for Part B flanges, inch-pounds $= H_D h_D + H_T h_T + H_G h_G$

M_S = total moment on flange ring due to continuity with hub, pipe, or shell $= M_H + Qt/2$, inch-pounds

M_T = component of moment due to H_T, inch-pounds $= H_T h_T$

m = gasket factor, obtain from Table UA-49.1 (see Note 1, UA-49(b)(1))

N = width, inches, used to determine the basic gasket seating width b_o, based upon the possible contact width of the gasket (see Table UA-49.2)

n = number of bolts

P = design pressure, pounds per square inch For flanges subject to external pressure see UA-55 for Part A flanges and UA-60 for Part B flanges

Q = shear force between flange ring and end of hub, pipe, or shell positive as indicated in Fig. UA-57 (6), pounds.

R = radial distance from bolt circle to point of intersection of hub and back of flange, inches (integral and hub flanges)

$$= \frac{C-B}{2} - g_1$$

r_B = bolt-hole flexibility factor (see Fig. UA-59.3)

r_B = elasticity factor, = modulus of elasticity of flange material divided by modulus of elasticity of bolting material, corrected for operating temperature (see Fig. UF-27)

r_S = prestress factor, $= 1 - (S_t/S_b)$

S_a = allowable bolt stress at atmospheric temperature, pounds per square inch (given in Subsection C)

S_b = allowable bolt stress at design temperature, pounds per square inch (given in Subsection C)

S_f = allowable design stress for material of flange at design temperature (operating condition) or atmospheric temperature (gasket seating), as may apply, pounds per square inch (given in Subsection C)

S_n = allowable design stress for material of nozzle neck, vessel or pipe wall, at design temperature (operating condition) or atmospheric temperature (gasket seating), as may apply, pounds per square inch (given in Subsection C)

S_H = calculated longitudinal stress in hub, pounds per square inch

S_t = calculated bolt prestress at design temperature, for Part B flanges, pounds per square inch

S_R = calculated radial stress in flange, pounds per square inch

S_T = calculated tangential stress in flange, pounds per square inch

T = factor involving K (from Fig. UA-51.1)

t = flange thickness, inches

t_n = nominal thickness of shell or nozzle wall to which flange or lap is attached, less corrosion allowance, inches

t_s = thickness of spacer, inches

t_o = two times the thickness g_0, when the design is calculated as an integral flange, inches, or two times the thickness of shell or nozzle wall required for internal pressure, when the design is calculated as a loose flange, but not less than ¼ in., inches

U = factor involving K (from Fig. UA-51.1)

V = factor for integral type flanges (from Fig. UA-51.3)

V_L = factor for loose type flanges (from Fig. UA-51.5)

W = flange design bolt load, for the operating conditions or gasket seating, as may apply, pounds (see UA-49(d) for Part A flanges and UA-57 for Part B flanges)

W_{m1} = minimum required bolt load for the operating conditions, pounds (see UA-49(b))

W_{m2} = minimum required bolt load for gasket seating, pounds (see UA-49(b))

w = width, in inches, used to determine the basic gasket seating width b_o, based upon the contact width between the flange facing and the gasket (see Table UA-49.2)

Y = factor involving K (from Fig. UA-51.1)

y = gasket or joint-contact-surface unit seating load, pounds per square inch (see Note 1, UA-49(b))

Z = factor involving K (from Fig. UA-51.1)

z = axial separation of identical mating flanges at inside diameter, inches

θ_A = slope of flange face at outside diameter, radians

θ_B = slope of flange face at inside diameter, radians

UA-48 Circular Flange Types

(a) For purposes of computation, there are three types:

(1) Loose Type Flanges. This type covers those designs in which the flange has no direct connection to the nozzle neck, vessel, or pipe wall, and designs where the method of attachment is not considered to give the mechanical strength equivalent of integral attachment. See Fig. UA-48 (1), (1a), (2), (3), and (4) for typical loose type flanges and the location of the loads and moments. Welds and other details of construction shall satisfy the dimensional requirements given in Fig. UA-48 (1), (1a), (2), (3), and (4).

(2) Integral Type Flanges. This type covers designs where the flange is cast or forged integrally with the nozzle neck, vessel or pipe wall, butt welded thereto, or attached by other forms of arc or gas welding of such a nature that the flange and nozzle neck, vessel or pipe wall is considered to be the equivalent of an integral structure. In welded construction, the nozzle neck, vessel, or pipe wall is considered to act as a hub. See Fig. UA-48 (5), (6), (6a), (6b), and (7) for typical integral type flanges and the location of the loads and moments. Welds and other details of construction shall satisfy the dimensional requirements given in Fig. UA-48 (5), (6), (6a), (6b), and (7).

(3) Optional Type Flanges. This type covers designs where the attachment of the flange to the nozzle neck, vessel or pipe wall is such that the assembly is considered to act as a unit, which shall be calculated as an integral flange, except that for simplicity the designer may calculate the construction as a loose type flange provided none of the following values is exceeded:

$g_0 = 5/8$ inch

$\dfrac{B}{g_0} = 300$

$P = 300$ psi

operating temperature = 700 F

See Fig. UA-48 (8), (8a), (8b), and (9) for typical optional type flanges. Welds and other details of construction shall satisfy the dimensional requirements given in Fig. UA-48 (8), (8a), (8b), and (9).

PART A—FLANGES WITH RING TYPE GASKETS

The rules in Part A apply specifically to flanges with gaskets that are entirely within the circle enclosed by the bolt holes and with no contact outside this circle.

The flange design methods outlined in UA-48 through UA-52 are applicable to circular flanges under internal pressure. Modifications of these methods are outlined in UA-53 and UA-54, for the design of split and noncircular flanges.

UA-49 Bolt Loads

(a) Calculations. In the design of a bolted flange connection, complete calculations shall be made for two separate and independent sets of conditions, which are defined as follows:

(1) Operating Conditions. The conditions required to resist the hydrostatic end force of the design pressure tending to part the joint, and to maintain on the gasket or joint-contact surface sufficient compression to assure a tight joint, all at the design temperature. The minimum load is a function of the design pressure, the gasket material, and the effective gasket or contact area to be kept tight under pressure, per Formula (1) in UA-49(b)(1), and determines one of the two requirements for the amount of the bolting, A_{m1}. This load is also used for the design of the flange, per Formula (3) in UA-49(d).

(2) Gasket Seating. The conditions existing when the gasket or joint-contact surface is seated by applying an initial load with the bolts when assembling the joint, at atmospheric temperature and pressure. The minimum initial load considered to be adequate for proper seating is a function of the gasket material, and the effective gasket or contact area to be seated, per Formula (2) in UA-49 (b)(2), and determines the other of the two requirements for the amount of bolting, A_{m2}. For the design of the flange, this load is modified per Formula (4) in UA-49(d),

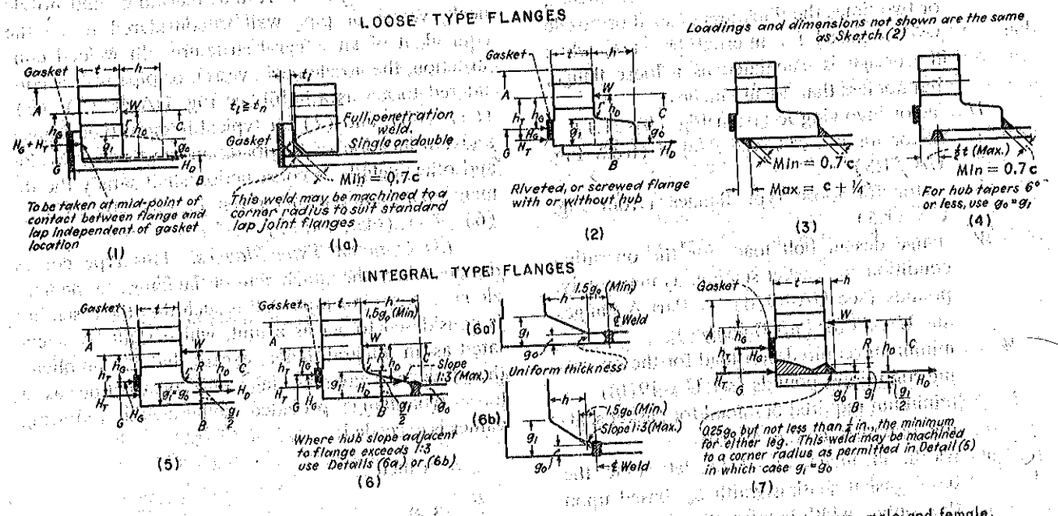


FIG. UA-48 TYPES OF FLANGES

General Note: Fillet radius r to be at least 0.25g, but not less than 3/16 in. Raised, tongue-groove, male and female, and ring joint facings shall be in excess of the required minimum flange thickness t.

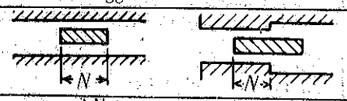
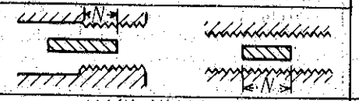
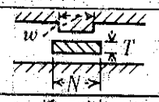
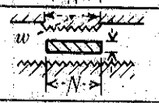
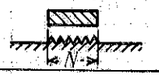
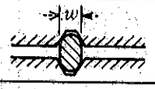
TABLE UA-49.1
GASKET MATERIALS AND CONTACT FACINGS

Gasket Factors (*m*) for Operating Conditions and Minimum Design Seating Stress (*y*)
NOTE: This table gives a list of many commonly used gasket materials and contact facings with suggested design values of *m* and *y* that have generally proved satisfactory in actual service when using effective gasket seating width *b* given in Table UA-49.2. The design values and other details given in this table are suggested only and are not mandatory.

Gasket material		Gasket factor *m*	Min design seating stress *y*	Sketches and notes	Refer to Table UA-49.2: Use facing sketch	Refer to Table UA-49.2: Use column	
Self-Energizing Types O Rings, Metallic, Elastomer other gasket types considered as self-sealing		0	0	–	–	–	
Elastomers without fabric or a high percentage of asbestos fiber: Below 75 Shore Durometer 75 or higher Shore Durometer		0.50 1.00	0 200		1 (a, b, c, d) 4, 5		
Asbestos with a suitable binder for the operating conditions	1/8 thick 1/16 thick 1/32 thick	2.00 2.75 3.50	1600 3700 6500				
Elastomers with cotton fabric insertion		1.25	400				
Elastomers with asbestos fabric insertion, with or without wire reinforcement	3-ply 2-ply 1-ply	2.25 2.50 2.75	2200 2900 3700				
Vegetable fiber		1.75	1100				
Spiral-wound metal, asbestos filled	Carbon Stainless or Monel	2.50 3.00	2900 4500		1 (a, b)		II
Corrugated metal, asbestos inserted or Corrugated metal, jacketed asbestos filled	Soft aluminum Soft copper or brass Iron or soft steel Monel or 4–6% chrome Stainless steels	2.50 2.75 3.00 3.25 3.50	2900 3700 4500 5500 6500				
Corrugated metal	Soft aluminum Soft copper or brass Iron or soft steel Monel or 4–6% chrome Stainless steels	2.75 3.00 3.25 3.50 3.75	3700 4500 5500 6500 7600		1 (a, b, c, d)		
Flat metal jacketed asbestos filled	Soft aluminum Soft copper or brass Iron or soft steel Monel 4–6% chrome Stainless steels	3.25 3.50 3.75 3.50 3.75 3.75	5500 6500 7600 8000 9000 9000		1a, 1b, 1c*, 1d*, 2*		
Grooved metal	Soft aluminum Soft copper or brass Iron or soft steel Monel or 4–6% chrome Stainless steels	3.25 3.50 3.75 3.75 4.25	5500 6500 7600 9000 10100		1 (a, b, c, d) 2, 3		
Solid flat metal	Soft aluminum Soft copper or brass Iron or soft steel Monel or 4–6% chrome Stainless steels	4.00 4.75 5.50 6.00 6.50	8800 13000 18000 21800 26000		1 (a, b, c, d) 2, 3, 4, 5		I
Ring joint	Iron or soft steel Monel or 4–6% chrome Stainless steels	5.50 6.00 6.50	18000 21800 26000		6		

*The surface of a gasket having a lap should not be against the nubbin.

TABLE UA-49.2 EFFECTIVE GASKET WIDTH

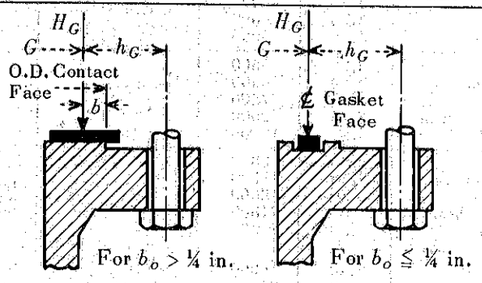
FACING SKETCH Exaggerated		BASIC GASKET SEATING WIDTH, b_o	
		COLUMN I	COLUMN II
1a		$\frac{N}{2}$	$\frac{N}{2}$
1b*			
1c	 $w \geqq N$	$\frac{w+T}{2}$; $\left(\frac{w+N}{4}\ max\right)$	$\frac{w+T}{2}$; $\left(\frac{w+N}{4}\ max\right)$
1d*	 $w \geqq N$		
2	 1/64" Nubbin $w \leqq \frac{N}{2}$	$\frac{w+N}{4}$	$\frac{w+3N}{8}$
3	 1/64" Nubbin $w \leqq \frac{N}{2}$	$\frac{N}{4}$	$\frac{3N}{8}$
4*		$\frac{3N}{8}$	$\frac{7N}{16}$
5*		$\frac{N}{4}$	$\frac{3N}{8}$
6		$\frac{w}{8}$	

EFFECTIVE GASKET SEATING WIDTH, "b"

$b = b_o$, when $b_o \leqq \frac{1}{4}$ in.

$b = \frac{\sqrt{b_o}}{2}$, when $b_o > \frac{1}{4}$ in.

LOCATION OF GASKET LOAD REACTION



NOTE: The gasket factors listed only apply to flanged joints in which the gasket is contained entirely within the inner edges of the bolt holes

*Where serrations do not exceed 1/64 in. depth and 1/32 in. width spacing, sketches 1b and 1d shall be used.

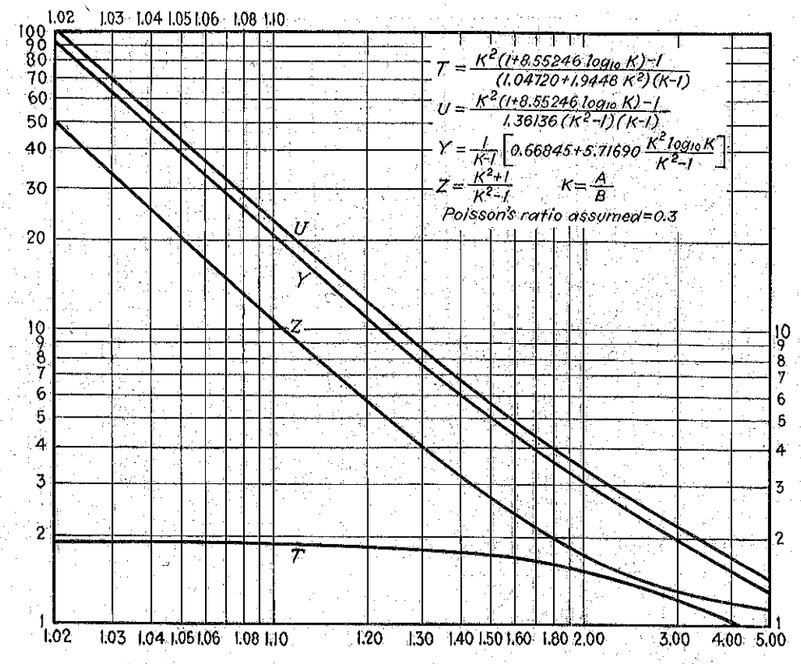


FIG. UA-51.1 VALUES OF T, U, Y, AND Z (Terms Involving K) ($K = A/B$)

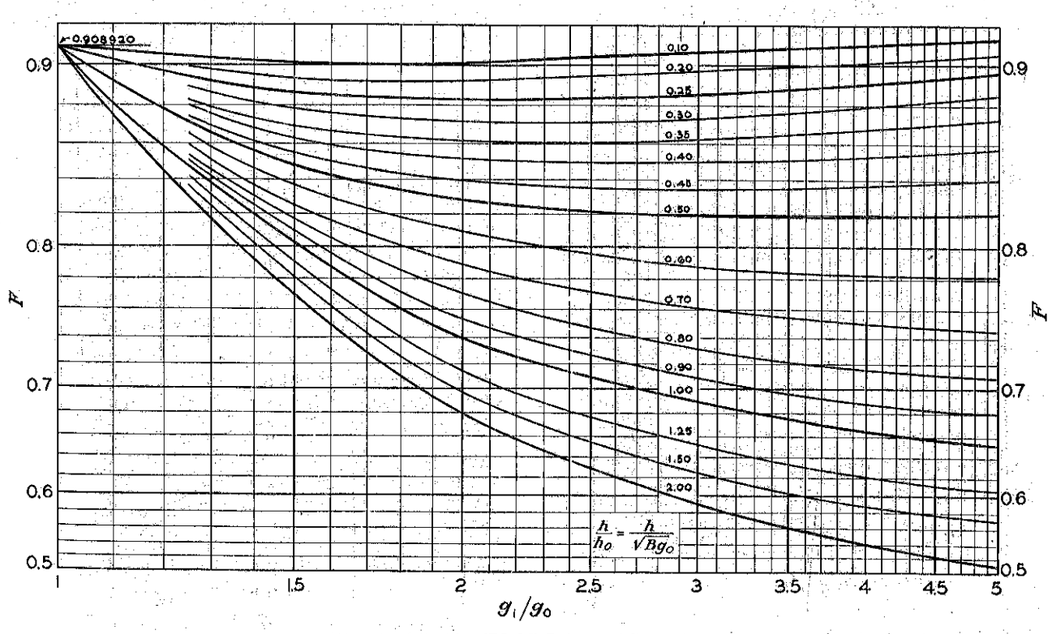


FIG. UA-51.2 VALUES OF F (Integral flange factors)

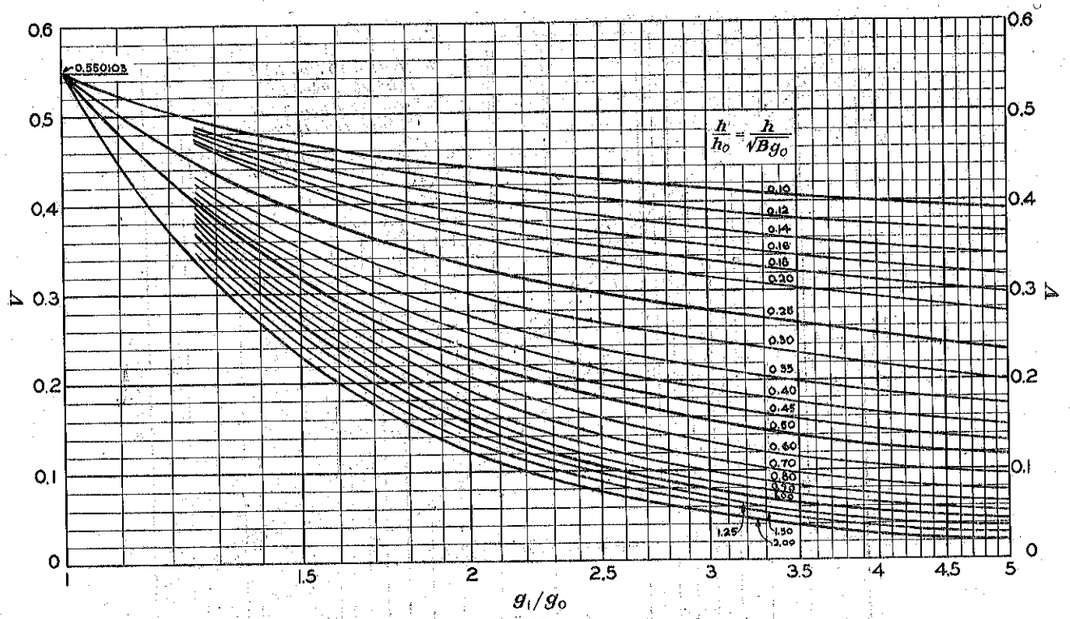


FIG. UA-51.3 VALUES OF V (Integral flange factors)

FIG. UA-51.4 VALUES OF F_L (Loose hub flange factors)

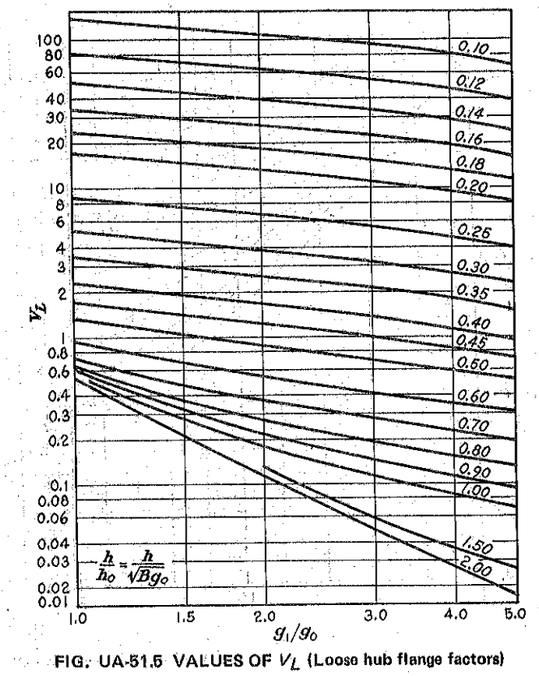


FIG. UA-51.5 VALUES OF V_L (Loose hub flange factors)

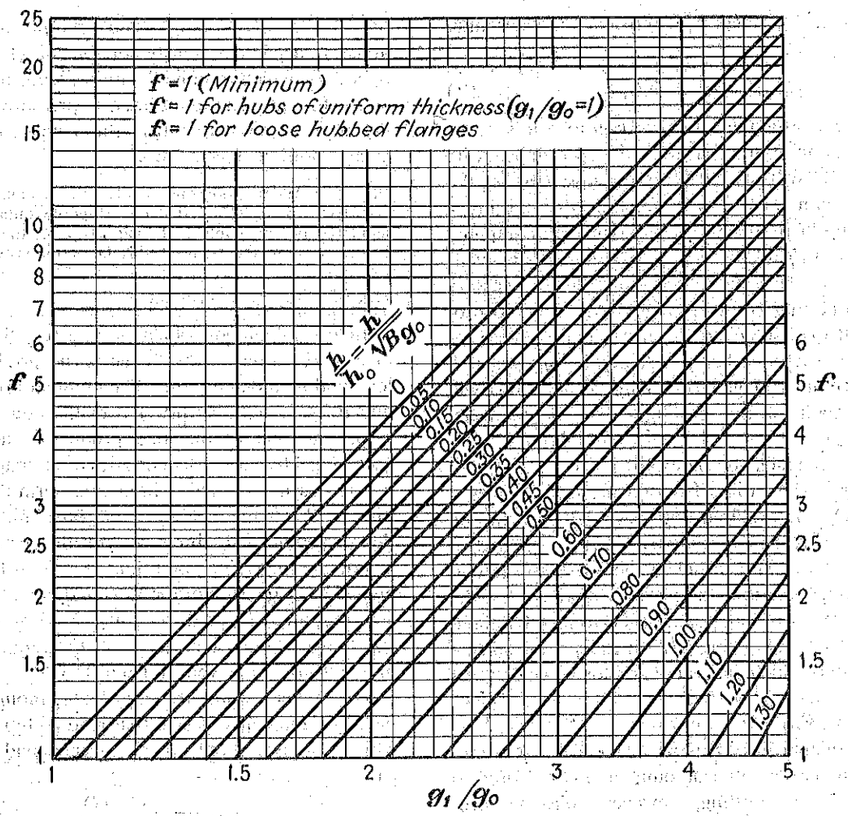


FIG. UA-51.6 VALUES OF f (Hub stress correction factor)

to take account of the operating conditions, when these govern the amount of bolting required, A_m, as well as the amount of bolting actually provided, A_b.

(b) Required Bolt Loads. The flange bolt loads used in calculating the required cross-sectional area of bolts shall be determined as follows:

(1) The required bolt load for the operating conditions, W_{m1}, shall be sufficient to resist the hydrostatic end force, H, exerted by the maximum allowable working pressure on the area bounded by the diameter of gasket reaction, and, in addition, to maintain on the gasket or joint-contact surface a compression load, H_p, which experience has shown to be sufficient to assure a tight joint. (This compression load is expressed as a multiple "m" of the internal pressure. Its value is a function of the gasket material and construction. See Note 1.)

NOTE 1: Tables UA-49.1 and UA-49.2 give a list of many commonly used gasket materials and contact facings, with suggested values of m, b, and y that have proved satisfactory in actual service. These values are suggested only and are not mandatory. Values that are too low may result in leakage at the joint without affecting the safety of the design. The primary proof that the values are adequate is the hydrostatic test.

The required bolt load for the operating conditions, W_{m1}, is determined in accordance with Formula (1).

$$W_{m1} = H + H_p = 0.785G^2P + (2b \times 3.14GmP) \quad (1)$$

(2) Before a tight joint can be obtained it is necessary to seat the gasket or joint-contact surface properly by applying a minimum initial load (under atmospheric temperature conditions without the presence of internal pressure), which is a function of the gasket material and the effective gasket area to be seated. The minimum initial bolt load required for

this purpose, W_{m2}, shall be determined in accordance with Formula (2)

$$W_{m2}=3.14b\,Gy \qquad (2)$$

The need for providing sufficient bolt load to seat the gasket or joint-contact surfaces in accordance with Formula (2) will prevail on many low-pressure designs and with facings and materials that require a high seating load, and where the bolt load computed by Formula (1) for the operating conditions is insufficient to seat the joint. Accordingly, it is necessary to furnish bolting and to pretighten the bolts to provide a bolt load sufficient to satisfy both of these requirements, each one being individually investigated. When Formula (2) governs, flange proportions will be a function of the bolting instead of internal pressure.

(3) Bolt loads for flanges using gaskets of the self-energizing type differ from those shown above.

(a) The required bolt load for the operating conditions, W_m, shall be sufficient to resist the hydrostatic end force, H, exerted by the maximum allowable working pressure on the area bounded by the outside diameter of the gasket. H_p is to be considered as 0 for all self-energizing gaskets except certain seal configurations which generate axial loads which must be considered.

(b) $W_{m2}=0$

Self-energizing gaskets may be considered to require an inconsequential amount of bolting force to produce a seal. Bolting, however, must be pretighten to provide a bolt load sufficient to withstand the hydrostatic end force H.

(c) Total Required and Actual Bolt Areas, A_m and A_b. The total cross-sectional area of bolts, A_m, required for both the operating conditions and gasket seating is the greater of the values for A_{m1} and A_{m2} where $A_{m1}=W_{m1}/S_b$ and $A_{m2}=W_{m2}/S_a$. A selection of bolts to be used shall be made such that the actual total cross-sectional area of bolts, A_b, will not be less than A_m.

(d) Flange Design Bolt Load, W. The bolt loads used in the design of the flange shall be the values obtained from Formulas (3) and (4). For operating conditions

$$W=W_{m1} \qquad (3)$$

For gasket seating

$$W=\frac{(A_m+A_b)\,S_a}{2} \qquad (4)$$

In addition to the minimum requirements for safety, Formula (4) provides a margin against abuse of the flange from overbolting. Since margin against such abuse is needed primarily for the initial, bolting-up operation which is done at atmospheric temperature and before application of internal pressure, the flange design is required to satisfy this loading only under such conditions (see Note 2).

NOTE 2: Where additional safety against abuse is desired, or where it is necessary that the flange be suitable to withstand the full available bolt load, $A_b \times S_a$, the flange may be designed on the basis of this latter quantity.

UA-50 Flange Moments

In the calculation of flange stresses, the moment of a load acting on the flange is the product of the load and its moment arm. The moment arm is determined by the relative position of the bolt circle with respect to that of the load producing the moment (see Fig. UA-48). No consideration shall be given to any possible reduction in moment arm due to cupping of the flanges or due to inward shifting of the line of action of the bolts as a result thereof.

For the operating conditions, the total flange moment, M_o, is the sum of the three individual moments, M_D, M_T, and M_G, as defined in UA-47 and based on the flange design bolt load of Formula (3) with moment arms as given in Table UA-50.

For gasket seating, the total flange moment, M_o is based on the flange design bolt load of Formula (4), which is opposed only by the gasket load, in which case

$$M_o=W\frac{(C-G)}{2} \qquad (5)$$

UA-51 Calculation of Flange Stresses

The stresses in the flange shall be determined for both the operating conditions and gasket seating,

TABLE UA-50
MOMENT ARMS FOR FLANGE LOADS UNDER OPERATING CONDITIONS

	h_D	h_T	h_G
Integral type flanges (see Fig. UA-48(5), (6), (6a), (6b), (7), (8), (8a), (8b), and (9))	$\frac{}{R+0.5g_1}$	$\frac{}{R+g_1+h_G}{2}$	$\frac{}{C-G}{2}$
Loose type, except lap-joint flanges (see Fig. UA-48(2), (3) and (4)); and optional type flanges (see Fig. UA-48(8), (8a), (8b), and (9))	$\frac{C-B}{2}$	$\frac{h_D+h_G}{2}$	$\frac{C-G}{2}$
Lap-joint flanges (see Fig. UA-48(1))	$\frac{C-B}{2}$	$\frac{C-G}{2}$	$\frac{C-G}{2}$

whichever controls, in accordance with the following formulas:

(1) For integral type flanges and all hub type flanges:

$$\text{Longitudinal hub stress } S_H=\frac{fM_o}{Lg_1^2B} \qquad (6)$$

$$\text{Radial flange stress } S_R=\frac{(1.33te+1)M_o}{Lt^2B} \qquad (7)$$

$$\text{Tangential flange stress } S_T=\frac{YM_o}{t^2B}-ZS_R \qquad (8)$$

(2) For loose type ring flanges (including optional type calculated as loose type) having a rectangular cross section

$$S_T=\frac{YM_o}{t^2B} \qquad (9)$$

$$S_R=0 \qquad S_H=0$$

UA-52 Allowable Flange Design Stresses

(a) The flange stresses calculated by the formulas in UA-51 shall not exceed the following values:

(1) Longitudinal hub stress S_H not greater than S_f for cast iron [1] and, except as otherwise limited by (1)(a) and (1)(b), not greater than 1.5 S_f for materials other than cast iron.

(a) Longitudinal hub stress S_H not greater than the smaller of $1.5S_f$ or $1.5S_n$ for optional type flanges designed as integral (Fig. UA-48(8), (8a), (8b) and (9)), also integral type (Fig. UA-48(7)) where the neck material constitutes the hub of the flange.

(b) Longitudinal hub stress S_H not greater than the smaller of $1.5S_f$ or $2.5S_n$ for integral type flanges with hub welded to the neck, pipe or vessel wall (Fig. UA-48(6), (6a) and (6b)).

(2) Radial flange stress S_R not greater than S_f.

(3) Tangential flange stress S_T not greater than S_f.

(4) Also $\frac{S_H+S_R}{2}$ not greater than S_f and $\frac{S_H+S_T}{2}$ not greater than S_f.

(b) For hub flanges attached as shown in Fig. UA-48(2), (3), and (4), the nozzle neck, vessel or pipe wall shall not be considered to have any value as a hub.

(c) In the case of loose type flanges with laps, as shown in Fig. UA-48(1), where the gasket is so located that the lap is subjected to shear, the shearing stress shall not exceed 0.8 times S_n for the material of the lap, as defined in UA-47. In the case of welded flanges, shown in Fig. UA-48(3), (4), (7), (8), (8a), and (8b) where the nozzle neck, vessel or pipe wall extends near to the flange face and may form the gasket contact face, the shearing stress carried by the welds shall not exceed 0.8 times S_n. The shearing stress shall be calculated on the basis of H_p, or W_{m2} as defined in UA-47, whichever is greater. Similar cases where flange parts are subjected to shearing stress shall be governed by the same requirements.

UA-53 Split Loose Flanges [2]

Loose flanges split across a diameter and designed under the rules given in Part A of this Appendix may be used under the following provisions:

(a) When the flange consists of a single split flange or flange ring, it shall be designed as if it were a solid flange (without splits), using 200 percent of the total moment M_o as defined in UA-50.

(b) When the flange consists of two split rings each ring shall be designed as if it were a solid flange (without splits), using 75 percent of the total moment M_o as defined in UA-50. The pair of rings shall be assembled so that the splits in one ring shall be 90 deg from the splits in the other ring.

(c) The splits should preferably be midway between bolt holes.

UA-54 Noncircular Shaped Flanges with Circular Bore

The outside diameter A for a noncircular flange with a circular bore shall be taken as the diameter of the largest circle, concentric with the bore, inscribed entirely within the outside edges of the flange. Bolt loads and moments, as well as stresses, are then calculated as for circular flanges, using a bolt circle drawn through the centers of the outermost bolt holes.

UA-55 Flanges Subject to External Pressures

(a) The design of flanges for external pressure only (see UG-99(f)) [3] shall be based on the for-

[1] When the flange material is cast iron, particular care should be taken when tightening the bolts to avoid excessive stress that may break the flange; an attempt should be made to apply no greater wrenching effort than is needed to assure tightness in the hydrostatic test.

[2] Loose flanges of the type shown in Fig. UA-48(1) are of the split design when it is necessary to install them after heat treatment of a stainless steel vessel, or when for any reason it is desired to have them completely removable from the nozzle neck or vessel.

[3] When internal pressure occurs only during the required pressure test, the design may be based on external pressure, and auxiliary devices such as clamps may be used during the application of the required test pressure.

mulas given in UA-51 for internal pressure except that for operating conditions:

$$M_o=H_D(h_D-h_G)+H_T(h_T-h_G) \quad (10)$$

For gasket seating

$$M_o=Wh_G \quad (11)$$

where

$$W=\frac{A_{m2}+A_b}{2}S_a$$
$$H_D=0.785B^2P_e$$
$$H_T=H-H_D$$
$$H=0.785G^2P_e$$

P_e=external design pressure, pounds per square inch. See UA-47 for definitions of other symbols.

(b) When flanges are subject at different times during operation to external or internal pressure, the design shall satisfy the external pressure design requirements given in (a) of this paragraph and the internal pressure design requirements given elsewhere in this Appendix.

NOTE: The combined force of external pressure and bolt loading may plastically deform certain gaskets to result in loss of gasket contact pressure when the connection is depressurized. To maintain a tight joint when the unit is repressurized, consideration should be given to gasket and facing details so that excessive deformation of the gasket will not occur. Joints subject to pressure reversals, such as in heat exchanger floating heads, are in this type of service.

PART B—FLAT FACE FLANGES WITH METAL-TO-METAL CONTACT OUTSIDE THE BOLT CIRCLE

The rules in Part B apply specifically to bolted flanged connections where the flanges are flat faced and bolted together directly or separated by a metal spacer such that there is metal-to-metal contact. It is assumed that a self-sealing gasket is used approximately in-line with the wall of attached pipe or vessel. The rules provide for hydrostatic end loads only and assume that the gasket seating loads are small and may in most cases be neglected. It is also assumed that the seal generates a negligible axial load under operating conditions. If such is not the case, allowance shall be made for a gasket load H_G, dependent on the size and configuration of the seal and design pressure.

Proper allowance shall be made if connections are subject to external forces other than external pressure, and if gasket seating requirements are significant.

The flange design methods outlined in UA-57 through UA-59 are applicable to circular flanges under internal pressure, and designed to operate in identical pairs. As with flanges with ring type gaskets, the stress in the bolts may vary appreciably with pressure. There is an additional stress increase due to a prying effect; that is, each bolt acts as a fulcrum with h_G as the lever arm. As a result, fatigue of the bolts and other parts comprising the flanged connection may require consideration (see UG-22) and controlled pretensioning of the bolts may be necessary. It is important to note that the operating bolt stress is relatively insensitive to change in pretightening stress up to a certain point. Thereafter, the two stresses are essentially the same.

UA-57 Bolt Loads

(a) Flange Thickness. The following approximate formula may be used for obtaining the necessary flange thickness to resist bending at the bolt circle. It is based on a loading due to hydrostatic end force only, with no compensation of a moment, either favorable or unfavorable, due to continuity with a hub or shell; allowance is made for removal of metal at the bolt holes, equivalent to 40 percent of the total bolt circle circumference.

$$t=1.78\sqrt{\frac{M_P}{S_fC}} \quad (12)$$

(b) Required Bolt Load. The flange bolt load used in calculating the required cross-sectional area of bolts shall be determined as follows:

(1) The required bolt load for the operating condition, W_{m1}, shall be sufficient to resist the sum of the hydrostatic end force, H, exerted by the maximum allowable working pressure on the area bounded by the diameter of the gasket reaction, and the contact force H_G exerted by the mating flange on the annular area where the flange faces are in contact. To this shall be added the gasket load H_G for those designs where gasket seating requirements are significant.

(2) Before the contact force H_G can be determined, it is necessary to obtain a value for its moment arm h_G. Due to the interrelation between bolt elongation and flange deflection, h_G involves the flange thickness, t, operating bolt stress S_b, bolt prestress factor r_S and calculated strain length l, elasticity factor r_E, and total moment loading on the flange M_P+M_S. The relation between these quantities is expressed by Formula (13), provided that the resulting solution for h_G is not greater than $\frac{A-C}{2}$, in which case θ_A, the slope of the flange face at its

outside diameter, equals zero. Note that the moment arms for M_P are given in Table UA-50.

$$h_G=0.929\sqrt{\frac{at^2lr_Er_SS_bB_1}{M_P+M_S}} \quad (13)$$

If the value of h_G calculated by Formula (13) exceeds $\frac{A-C}{2}$, the actual value of h_G is to be taken as $h_{G_{max}}=\frac{A-C}{2}$, and the face of the flange then has a slope at its outside diameter equal to θ_A radians, as expressed by Formula (14).

$$E\theta_A=\frac{r_Er_SS_bl}{A-C}-0.290\frac{(A-C)(M_P+M_S)}{B_1at^3} \quad (14)$$

For loose type and optional type flanges without hubs, the moment M_S in Formulas (13) and (14) equals zero. For all other flanges, M_S in these two formulas may be neglected, provided that a final check calculation is made to establish the adequacy of the bolting and flange stresses. For calculation of M_S, see UA-58.

(3) The contact force H_G is determined by Formula (15a) for loose type and optional type calculated as loose type flanges without hubs, and by Formula (15b) for all integral type flanges, and hubbed flanges of the loose or optional type where advantage may be taken of significant interaction between flange and hub.

$$H_G=M_P/h_G \quad (15a)$$
$$H_G=(M_P+M_S)/h_G \quad (15b)$$

(4) The required bolt load for operating conditions is determined in accordance with Formula (16).

$$W_{m1}=H+H_G+H_G \quad (16)$$

(c) Total Required and Actual Bolt Areas, and Flange Design Bolt Load. The total required cross-sectional area of bolts, A_m, equals W_{m1}/S_b. A selection of bolts to be used shall be made such that the actual total cross-sectional area of bolts A_b, will not be less than A_m. The flange design bolt load W shall be taken equal to W_{m1}.

UA-58 Flange-Hub Moments, Shear, Deflection and Slope of Flange Face

(a) For loose type and optional type calculated as loose type flanges, without hubs, the interaction moment M_S, hub moment M_H, and shear Q are assumed to be nonexistent. The slope and deflection at the flange i.d. are computed by Formulas (27) and (28).

(b) For all flanges with hubs, including flanges integral with or welded to pipe or shell as in Fig. UA-57(3), (4), (4a), (5), (5a), or (5b); the interaction moment M_S, hub moment M_H, shear Q, slope at flange-hub junction θ_H, and internal pressure P are interrelated in accordance with these formulas:

$$M_H=-\left(\frac{g_o}{t}\right)^2J_1E\theta_Bt^3+J_2Pt^3/\left(\frac{g_o}{t}\right) \quad (17)$$

$$Q=-\left(\frac{g_o}{t}\right)^2J_3E\theta_Bt^3+J_4Pt^2/\left(\frac{g_o}{t}\right) \quad (18)$$

$$M_S=M_H+Qt/2 \quad (19)$$

$$E(\theta_B-\theta_A)t^3=J_5M_S+J_6M_P \quad (20)$$

If the flange contact distance h_G is less than $H_{G_{max}}$, $\theta_A=0$. Otherwise, there is an additional relation between M_S and θ_A given by Formula (14). However, a good approximation for θ_A may be obtained by using Formula (14) with M_S assumed equal to zero.

The symbols J_1, J_2, . . . , J_6 represent the dimensional characteristics of flange and hub, and contain the ratio factors j and k for all types of hub, with c_1, c_2, c_3, etc. for tapered hubs and hubs of loose type flanges. See UA-47 for j and k, also Fig. UA-58 for j, k, and applicable c factors.

$$J_1=0.951c_1\left[\frac{c_2(1+c_2j)}{1+c_1jk}+c_3j\right] \quad (21)$$

$$J_2=5.19j^2\left[\frac{c_1c_2(c_4-k)}{1+c_1jk}+1.100c_5\right] \quad (22)$$

$$J_3=1.901\frac{c_1(1+c_2j)}{j(1+c_1jk)} \quad (23)$$

$$J_4=10.38\frac{c_1j^2(c_4-k)}{1+c_1jk} \quad (24)$$

$$J_5=\frac{1.738}{B_1}\left(2\frac{h_D}{c}+\frac{h_G}{a}+\pi B_1r_B\right) \quad (25)$$

$$J_6=J_5-1.738\frac{h_D}{B_1c} \quad (26)$$

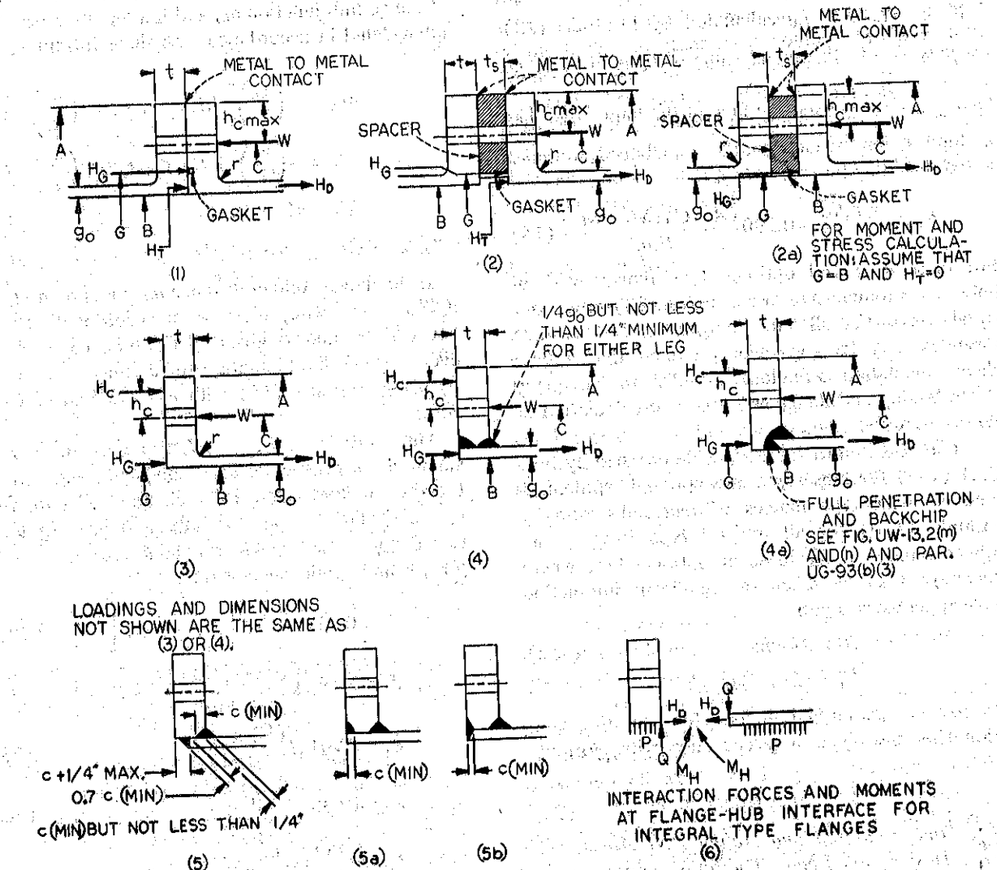
(c) Allocation of c factors. For loose type flanges with constant thickness hubs, see Fig. UA-58(3) for c_1, c_2, and c_3. J_2 and J_4 equal zero.

For loose type flanges with tapered hubs, see Fig. UA-58(9), (10), and (11) for c_1, c_2, and c_3. J_2 and J_4 equal zero.

For integral flanges with constant thickness hubs, c_1, c_2, and $c_3=1$, $c_4=0.85$, $c_5=0$.

For integral flanges with tapered hubs, see Fig. UA-58(4), (5), (6), (7), and (8) for c_1, c_2, c_3, c_4, and c_5.

(d) The slope of the flange face at its inside diam-



GENERAL NOTE: FILLET RADIUS (r) TO BE AT LEAST 0.25 g_0 BUT NOT LESS THAN 3/16 in.

FIG. UA-57

eter is given by Formula (27), derived from the preceding formulas (17), (18), (19), and (20). This formula is applicable to all types of flange, with or without hubs.

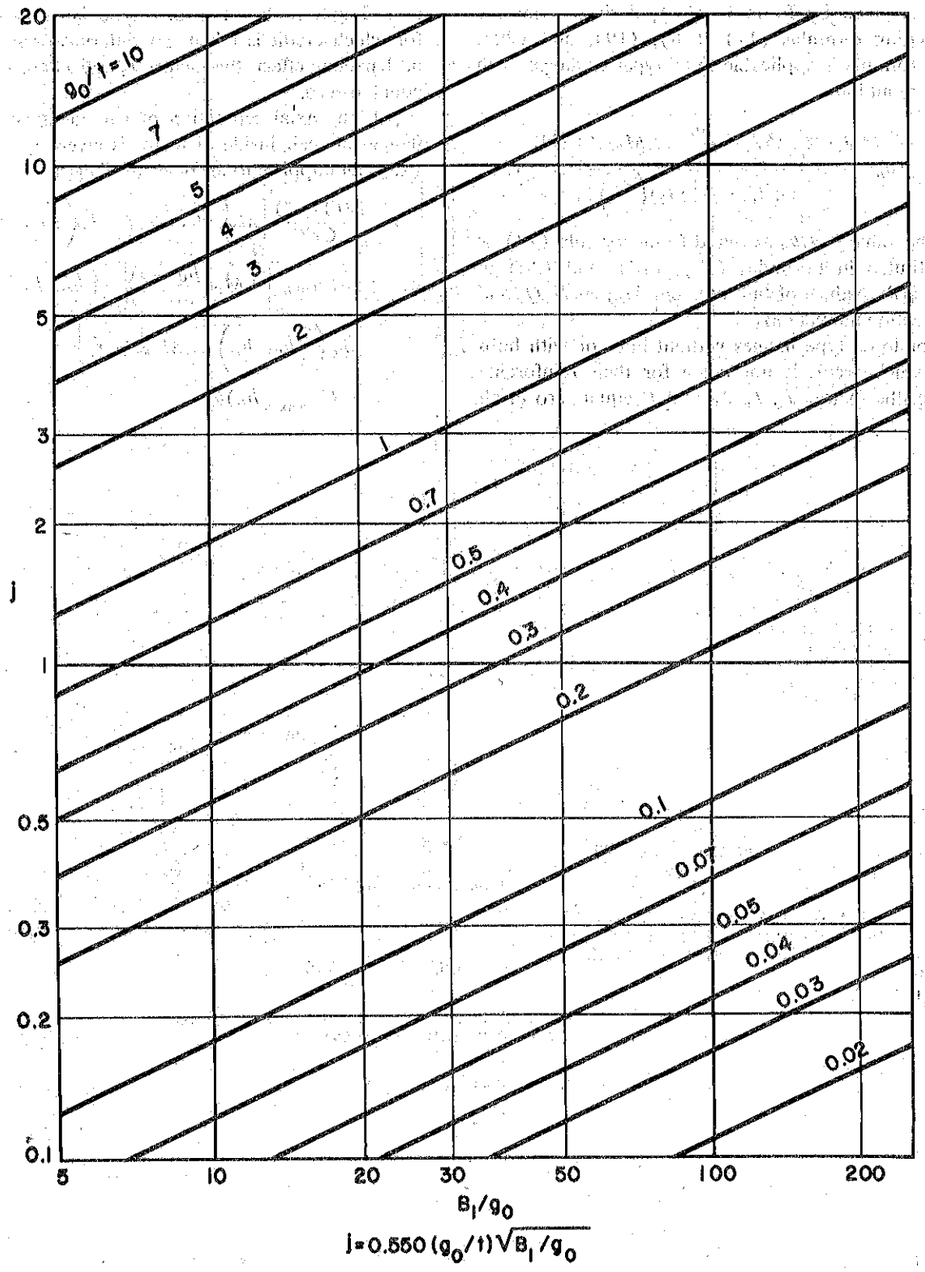
$$E\theta_B = \frac{J_5(J_2+\tfrac{1}{2}J_4)P/\frac{g_0}{t} + J_6 M_P/t^3 + E\theta_A}{1+J_5(J_1+\tfrac{1}{2}J_3)\left(\frac{g_0}{t}\right)^2} \quad (27)$$

The value of $E\theta_B$ as found from Formula (27), is substituted in Formulas (17), (18), and (20) to obtain the values of hub moment M_H, shear Q, and interaction moment M_S.

For loose type flanges without hubs or with hubs for which credit is not taken for their reinforcing value, the factors J_1, J_2, J_3, and J_4 equal zero in all preceding formulas. For loose type flanges with hubs for which credit is taken, but internal pressure has no barreling effect, the factors J_2 and J_4 are taken as equal to zero.

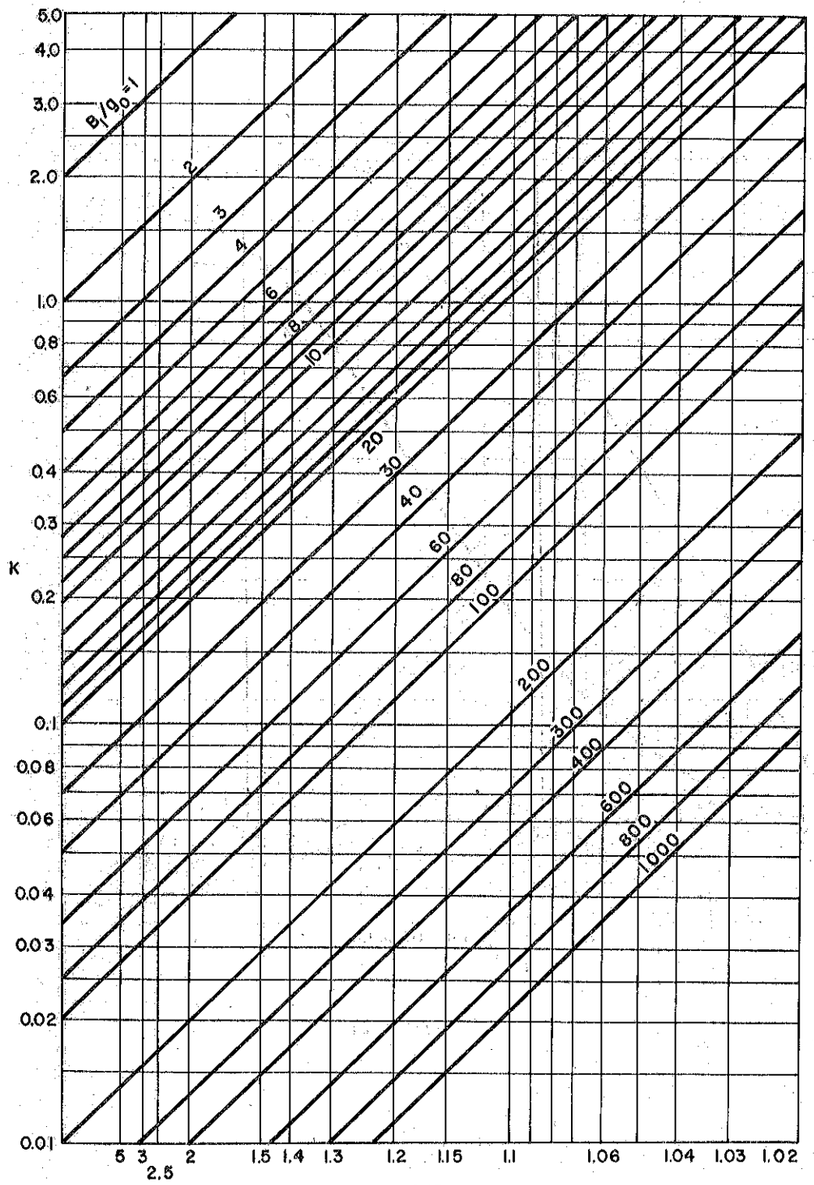
(e) The axial separation of two identical mating flanges at their inside diameter is given by Formula (28), and applies to all types of flanges.

$$z = \frac{12(1-\nu^2)}{\pi C E t^3}\left\{M_S\left[(h_G+h_D)^2 - h_G\left(\frac{2}{3}h_G+h_D\right) + \pi C h_D r_B\right] + M_P\left(\frac{h_G}{h_D}+1\right)\left[\frac{2}{3}\left(h_G+h_D\right)^2 - h_G\left(\frac{2}{3}h_G+h_D\right)\right] + M_P \pi C h_D r_B\right\} + 2(h_{G_{max}}+h_D)\theta_A \quad (28)$$



$$j = 0.550\,(g_0/t)\sqrt{B_1/g_0}$$

FIG. UA-58(1)



$$K = 2\,(Z+\nu)/B_1/g_0$$

FIG. UA-58(2)

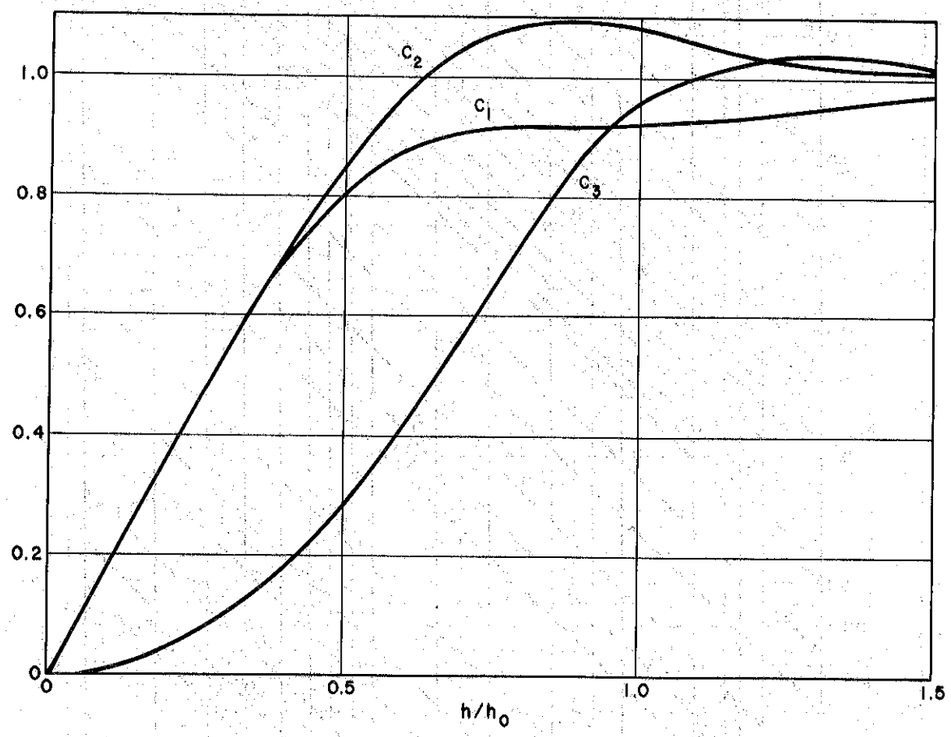


FIG. UA-58(3)

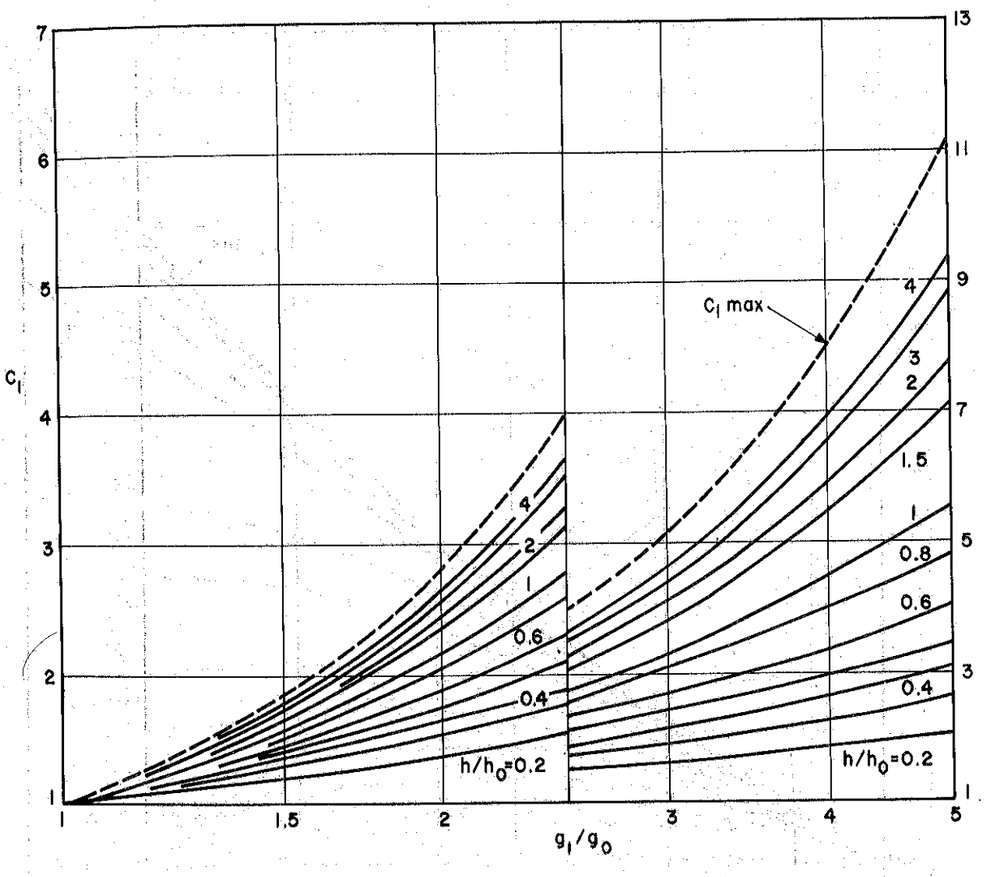


FIG. UA-58(4)

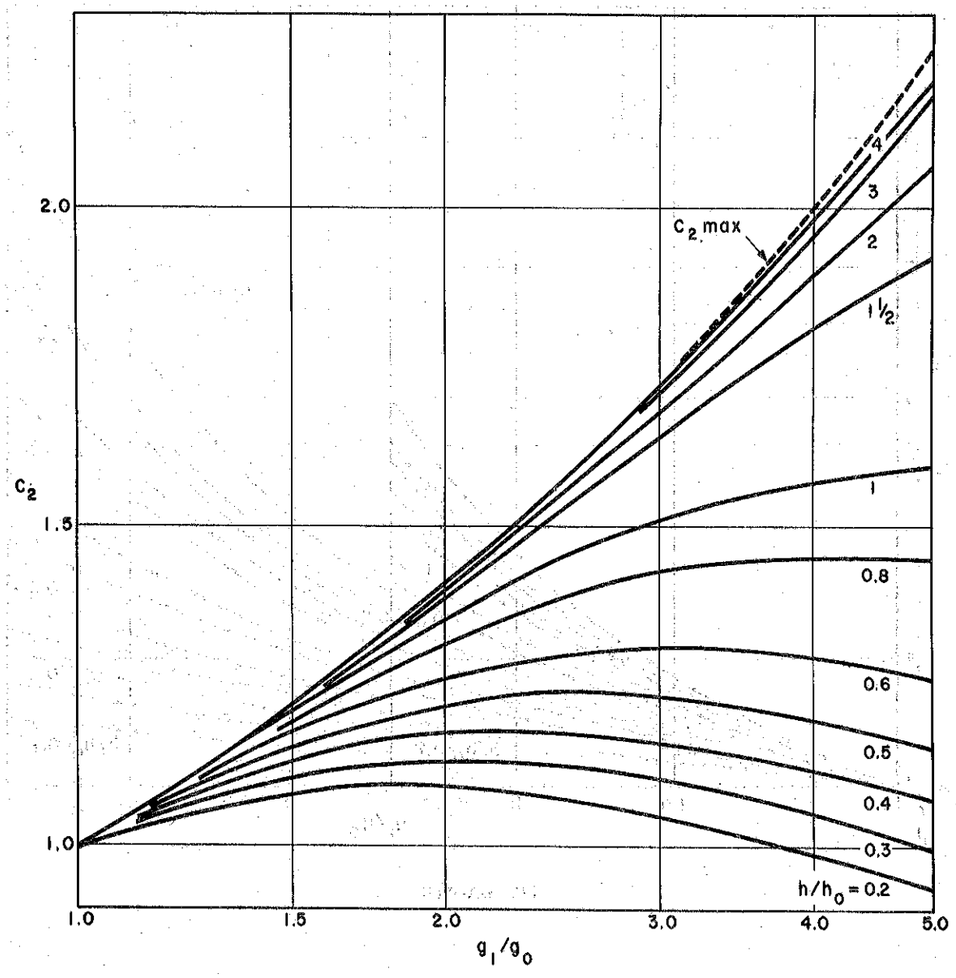


FIG. UA-58(5)

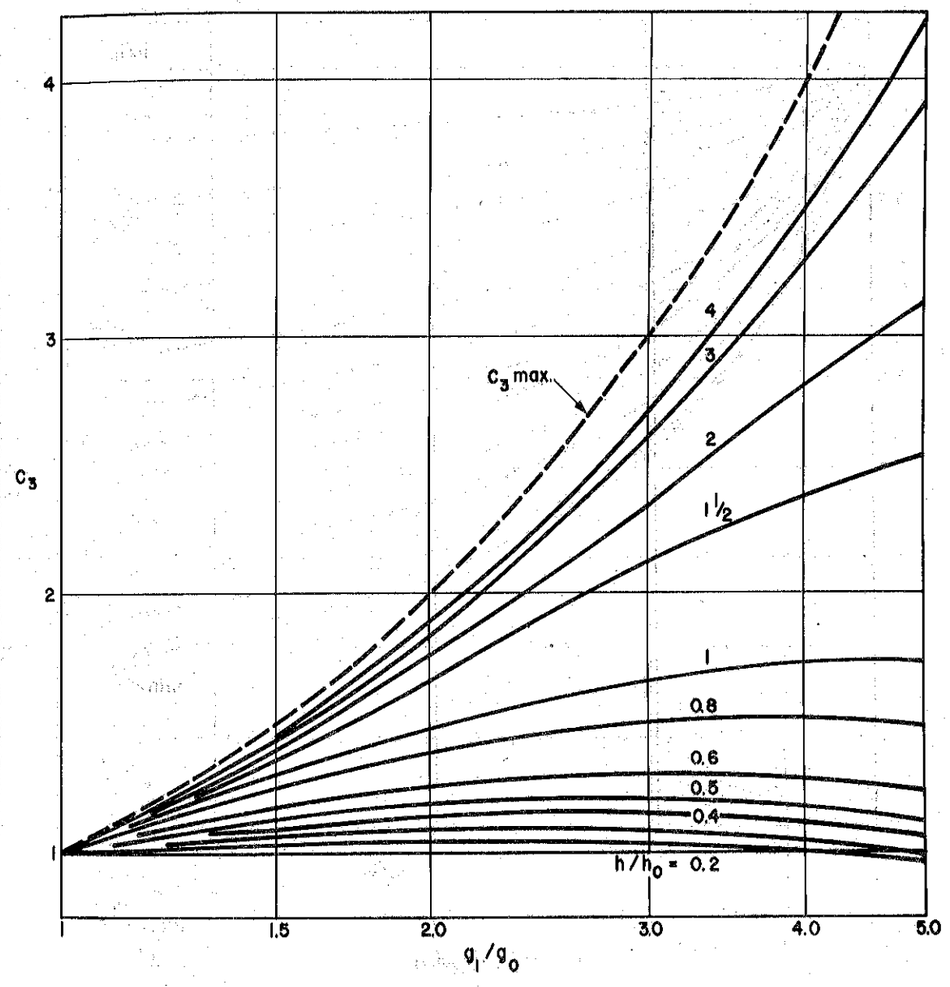


FIG. UA-58(6)

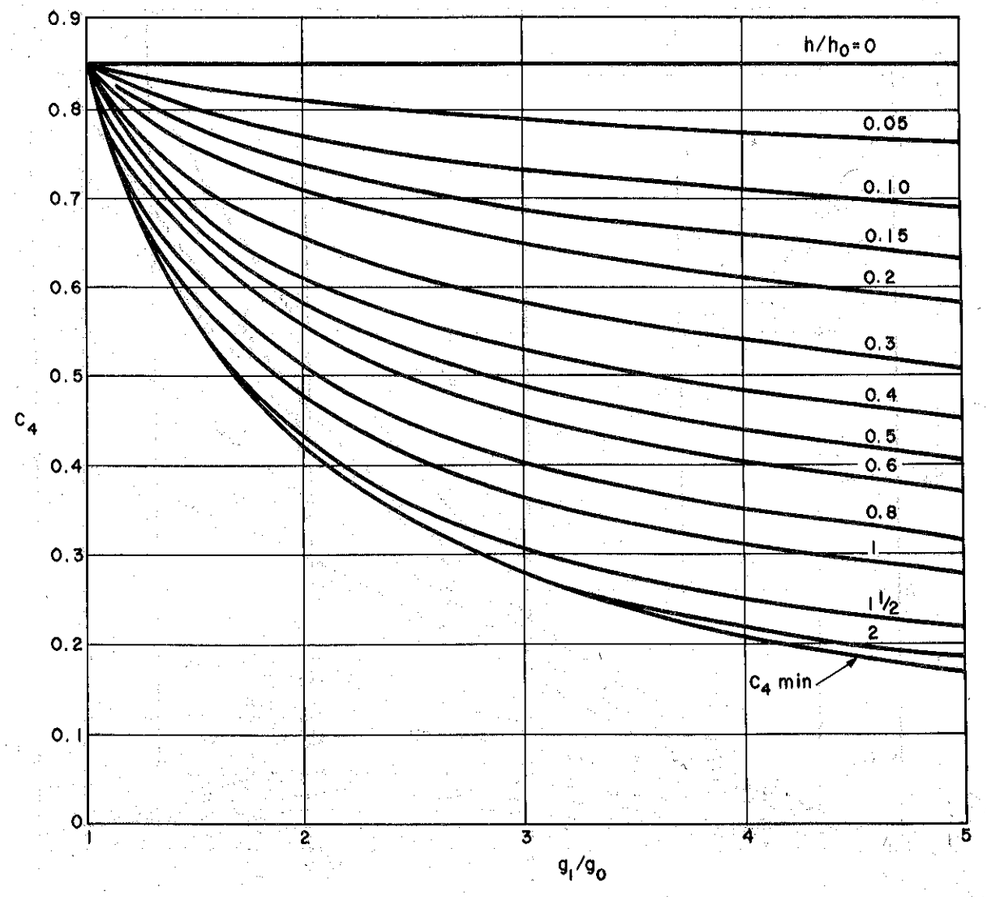


FIG. UA-58(7)

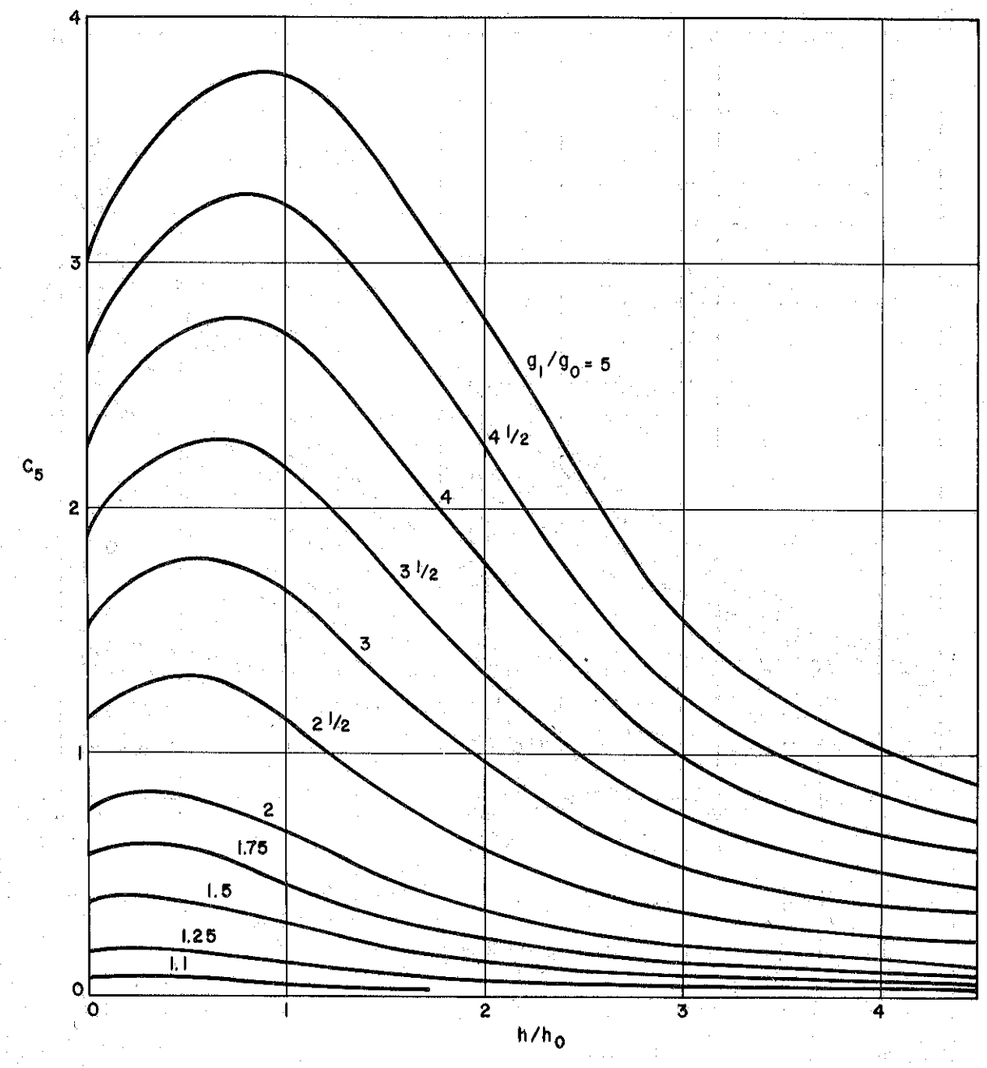


FIG. UA-58(8)

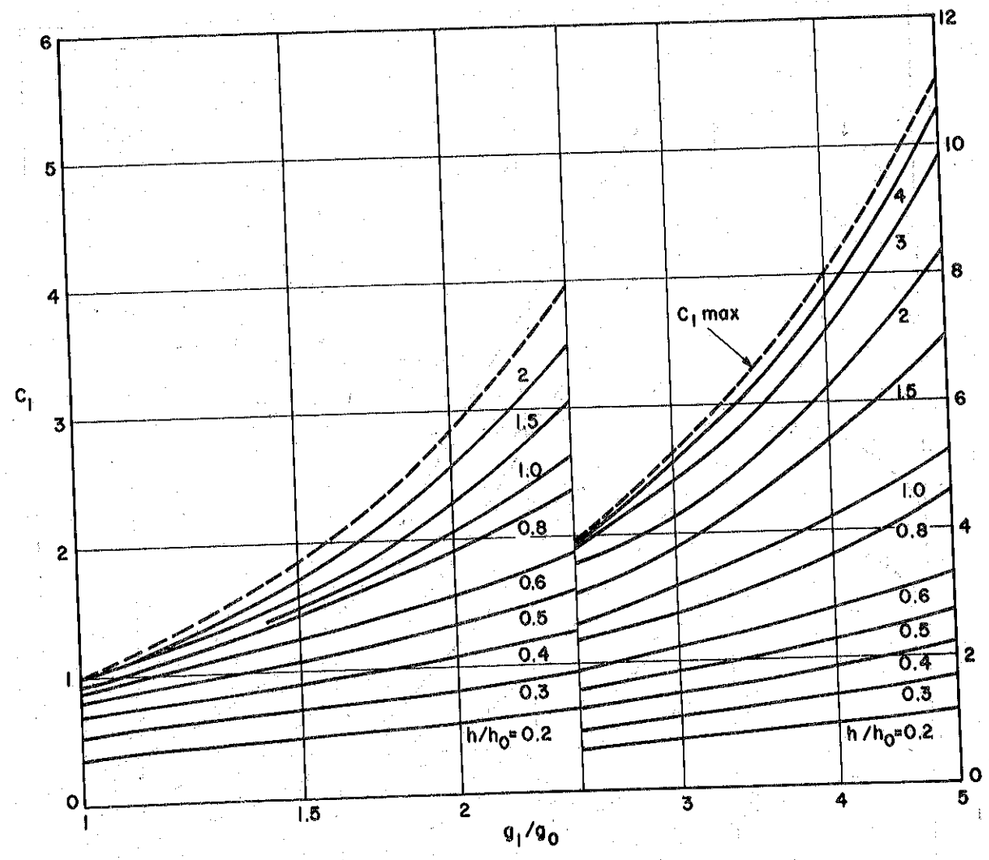


FIG. UA-58(9)

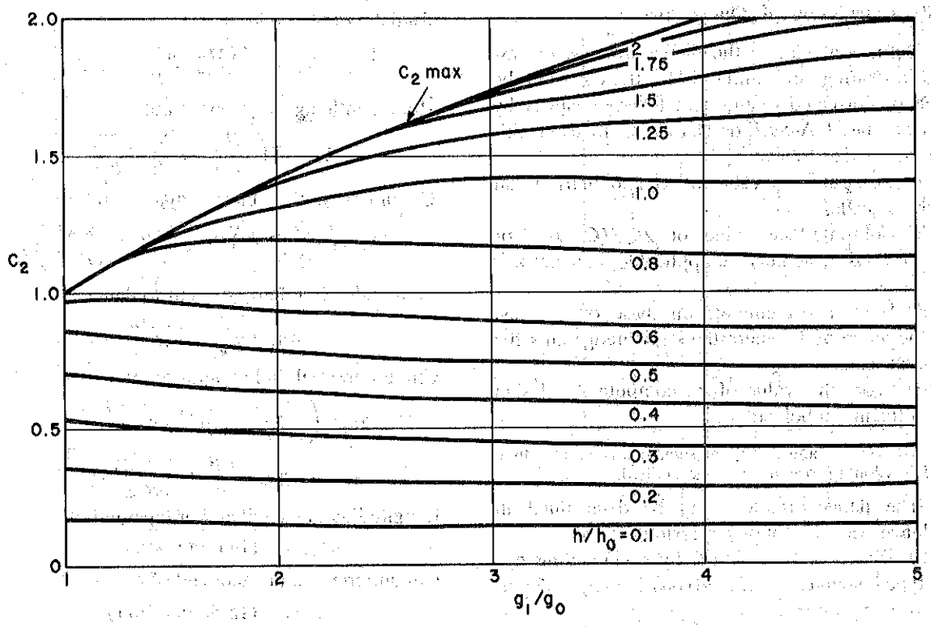


FIG. UA-58(10)

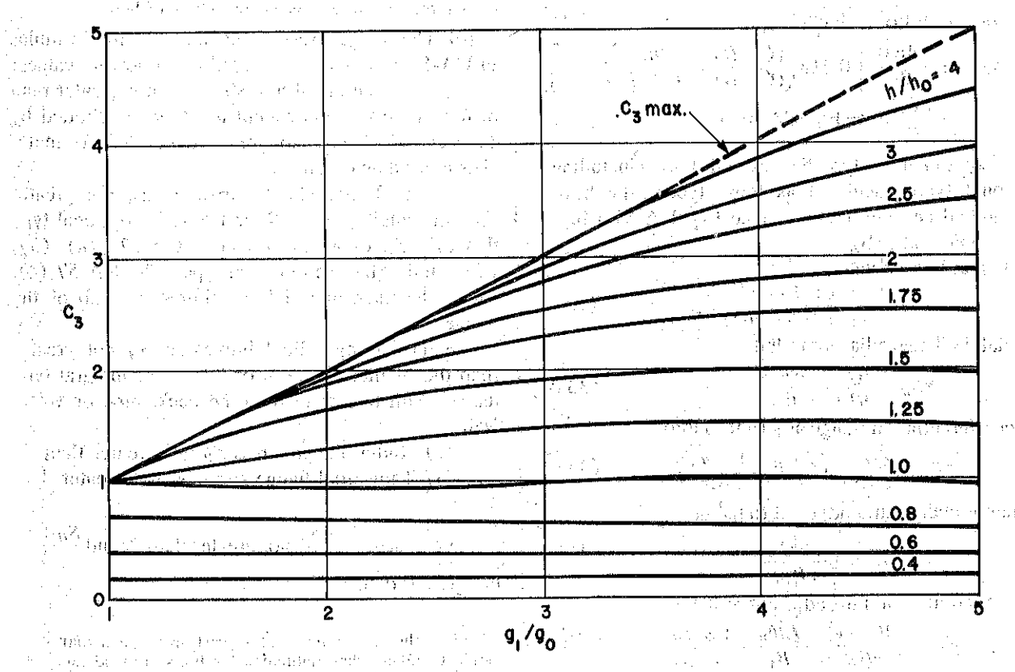


FIG. UA-58(11)

UA-59 Calculation of Flange Stresses

(a) Before calculating the flange stresses, the assumed operating and initial bolt stresses shall be verified or corrected to the actual design values by means of Figs. UA-59.1 or UA-59.2. In using this figure, proceed as follows:

(1) Compute the value of x_2 and mark it on the vertical scale.

(2) Compute the value of $2h_G/(C-B_1)$ or $2h_{G_{max}}/(C-B_1)$, as may be applicable, and mark it on the curve.

(3) With a straightedge on these two points, mark the value of x_1 where the straightedge cuts the horizontal scale.

(4) From this value of x_1, compute the design value of the initial bolt stress.

NOTE: If $M_S = 0$ and A_b is not significantly greater than A_m, the foregoing procedure may be omitted.

(b) The flange stresses shall be determined in accordance with the following formulas:

(1) For loose type ring flanges (including optional type calculated as loose type) having a rectangular cross section:

$$*S_R = \pm \frac{6\,M_P}{t^2\,(3.14C-nD)} \quad \text{at bolt circle} \tag{29}$$

$$S_R = 0 \quad \text{at inside diameter} \tag{30}$$

$$*S_T = \pm \frac{5.46M_P}{Bt^2}\left[0.318\left(\frac{(C-B)}{(C+B)}+\frac{(2h_G)}{(C+A)}\right)+r_B\right] + \frac{E\theta_A t}{B} \text{ (see Fig. UA-59.3)} \tag{31}$$

(2) For loose type flanges with hubs (including optional type calculated as loose type); the hubs considered as reinforcement (see Fig. UA-57 (4a), (5), (5a), and (5b):

Radial, at bolt circle

$$S_R = \pm \frac{6(M_P+M_S)}{t^2(\pi C-nD)} \tag{32}$$

Radial, in flange adjacent to hub

$$*S_R = \frac{Q}{\pi B_1 t} \pm \frac{6M_S}{\pi B_1 t^2} \tag{33}$$

Circumferential, in flange adjacent to hub

$$*S_T = \frac{QZ}{\pi B_1 t} \pm \left(\frac{Et\theta_B}{B_1}+\frac{1.8M_S}{\pi B_1 t^2}\right) \tag{34}$$

Longitudinal, in hub adjacent to flange

$$*S_{H1} = \pm \frac{6M_H}{\pi B_1 g_1^2} \tag{35}$$

Circumferential, in hub adjacent to flange

$$*S_{H2} = \frac{Q(z+\nu)}{\pi B_1 t} + \frac{Et\theta_B}{B_1} \pm \frac{1.8M_H}{\pi B_1 g_1^2} \tag{36}$$

(3) For flanges integral with pipe, shell or tapered hub (see Fig. UA-57(4)):

Radial, at bolt circle

$$S_R = \pm \frac{6(M_P+M_S)}{t^2(\pi C-nD)} \tag{37}$$

Radial, in flange adjacent to hub

$$*S_R = -\left(\frac{Q}{\pi B_1 t}+P\right) \pm \frac{6M_S}{\pi B_1 t^2} \tag{38}$$

Circumferential, in flange adjacent to hub

$$*S_T = \left(\frac{Q}{\pi B_1 t}+P\right)Z \pm \left(\frac{Et\theta_B}{B_1}+\frac{1.8\,M_S}{\pi B_1 t^2}\right) \tag{39}$$

Longitudinal, in hub adjacent to flange

$$*S_{H1} = \frac{PB_1}{4\,g_1} \pm \frac{6\,M_H}{\pi B_1 g_1^2} \tag{40}$$

Circumferential, in hub adjacent to flange

$$S_{H2} = \left(\frac{Q}{\pi B_1 t}+P\right)(Z+\nu)+\frac{Et\theta_B}{B_1} + 0.075\,\frac{PB_1}{g_1} \pm \frac{1.8\,M_H}{\pi B_1 g_1^2} \tag{41}$$

Longitudinal, at small end of tapered hub

$$S_{H3} = \quad \text{(In preparation)} \tag{42}$$

Circumferential, at small end of tapered hub

$$S_{H4} = \quad \text{(In preparation)} \tag{43}$$

* Use + sign for contact face of flange or inside of hub, – sign for back face of flange or outside of hub.

(c) The flange stresses calculated by the formulas in UA-59 (b) shall not exceed the following values:

(1) Longitudinal hub-stress S_H not greater than S_f for cast iron [1] and except as otherwise limited by (1)(a) and (1)(b), not greater than 1.5 S_f for materials other than cast iron.

(a) Longitudinal hub-stress S_H not greater than the smaller of 1.5 S_f or 1.5 S_n for optional type flanges designed as integral (Fig. UA-57 (4a), (5), (5a), and (5b), also integral type (Fig. UA-57 (4)) where the neck material constitutes the hub of the flange.

(b) Longitudinal hub-stress S_H not greater than the smaller of 1.5 S_f or 2.5 S_n for integral type flanges with hub welded to the neck, pipe or vessel wall.

(2) Radial flange stress S_R not greater than S_f.

(3) Tangential flange stress S_T not greater than S_f.

(4) Also, $\frac{S_H+S_R}{2}$ not greater than S_f and $\frac{S_H+S_T}{2}$ not greater than S_f.

[1] When the flange material is cast iron, particular care should be taken when tightening the bolts to avoid excessive stress that may break the flange; an attempt should be made to apply no greater wrenching effort than is needed to assure tightness in the hydrostatic test.

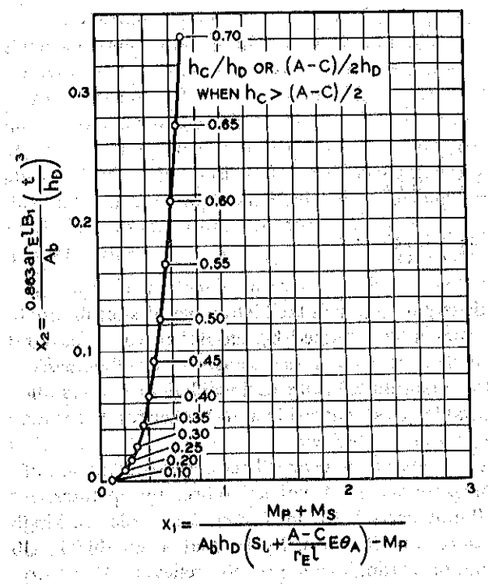


FIG. UA-59.1

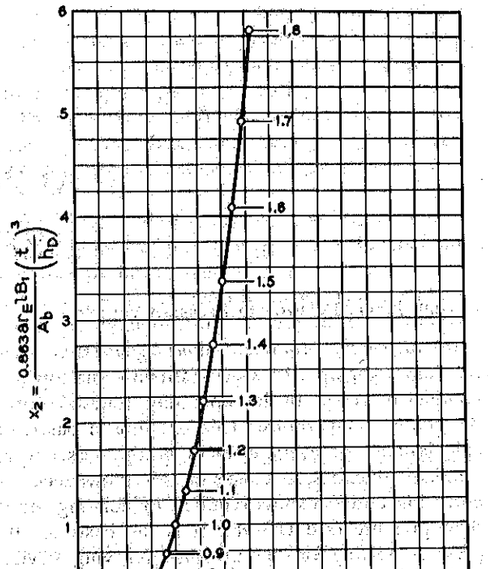


FIG. UA-59.2

EXAMPLE:
n = 16, D = 27/8 (LINE 1)
C = 30 1/2; F_1 = 0.62 (LINE 2)
F_1 = 0.62, n = 16 (LINE 3)
r_B = 0.039

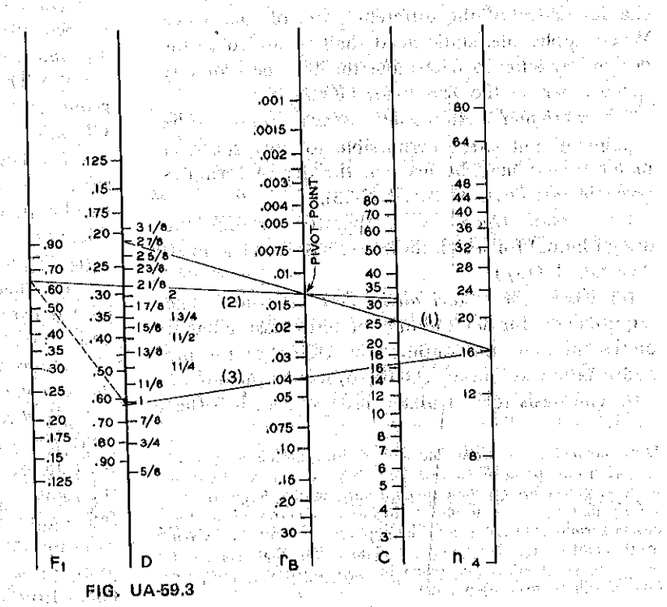


FIG. UA-59.3

APPENDIX III
DEFINITIONS

UA-60 Terms Relating to Pressure Vessels

(*a*) *Maximum Allowable Working Pressure*—The maximum gage pressure permissible at the top of a completed vessel in its operating position for a designated temperature. This pressure is based on calculations for every element of the vessel using nominal thicknesses exclusive of allowances for corrosion and thickness required for loadings other than pressure (see UG-98). It is the basis for the pressure setting of the pressure relieving devices protecting the vessel. The design pressure (see (b)) may be used in place of the maximum allowable working pressure in all cases in which calculations are not made to determine the value of the maximum allowable working pressure.

(*b*) *Design Pressure*—The pressure used in the design of a vessel for the purpose of determining the minimum permissible thickness or physical characteristics of the different parts of the vessel. When applicable, static head shall be added to the design pressure to determine the thickness of any specific part of the vessel (see UG-21).

(*c*) *Maximum Allowable Stress Value*—The maximum unit stress permissible for any specified material that may be used in the design formulas given in this Division (see UG-23).

(*d*) *Normal Operation*— Operation within the design limits[1] for which the vessel has been stamped. (See UG-116(a).)

(*e*) *Basis for Calculated Test Pressure*—The requirements for determining the test pressure based on calculations are outlined in UG-99(c) for the hydrostatic test and in UG-100(b) for the pneumatic test. The basis for calculated test pressure in either of these paragraphs is the highest permissible internal pressure as determined by the design formulas, for each element of the vessel using nominal thicknesses with corrosion allowances included and using the allowable stress values given in Subsection C for the temperature of the test.

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

(*g*) *Operating or Working Temperature*—The temperature that will be maintained in the metal of the part of the vessel being considered for the specified operation of the vessel (see UG-20 and UG-23).

(*h*) *Thickness of Vessel Wall*

(*1*) The "required thickness" is that computed by the formulas in this Division, before corrosion allowance is added (see UG-22).

(*2*) The "design thickness" is the sum of the required thickness and the corrosion allowance (see UG-25).

(*3*) The "nominal thickness" is the thickness selected as commercially available, and as supplied to the manufacturer; it may exceed the design thickness.

(*i*) *Efficiency of a Joint*

(*1*) *Welded Joint*—The efficiency of a welded joint is expressed as a numerical (decimal) quantity and is used in the design of a joint as a multiplier of the appropriate allowable stress value taken from the applicable table in Subsection C.

(*2*) *Riveted Joint*—The efficiency of a riveted joint is a reduction (decimal) factor which expresses the ratio of the lowest computed working strength of the joint for all the ways in which it might normally fail under a bursting pressure to the computed working strength of the solid plate adjacent to the joint, using the appropriate allowable stress values taken from the applicable table in Subsection C.

[1]Any coincident pressure and temperature during a specific operation are permissible, provided they do not constitute a more severe condition than that assumed in the design of the vessel; that is, if the resultant stresses as determined by the design formulas do not exceed the applicable stress values given in the tables in Subsection C; and assuming that any extra metal thickness added, or remaining, for corrosion allowance (and if still so needed) is gone.

(*j*) *Radiographing* (*RT*)—The process of passing electronic radiations through an object and obtaining a record of its soundness upon a sensitized film.

(*k*) *Magnetic Particle Examination* (*MT*)—A method of detecting cracks and similar discontinuities at or near the surface in iron and the magnetic alloys of steel. It consists of properly magnetizing the material and applying finely divided magnetic particles which form patterns indicating the discontinuities.

(*l*) *Liquid Penetrant Examination* (*PT*)—A method of nondestructive examination which provides for the detection of discontinuities open to the surface in ferrous and nonferrous materials which are nonporous. Typical discontinuities detectable by this method are cracks, seams, laps, cold shuts, and laminations.

(*m*) *Ultrasonic Examination* (*UT*)—A nondestructive means for locating and identifying internal discontinuities by detecting the reflections they produce of a beam of ultrasonic vibrations.

(*n*) *Bolt*—A threaded fastener with a head on one end.

(*o*) *Stud*— A threaded fastener without a head, with threads on one end or both ends, or threaded full length.

(*p*) *Clad Vessel*—A vessel made from plate having a corrosion resistant material integrally bonded to a base of less resistant material.

(*q*) *Lined Vessel*—A vessel having a corrosion resistant lining attached intermittently to the vessel wall.

(*r*) *Layer or Laminated Vessel*—A vessel having a shell which is made up of two or more separate layers.

(*s*) *Terms Relating to Welding*

Angle Joint—A joint between two members located in intersecting planes between zero (a butt joint) and 90 deg (a corner joint).

Arc Welding—A group of welding processes wherein coalescence is produced by heating with an electric arc or arcs, with or without the application of pressure and with or without the use of filler metal.

Atomic Hydrogen Welding—An arc welding process wherein coalescence is produced by heating with an electric arc maintained between two metal electrodes in an atmosphere of hydrogen. Shielding is obtained from the hydrogen. Pressure may or may not be used and filler metal may or may not be used.

Automatic Welding—Welding with equipment which performs the entire welding operation without constant observation and adjustment of the controls by an operator. The equipment may or may not perform the loading and unloading of the work.

Backing—Material (metal, weld metal, asbestos, carbon, granular flux, etc.) backing up the joint during welding to facilitate obtaining a sound weld at the root.

Base Metal—The metal to be welded or cut.

Butt Joint—A joint between two members lying approximately in the same plane.

Corner Joint—A joint between two members located approximately at right angles to each other in the form of an L.

Double-Welded Butt Joint—A butt joint welded from both sides.

NOTE: A joint with filler metal added from one side only may be considered equivalent to a double-welded butt joint only within the limitations of Type No. (1) of Table UW-12.

Double-Welded Lap Joint—A lap joint in which the overlapped edges of the members to be joined are welded along the edges of both members.

Edge Joint—A joint between the edges of two or more parallel or nearly parallel members.

Filler Metal—Metal to be added in making a weld.

Fillet Weld—A weld of approximately triangular cross section joining two surfaces approximately at right angles to each other in a lap joint, tee joint, or corner joint.

Forge Welding—A group of welding processes wherein coalescence is produced by heating in a forge or other furnace and by applying pressure or blows.

Full Fillet Weld—A fillet weld whose size is equal to the thickness of the thinner member joined.

Fusion—The melting together of filler metal and base metal, or of base metal only, which results in coalescence.

Gas Metal-Arc Welding—An arc welding process wherein coalescence is produced by heating with an electric arc between a filler metal (consumable) electrode and the work. Shielding is obtained from a gas, a gas mixture (which may contain an inert gas) or a mixture of a gas and a flux. (This process has sometimes been called Mig welding).

Gas Tungsten-Arc Welding—An arc welding process wherein coalescence is produced by heating with an electric arc between a single tungsten nonconsumable electrode and the work. Shielding is obtained from a gas or gas mixture (which may

contain an inert gas). Pressure may or may not be used and filler metal may or may not be used. (This process has sometimes been called Tig welding.)

Gas Welding—A group of welding processes wherein coalescence is produced by heating with a gas flame or flames with or without the application of pressure, and with or without the use of filler metal.

Groove Weld—A weld made in the groove between two members to be joined.

Heat Affected Zone—That portion of the base metal which has not been melted, but whose mechanical properties or microstructures have been altered by the heat of welding or cutting.

Induction Welding—A welding process wherein coalescence is produced by the heat obtained from resistance of the work to the flow of induced electric current, with or without the application of pressure.

Joint Penetration—The minimum depth a groove weld extends from its face into a joint, exclusive of reinforcement.

Lap Joint—A joint between two overlapping members.

Machine Welding—Welding with equipment which performs the welding operation under the observation and control of an operator. The equipment may or may not perform the loading and unloading of the work.

Manual Welding—Welding wherein the entire welding operation is performed and controlled by hand.

Overlap—Protrusion of weld metal beyond the bond at the toe of the weld.

Oxyacetylene Welding—A gas welding process wherein coalescence is produced by heating with a gas flame or flames obtained from the combustion of acetylene with oxygen, with or without the application of pressure and with or without the use of filler metal.

Oxygen Cutting—A group of cutting processes wherein the severing of metals is effected by means of the chemical reaction of oxygen with the base metal at elevated temperatures. In the case of oxidation resistant metals the reaction is facilitated by use of a flux or metal powder.

Oxyhydrogen Welding—A gas welding process wherein coalescence is produced by heating with a gas flame or flames obtained from combustion of hydrogen with oxygen, without the application of pressure and with or without the use of filler metal.

Plasma arc welding—A gas tungsten-arc welding process wherein coalescence is produced by heating with a constricted arc between an electrode and a work piece (transferred arc) or the electrode and the constricting nozzle (nontransferred arc). Shielding is obtained from hot ionized gas issuing from the orifice which may be supplemented by an auxiliary source of shielding gas. Shielding gas may be an inert gas or a mixture of gases, pressure may or may not be used, and filler metal may or may not be used.

Plug Weld—A circular weld made through a hole in one member of a lap or tee joint joining that member to the other. The walls of the hole may or may not be parallel and the hole may be partially or completely filled with weld metal. (A fillet welded hole or a spot weld should not be construed as conforming to this definition.)

Porosity—Gas pockets or voids in metal.

Postweld Heat Treatment—Uniform heating of a structure or portion thereof to a sufficient temperature, below the critical range, to relieve the major portion of the residual stresses, followed by uniform cooling.

Pressure Gas Welding—A gas welding process wherein coalescence is produced simultaneously over the entire area of abutting surfaces, by heating with gas flames obtained from the combustion of a fuel gas with oxygen and by the application of pressure without the use of filler metal.

Pressure Welding—Any welding process or method wherein pressure is used to complete the weld.

Reinforcement of Weld—Weld metal on the face of a groove weld in excess of the metal necessary for the specified weld size.

Resistance Welding—A group of welding processes wherein coalescence is produced by the heat obtained from resistance of the work to the flow of electric current in a circuit of which the work is a part, and by the application of pressure.

Seal Weld—Any weld used primarily to obtain tightness.

Semiautomatic Arc Welding—Arc welding with equipment which controls only the filler metal feed. The advance of the welding is manually controlled.

Shielded Metal-Arc Welding—An arc welding process wherein coalescence is produced by heating with an electric arc between a covered metal electrode and the work. Shielding is obtained from decomposition of the electrode covering. Pressure is not used and filler metal is obtained from the electrode.

Single-Welded Butt Joints—A butt joint welded from one side only.

Single-Welded Lap Joint—A lap joint in which

the overlapped edges of the members to be joined are welded along the edge of one member.

Size of Weld:

Groove Weld—The joint penetration (depth of chamfering plus the root penetration when specified).

Fillet Weld—For equal-leg fillet welds, the leg length of the largest isosceles right-triangle which can be inscribed within the fillet weld cross section.

For unequal-leg fillet welds, the leg lengths of the largest right triangle which can be inscribed within the fillet weld cross section.

Slag Inclusion—Nonmetallic solid material entrapped in weld metal or between weld metal and base metal.

Submerged Arc Welding—An arc welding process wherein coalescence is produced by heating with an electric arc or arcs between a bare metal electrode or electrodes and the work. The welding is shielded by a blanket of granular, fusible material on the work. Pressure is not used and filler metal is obtained from the electrode and sometimes from a supplementary welding rod.

Tee Joint—A joint between two members located approximately at right angles to each other in the form of a T.

Thermit Welding—A group of welding processes wherein coalescence is produced by heating with superheated liquid metal and slag resulting from a chemical reaction between a metal oxide and aluminimum, with or without the application of pressure. Filler metal, when used, is obtained from the liquid metal.

Throat of a Fillet Weld:

Theoretical—The distance from the beginning of the root of the joint perpendicular to the hypotenuse of the largest right triangle that can be inscribed within the fillet weld cross section.

Actual—The shortest distance from the root of a fillet weld to its face.

Undercut—A groove melted into the base metal adjacent to the toe of a weld and left unfilled by weld metal.

Weld—A localized coalescence of metal wherein coalescence is produced by heating to suitable temperatures, with or without the application of pressure, and with or without the use of filler metal. The filler metal has a melting point approximately the same as the base metals.

Weld Metal—That portion of a weld which has been melted during welding.

Welded Joint—A union of two or more members produced by the application of a welding process.

Welder—One who is capable of performing a manual or semiautomatic welding operation.

Welding Operator—One who operates machine or automatic welding equipment.

APPENDIX IV
POROSITY CHARTS

UA-65 Acceptance Standards for Radiographically Determined Porosity in Welds

(*a*) These standards are applicable to ferritic, austenitic, and nonferrous materials.

(*b*) The total area of porosity as determined from the radiographic film shall not exceed 0.060*T* square inches in any 6-in. length of weld, where *T* is the thickness of the weld. If the weld is less than 6-in. long, the total area of porosity will be reduced in proportion.

(*1*) The maximum pore dimension shall be 20 percent of *T*, or 1/8 in., whichever is smaller, except that an isolated pore separated from an adjacent pore by 1-in. or more may be 30 percent of *T*, or 1/4 in., whichever is less.

(*2*) Dark images of a generally circular or oval shape shall be interpreted as porosity for the purposes of this standard.

(*c*) The porosity charts in this Appendix illustrate various types of assorted and uniform, randomly dispersed porosity indications. These charts for each thickness represent the maximum acceptable porosity. The charts represent full-scale 6-in. radiographs, and shall not be enlarged or reduced. The porosity distributions shown are not necessarily the patterns that may appear on the radiograph, but are typical of the number and size of indications permitted. When porosity indications differ significantly from the porosity charts, the actual numbers and sizes of the pores may be measured and the total area of porosity calculated.

(*d*) In any 1-in. length of weld or 2*T*, whichever is smaller, porosity may be clustered to a concentration 4 times that permitted by 0.06*T*. Such clustered porosity shall be included in the porosity in any 6-in. length of weld which includes the cluster.

(*e*) Aligned porosity shall be acceptable providing the summation of the diameters of the pores is no more than *T* in a length 12*T*, or 6 in., whichever is less, providing each pore is separated by a distance at least 6 times the diameter of the largest adjacent pore. Aligned porosity indications shall be counted in the total area of permissible indications in any 6-in. length of weld.

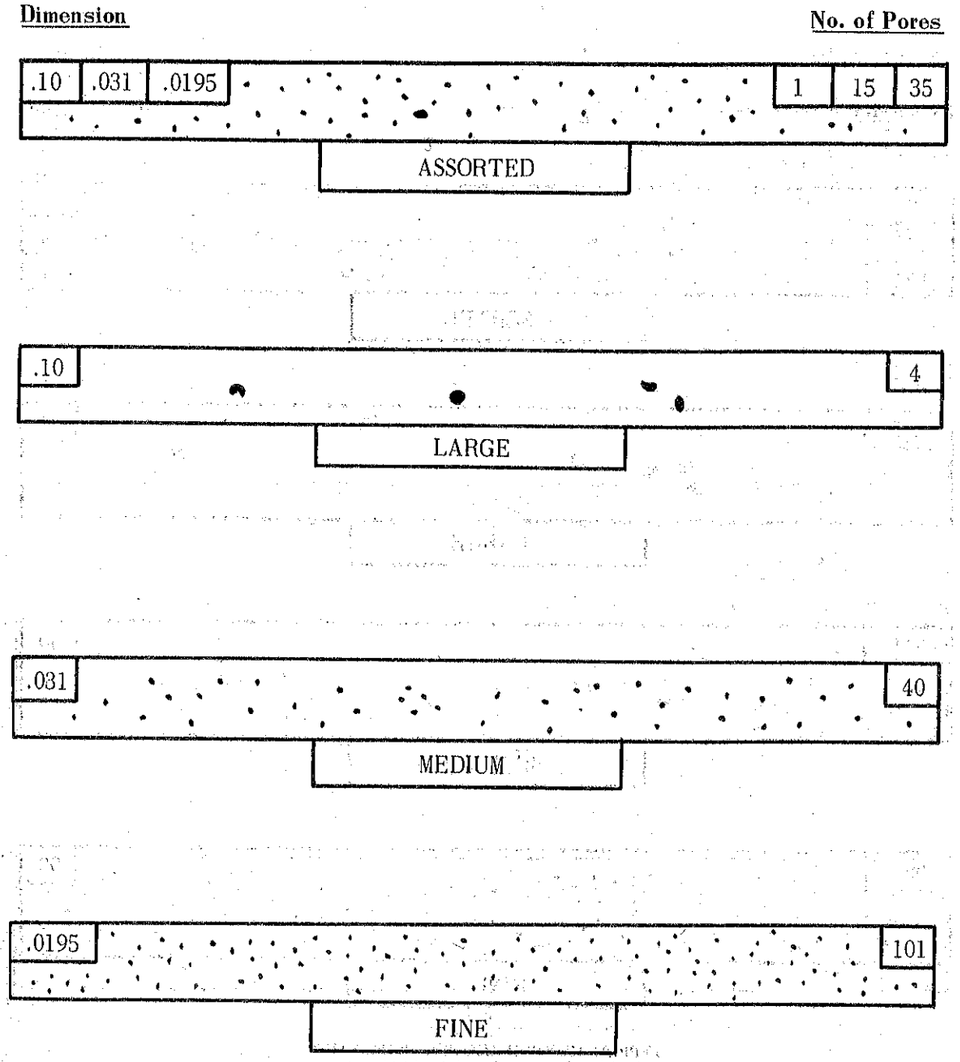
(*f*) Permissible porosity indications for weld thicknesses intermediate to those illustrated may be evaluated either by comparison with the next thinner material or by calculation as shown in Table UA-65.

Permissible porosity for greater thicknesses shall not exceed 0.060*T* in. in any 6-in. length of weld.

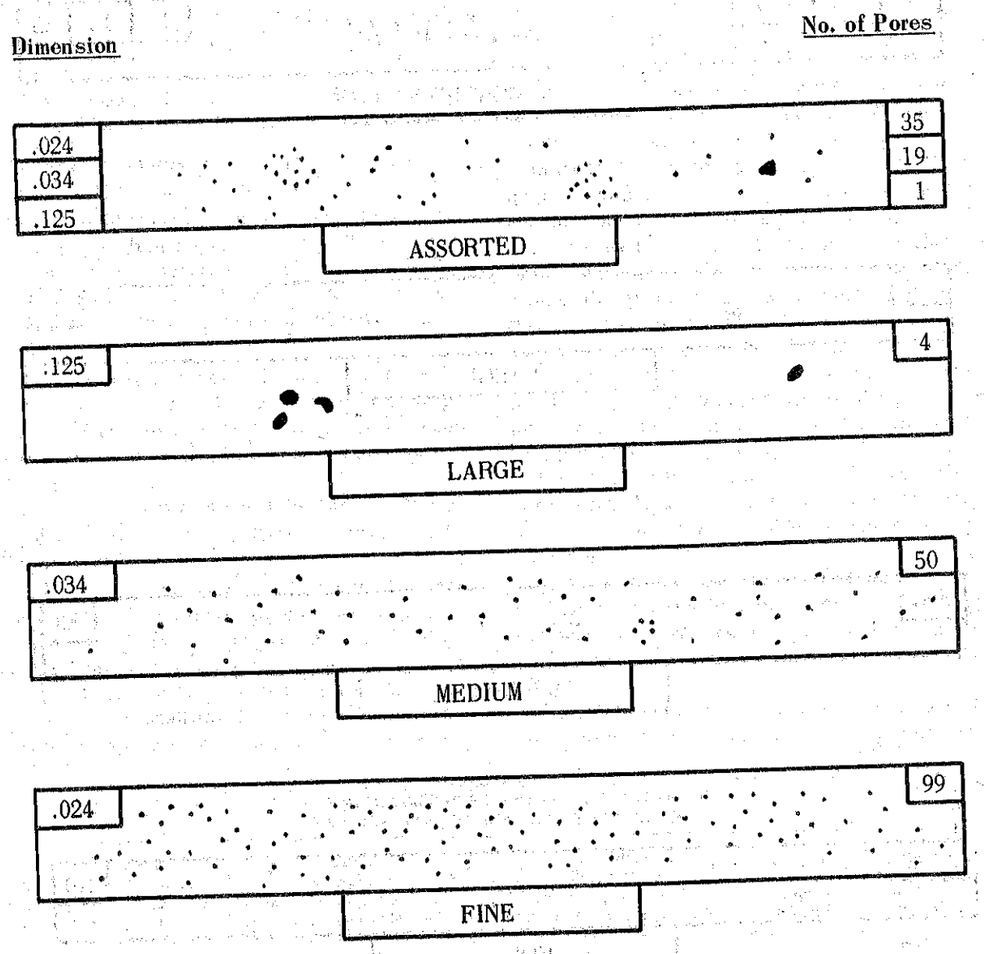
TABLE UA-65
MAXIMUM PERMISSIBLE POROSITY INDICATIONS IN RADIOGRAPHS PER 6-IN. LENGTH OF WELD

Weld Thickness, in.	Total Area of Permitted Porosity, sq in.	LARGE Pore Size, in. Approx. Fraction	LARGE Pore Size, in. Decimal Value (1)	LARGE No.	MEDIUM Pore Size, in. Approx. Fraction	MEDIUM Pore Size, in. Decimal Value (1)	MEDIUM No.	FINE Pore Size, in. Approx. Fraction	FINE Pore Size, in. Decimal Value (1)	FINE No.
1/8	.0075	....	....	....	....	....	....	1/64	.014	49
1/4	.015	....	....	....	3/128	.025	31	1/64	.0138	100
1/2	.030	3/32	.10	4	1/32	.031	40	3/128	.0195	101
3/4	.045	1/8	.125	4	1/32	.034	50	5/128	.024	99
1	.060	1/8	.125	5	5/128	.039	50	1/32	.0275	101
1 1/2	.090	1/8	.125	7	3/64	.048	50	1/32	.034	99
2	.120	1/8	.125	10	7/128	.055	51	5/128	.039	100
2 1/2	.150	1/8	.125	12	1/16	.061	51	3/64	.044	99
3	.180	1/8	.125	15	1/16	.068	50	3/64	.048	99
3 1/2	.210	1/8	.125	17	5/64	.073	50	7/128	.052	99
4	.240	1/8	.125	20	5/64	.078	50	7/128	.055	101

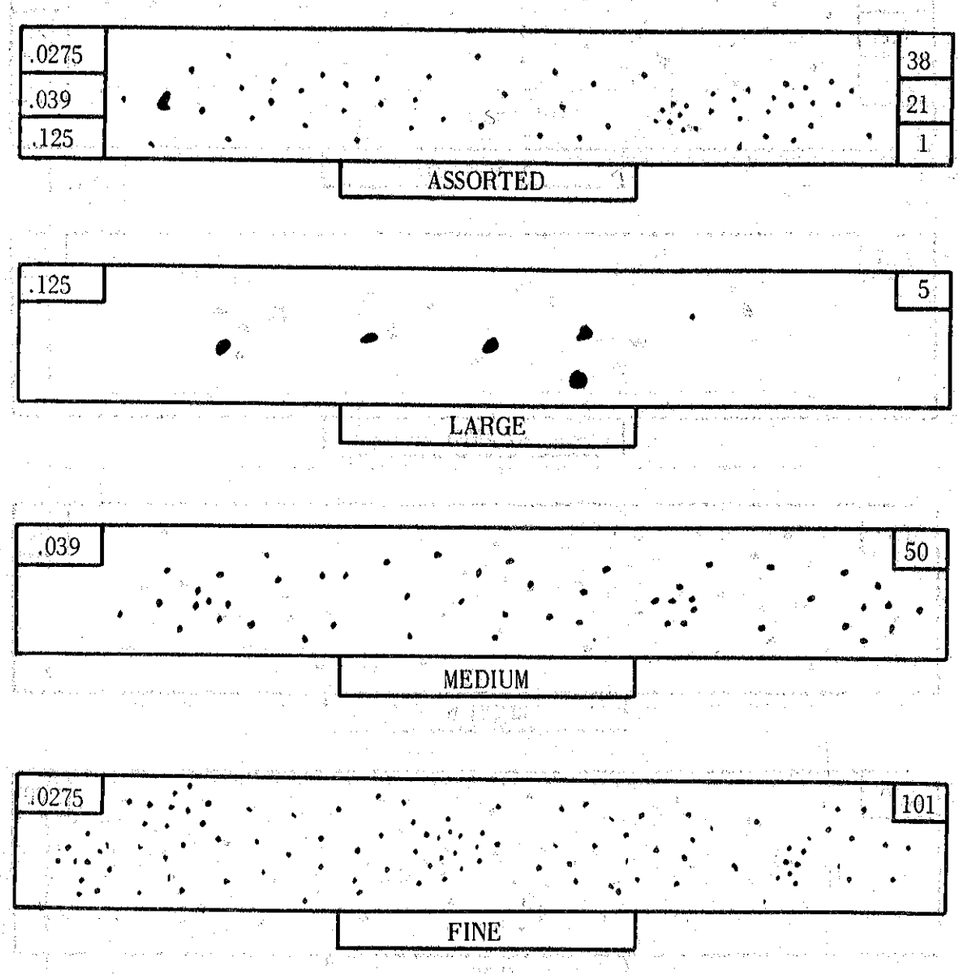
(1) These values used for calculating total area of permissible porosity given in second column.



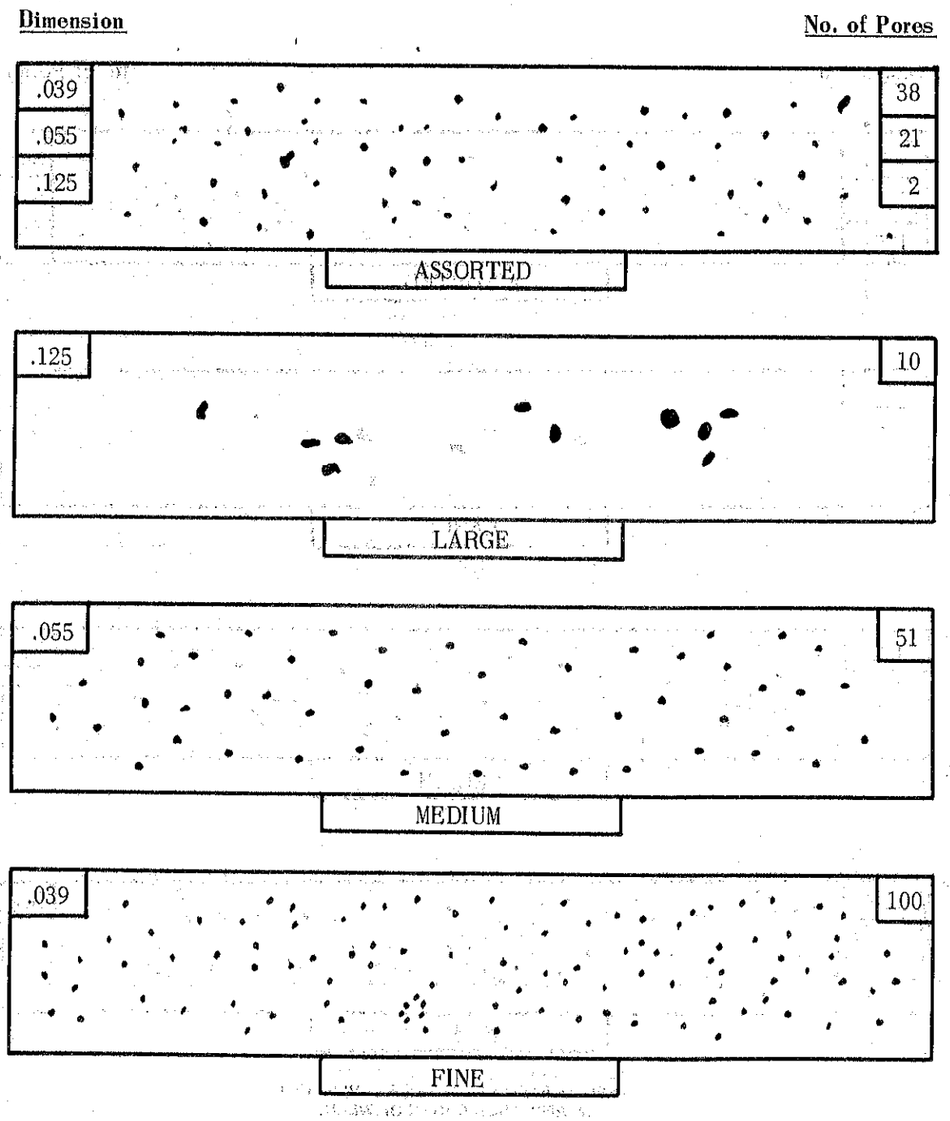
TYPICAL NUMBER AND SIZE PERMITTED IN ANY 6-IN. LENGTH OF WELD. ½-IN. WELD THICKNESS. TOTAL PORE AREA PERMITTED IS 0.030 SQ IN.



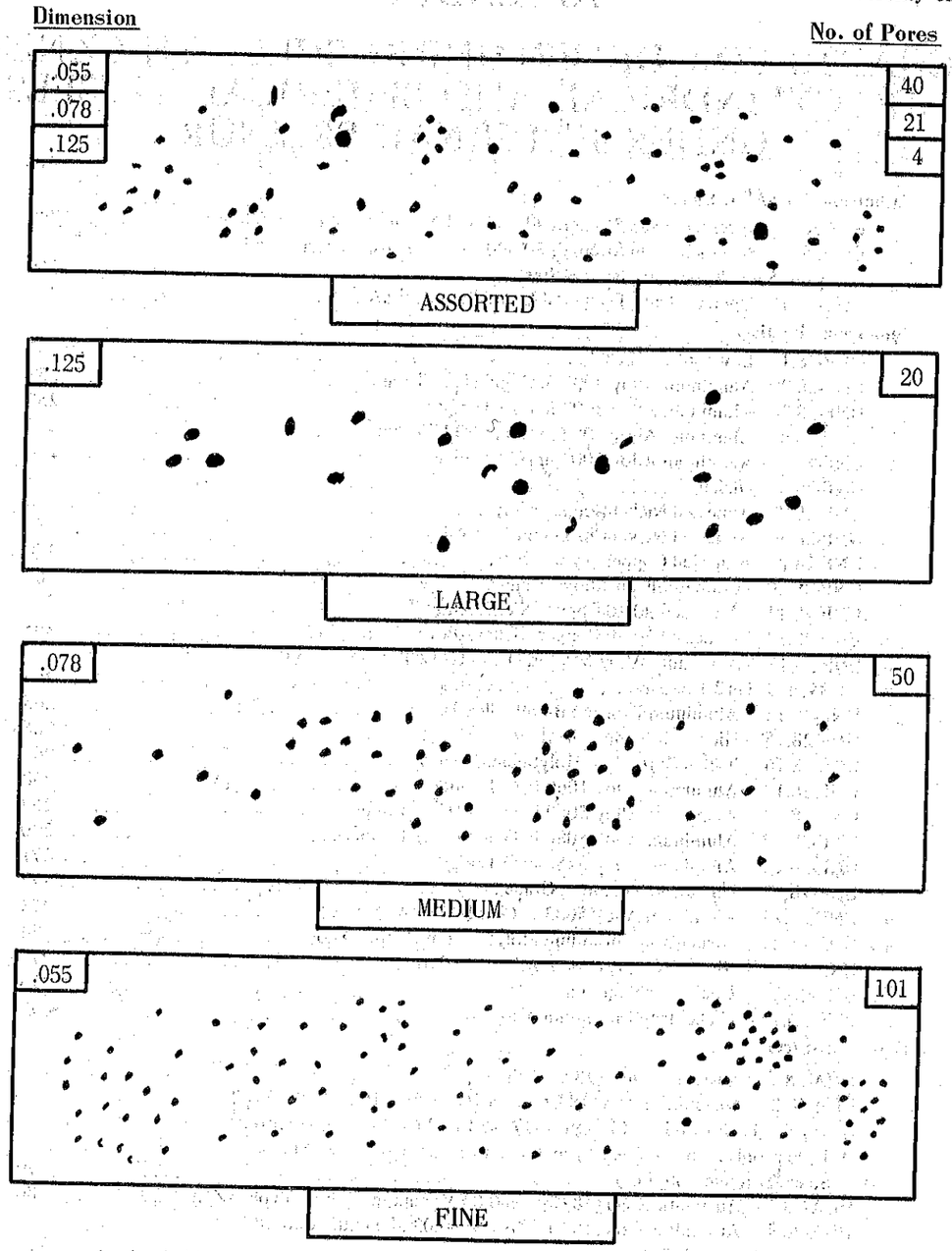
TYPICAL NUMBER AND SIZE PERMITTED
IN ANY 6-IN. LENGTH OF WELD.
¾-IN. WELD THICKNESS.
TOTAL PORE AREA PERMITTED IS 0.045 SQ IN.



TYPICAL NUMBER AND SIZE PERMITTED
IN ANY 6-IN. LENGTH OF WELD.
1-IN. WELD THICKNESS.
TOTAL PORE AREA PERMITTED IS 0.060 SQ IN.



TYPICAL NUMBER AND SIZE PERMITTED
IN ANY 6-IN. LENGTH OF WELD,
2-IN. WELD THICKNESS,
TOTAL PORE AREA PERMITTED IS 0.120 SQ IN.



TYPICAL NUMBER AND SIZE PERMITTED
IN ANY 6-IN. LENGTH OF WELD,
4-IN. WELD THICKNESS,
TOTAL PORE AREA PERMITTED IS 0.240 SQ IN.

APPENDIX V

CHARTS FOR DETERMINING SHELL THICKNESS OF CYLINDRICAL AND SPHERICAL VESSELS UNDER EXTERNAL PRESSURE

Fig. — Page

Carbon and Low-Alloy Steels

UCS-28.1 – Specified Yield Strength 24,000 to, but not including, 30,000 psi 249
UCS-28.2 – Specified Yield Strength 30,000 to 38,000 psi, inclusive, and Type 405 and Type 410 Stainless Steel 250
UHT-28.1 – Quenched and Tempered Low-Alloy Steel SA-517A, E, and F 251

Nonferrous Materials

UNF-28.1 – Low-Carbon Nickel 252
UNF-28.2 – Aluminum Alloy 3003 in O and H112 Temper 253
UNF-28.3 – Aluminum Alloy 3003 in H14 Temper 254
UNF-28.4 – Aluminum Alloy 3004 in O and H112 Temper 255
UNF-28.5 – Aluminum Alloy 3004 in H34 Temper 256
UNF-28.6 – Nickel 257
UNF-28.7 – Annealed Nickel-Copper Alloy 258
UNF-28.8 – Annealed Nickel-Chromium-Iron Alloy 259
UNF-28.9 – Annealed Copper, Type DHP 260
UNF-28.10 – Copper-Silicon Alloys A and C 261
UNF-28.11 – Annealed 90-10 Copper-Nickel Alloy 262
UNF-28.12 – Annealed 70-30 Copper-Nickel Alloy 263
UNF-28.13 – Aluminum Alloy 5154 in O and H112 Temper and 5454 in O, H32, H34, and H112 Temper 264
UNF-28.14 – Aluminum Bronze SB-169 Alloy D 265
UNF-28.15 – Nickel-Molybdenum Alloy 266
UNF-28.16 – Nickel-Chromium-Molybdenum Alloy 267
UNF-28.17 – Aluminum Alloy 1060 in O Temper 268
UNF-28.18 – Aluminum Alloy 5052 in O and H112 Temper 269
UNF-28.19 – Aluminum Alloy 5086 in O and H112 Temper 270
UNF-28.20 – Aluminum Alloy 5456 in O Temper 271
UNF-28.22 – Unalloyed Titanium, Grade 3 272
UNF-28.23 – Aluminum Alloy 5083 in O or H113 Temper 273
UNF-28.25 – Nickel-Iron-Chromium-Molybdenum-Copper Alloy 274
UNF-28.27 – Nickel-Iron-Chromium Alloy, Grade 1 275
UNF-28.28 – Unalloyed Titanium Grade 2 276
UNF-28.29 – Nickel-Iron-Chromium Alloy Grade 2 277

High-Alloy Steel

UHA-28.1 – Austenitic Steel (18 Cr-8 Ni, Type 304) 278
UHA-28.2 – Austenitic Steels (18 Cr-8 Ni + Mo, Type 316; 18 Cr-8 Ni + Ti, Type 321; 18 Cr-8 Ni + Cb, Type 347; 25 Cr-12 Ni, Type 309 (Through 1100 F only); 25 Cr-20 Ni, Type 310; and 17 Cr, Type 430B Stainless Steel (Through 700 F only) 279
UHA-28.3 – Austenitic Steel (18 Cr-8 Ni-0.03 Maximum Carbon, Type 304L) 280
UHA-28.4 – Austenitic Steel (18 Cr-8 Ni + Mo-0.03 Maximum Carbon, Types 316L and 317L) 281
UCS-28.2 – Type 405 and Type 410 Stainless Steel 250

Cast Iron

UCI-28 – Cast Iron 282
UCN-28 – Cast Ductile Iron 283

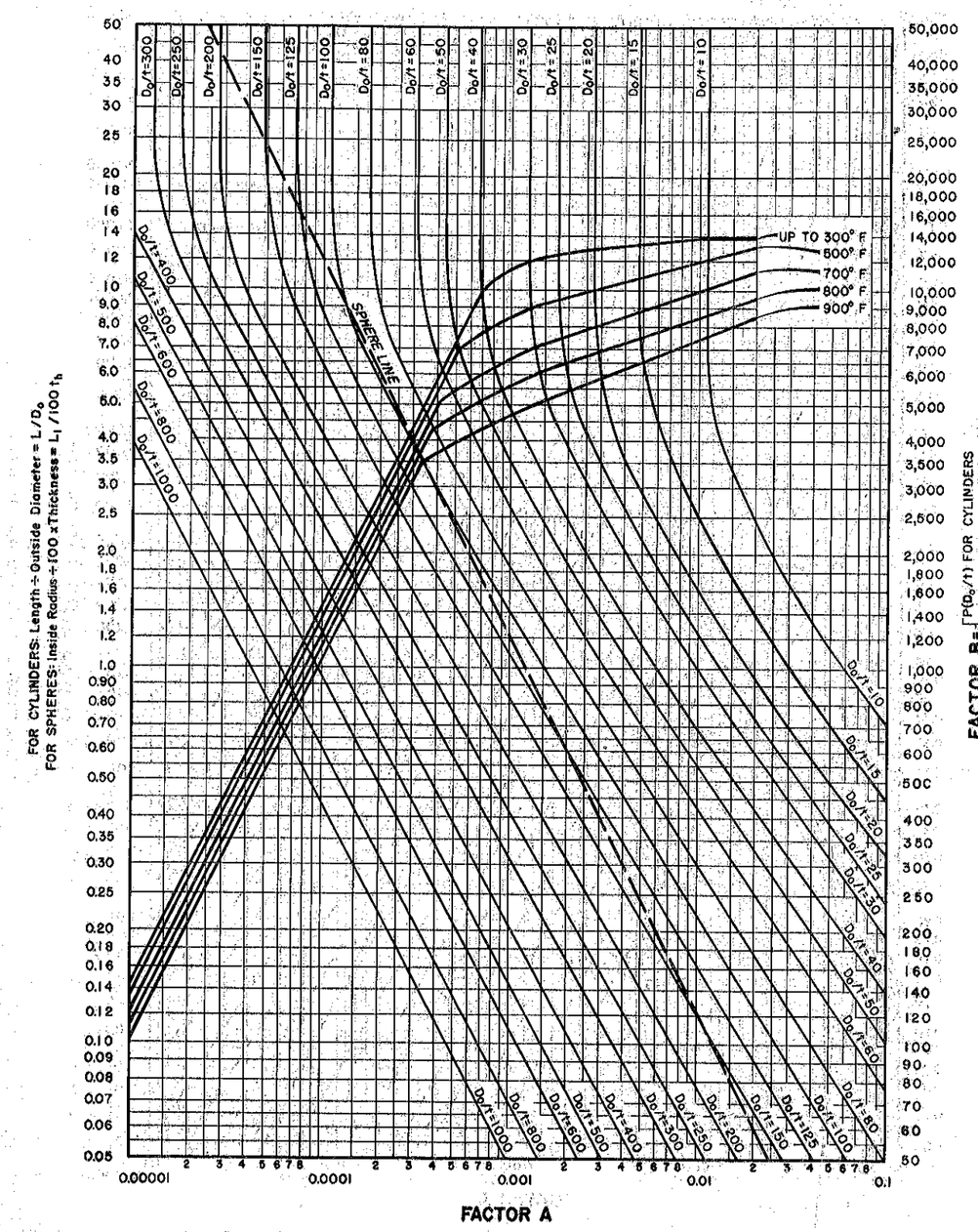


FIG. UCS-28.1 CHART FOR DETERMINING SHELL THICKNESS OF CYLINDRICAL AND SPHERICAL VESSELS UNDER EXTERNAL PRESSURE WHEN CONSTRUCTED OF CARBON STEEL (Specified Yield Strength 24,000 psi to, but not including, 30,000 psi)

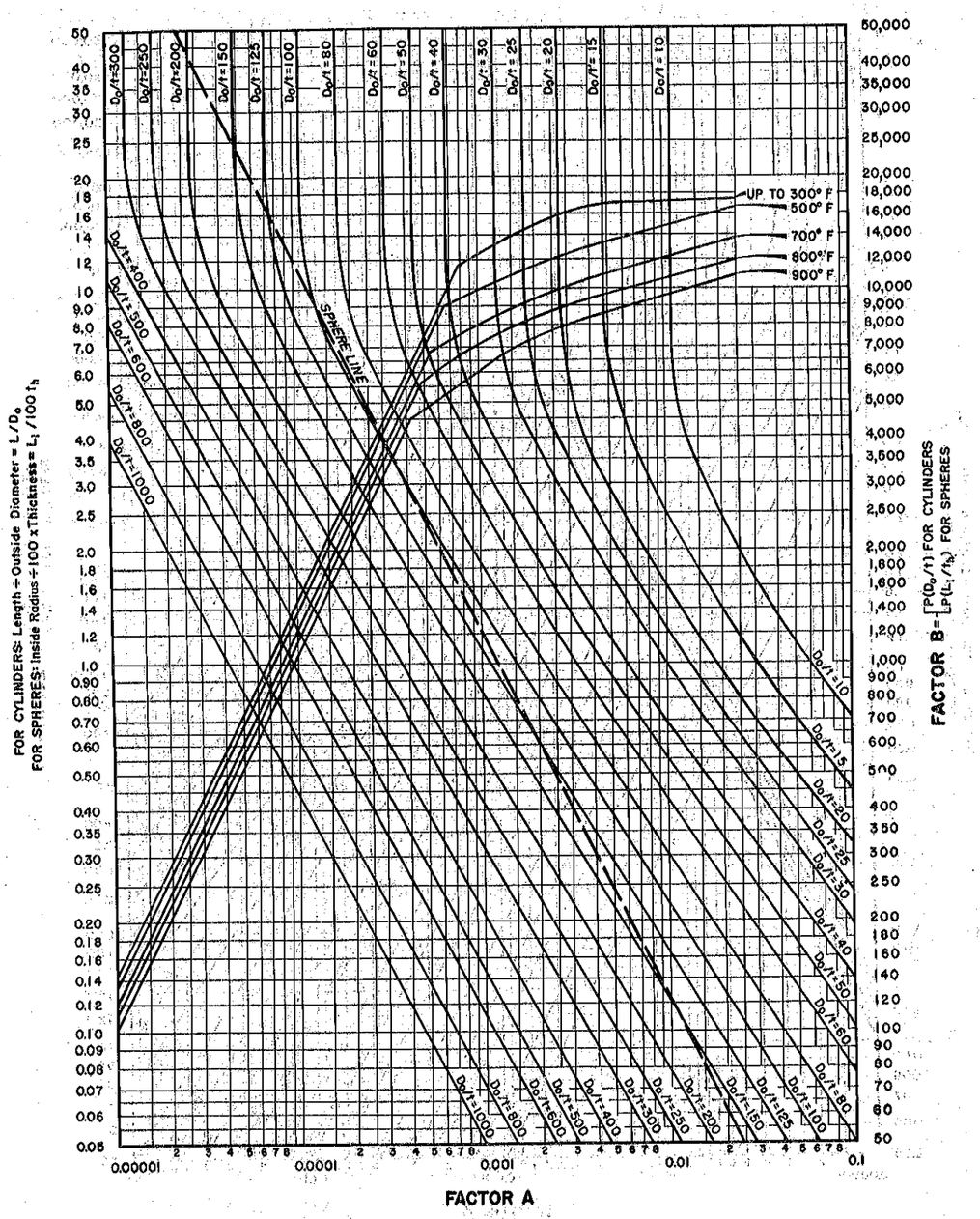


FIG. UCS-28.2 CHART FOR DETERMINING SHELL THICKNESS OF CYLINDRICAL AND SPHERICAL VESSELS UNDER EXTERNAL PRESSURE WHEN CONSTRUCTED OF CARBON STEEL (Specified Yield Strength 30,000 to 38,000 psi, inclusive) AND TYPE 405 AND TYPE 410 STAINLESS STEEL

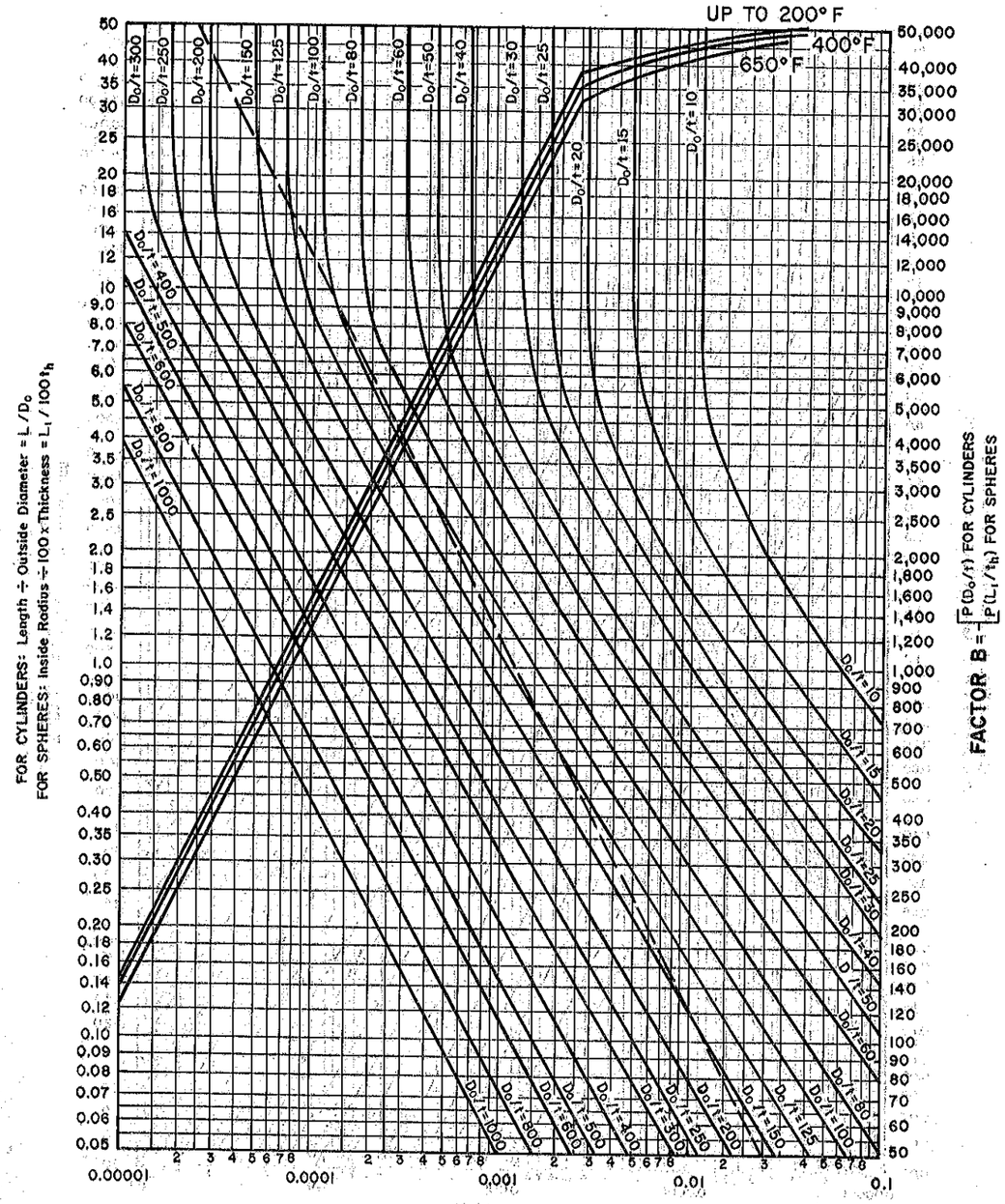


FIG. UHT-28.1 CHART FOR DETERMINING SHELL THICKNESS OF CYLINDRICAL AND SPHERICAL VESSELS UNDER EXTERNAL PRESSURE WHEN CONSTRUCTED OF QUENCHED AND TEMPERED LOW-ALLOY STEEL SA-517A, E, AND F

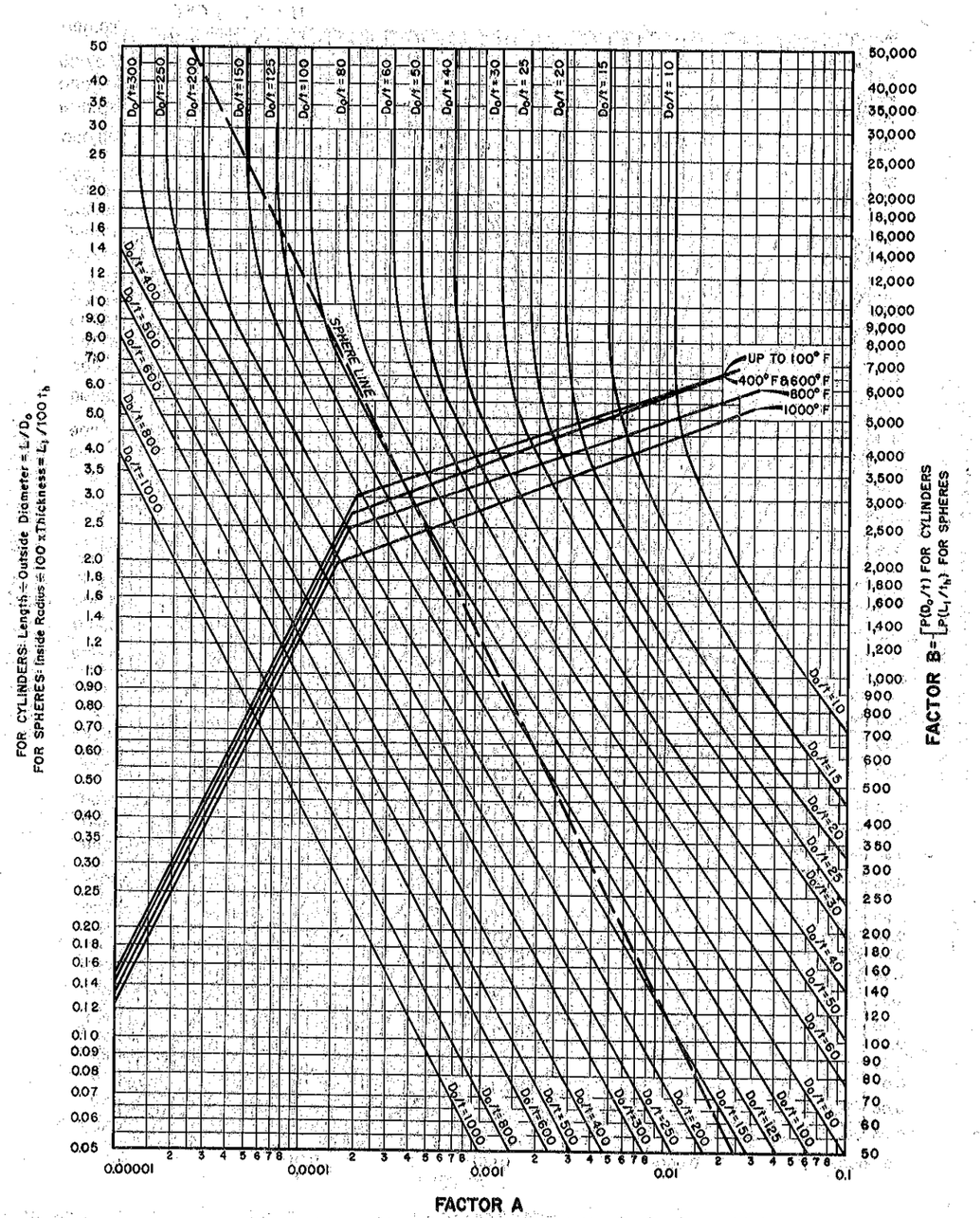


FIG. UNF-28.1 CHART FOR DETERMINING SHELL THICKNESS OF CYLINDRICAL AND SPHERICAL VESSELS UNDER EXTERNAL PRESSURE WHEN CONSTRUCTED OF LOW-CARBON NICKEL

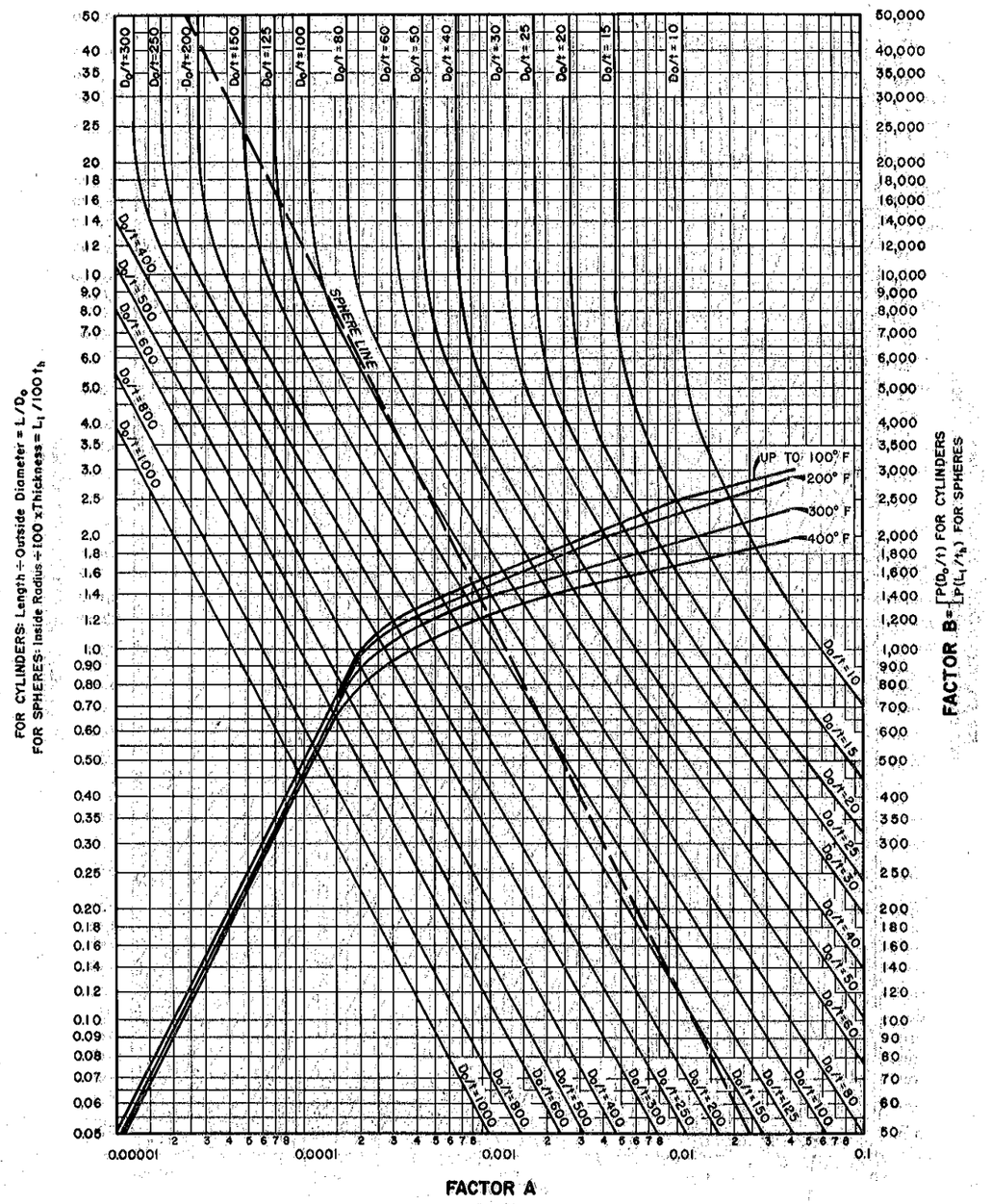


FIG. UNF-28.2 CHART FOR DETERMINING SHELL THICKNESS OF CYLINDRICAL AND SPHERICAL VESSELS UNDER EXTERNAL PRESSURE WHEN CONSTRUCTED OF ALUMINUM ALLOY 3003 IN O AND H112 TEMPER

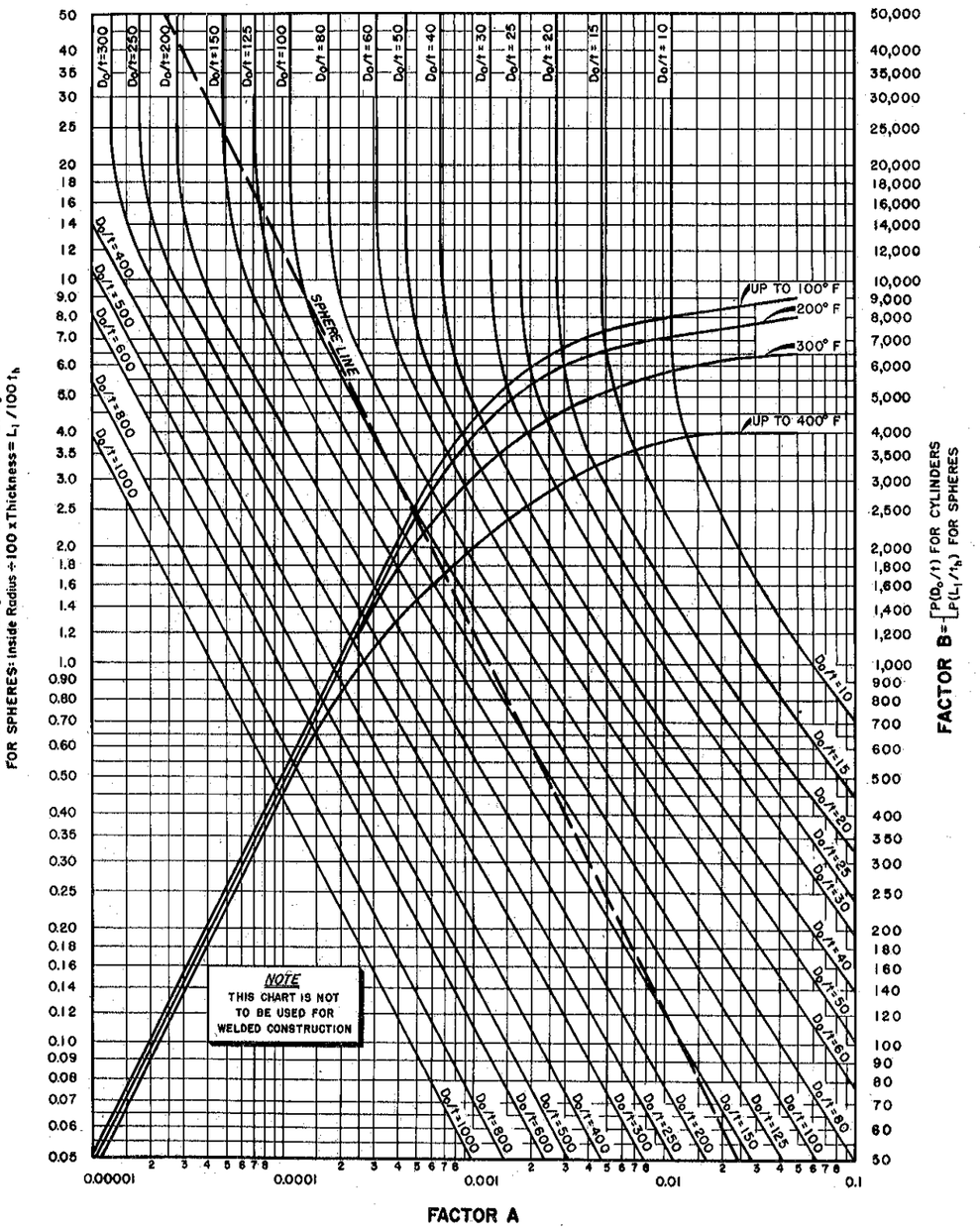


FIG. UNF-28.3 CHART FOR DETERMINING SHELL THICKNESS OF CYLINDRICAL AND SPHERICAL VESSELS UNDER EXTERNAL PRESSURE WHEN CONSTRUCTED OF ALUMINUM ALLOY 3003 IN H14 TEMPER

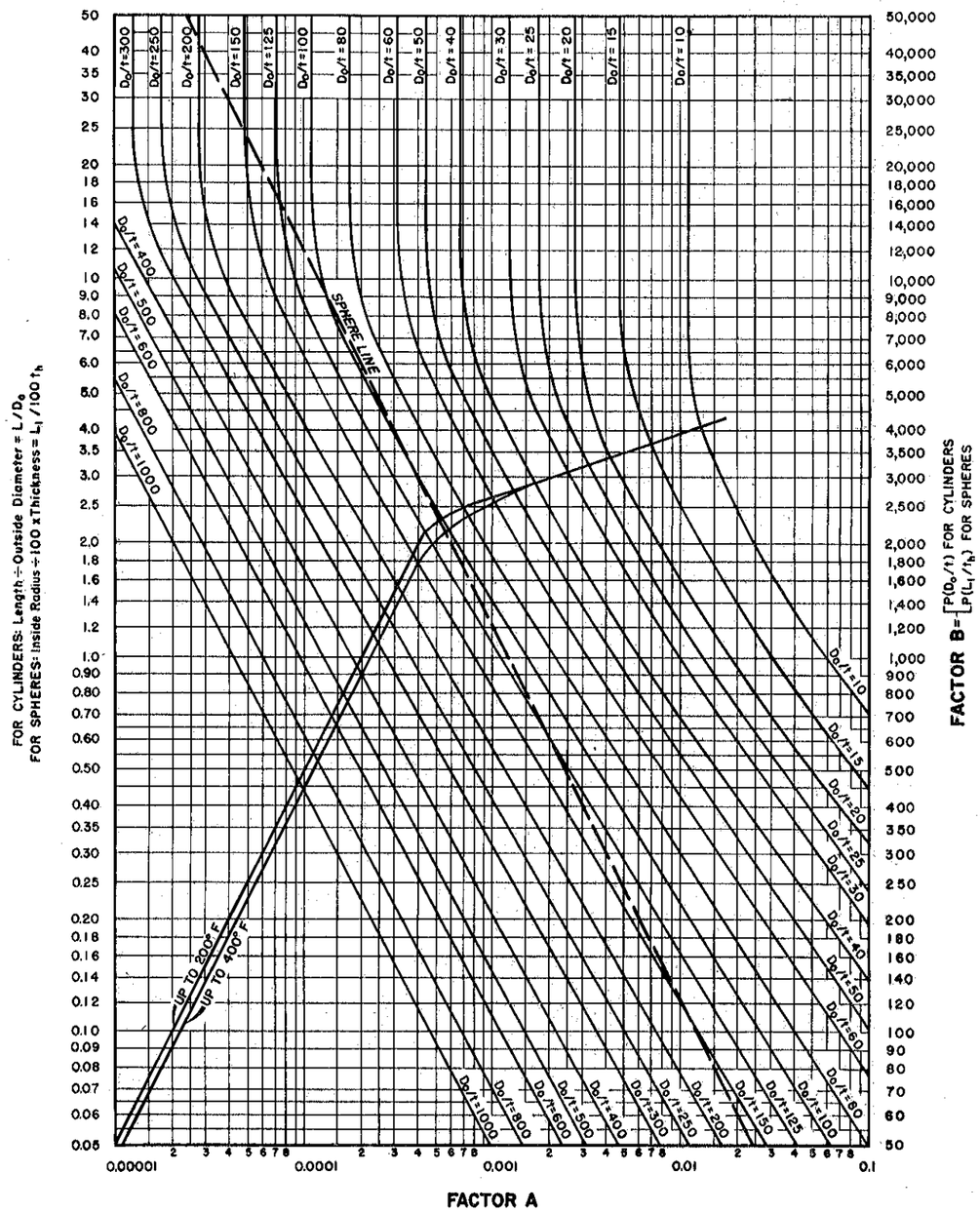


FIG. UNF-28.4 CHART FOR DETERMINING SHELL THICKNESS OF CYLINDRICAL AND SPHERICAL VESSELS UNDER EXTERNAL PRESSURE WHEN CONSTRUCTED OF ALUMINUM ALLOY 3004 IN O AND H112 TEMPER

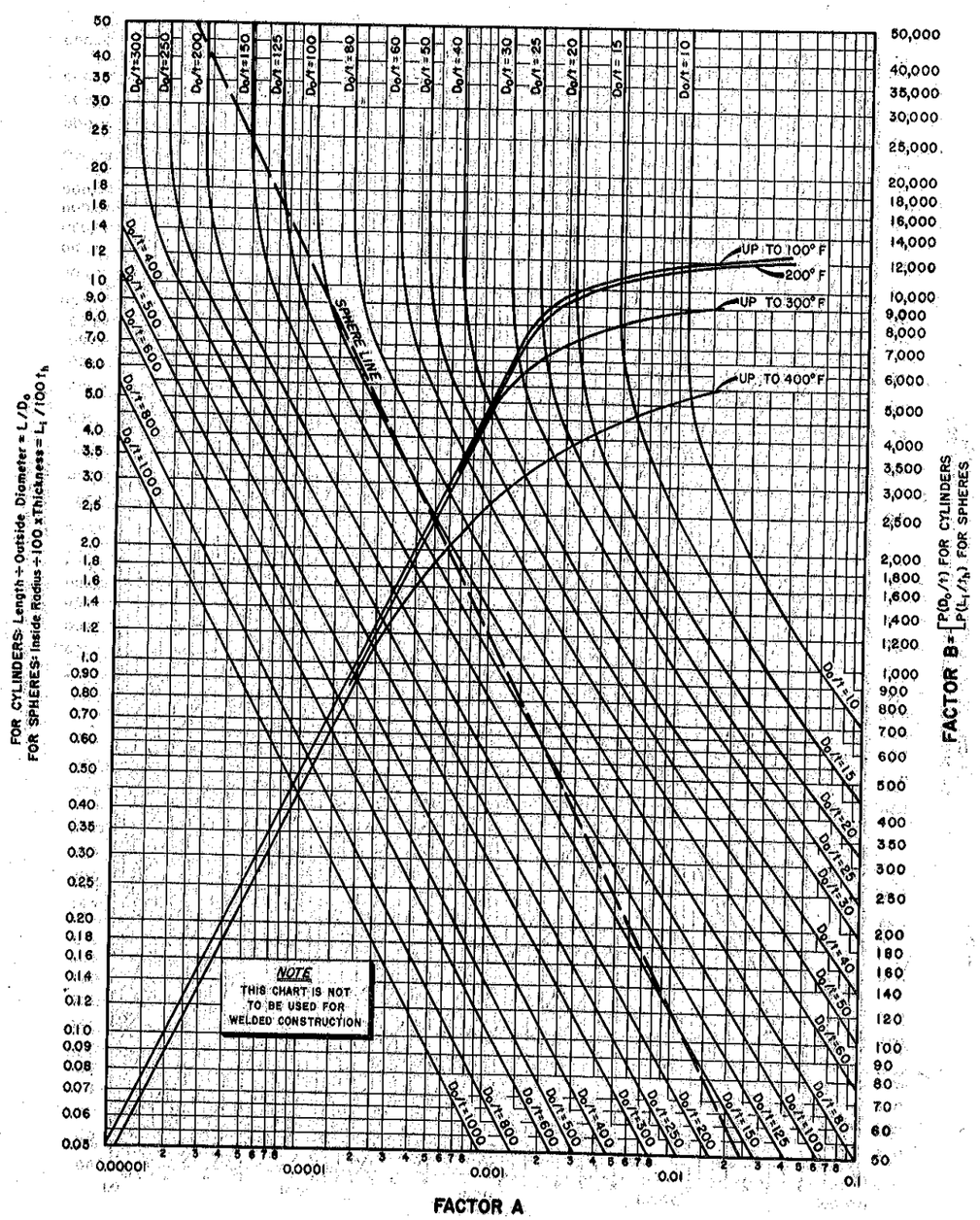


FIG. UNF-28.5 CHART FOR DETERMINING SHELL THICKNESS OF CYLINDRICAL AND SPHERICAL VESSELS UNDER EXTERNAL PRESSURE WHEN CONSTRUCTED OF ALUMINUM ALLOY 3004 IN H34 TEMPER

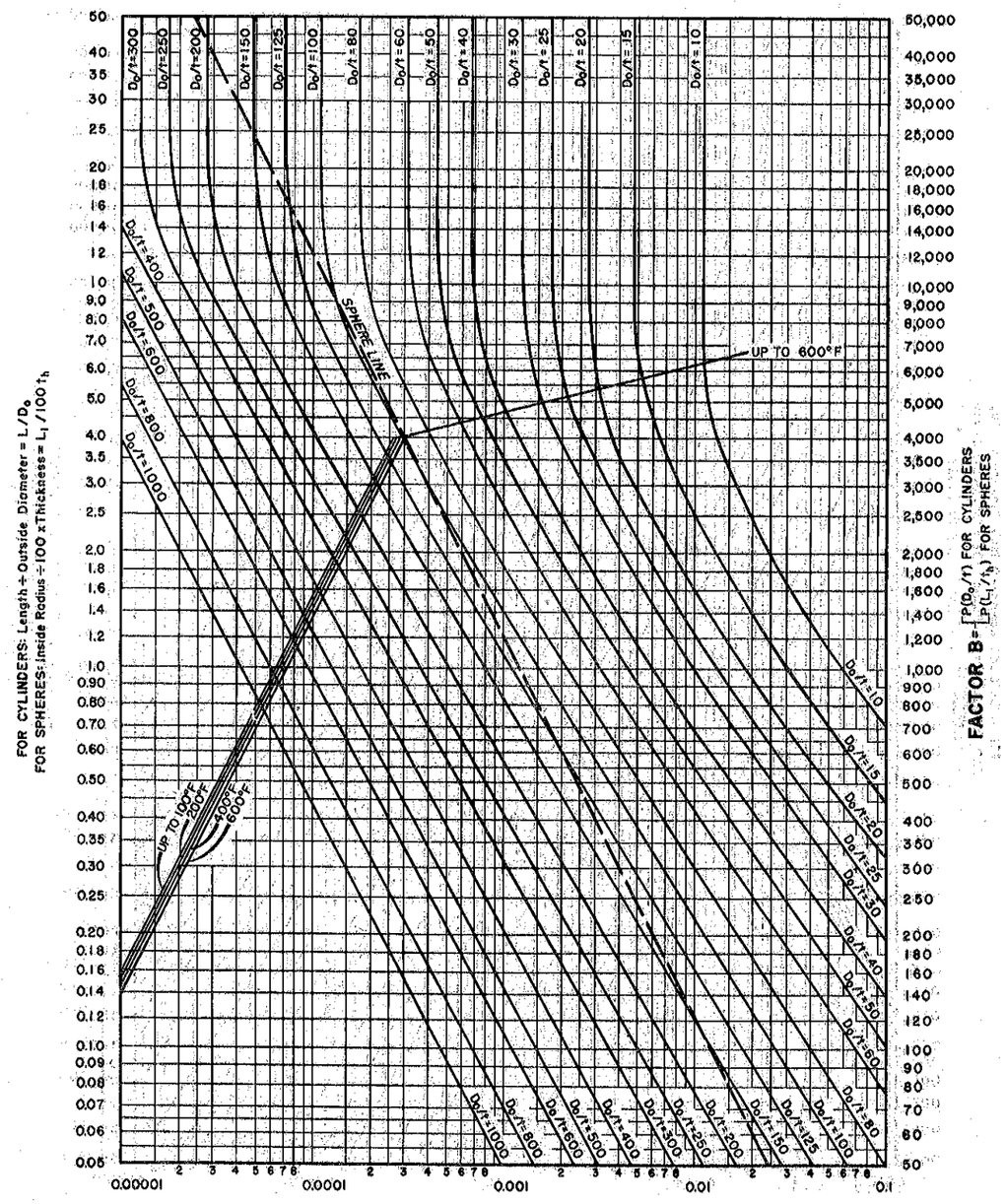


FIG. UNF-28.6 CHART FOR DETERMINING SHELL THICKNESS OF CYLINDRICAL AND SPHERICAL VESSELS UNDER EXTERNAL PRESSURE WHEN CONSTRUCTED OF NICKEL

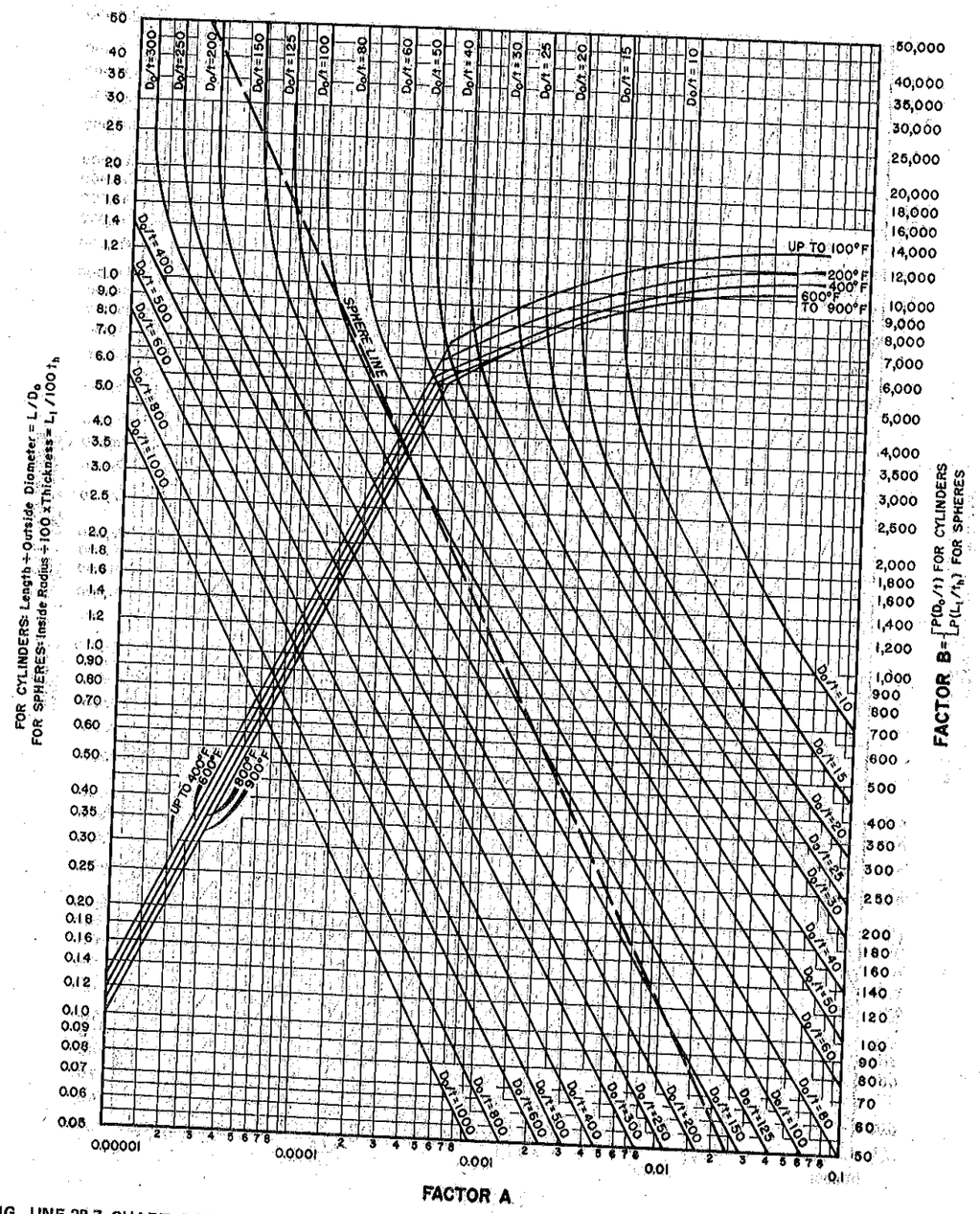


FIG. UNF-28.7 CHART FOR DETERMINING SHELL THICKNESS OF CYLINDRICAL AND SPHERICAL VESSELS UNDER EXTERNAL PRESSURE WHEN CONSTRUCTED OF ANNEALED NICKEL-COPPER ALLOY

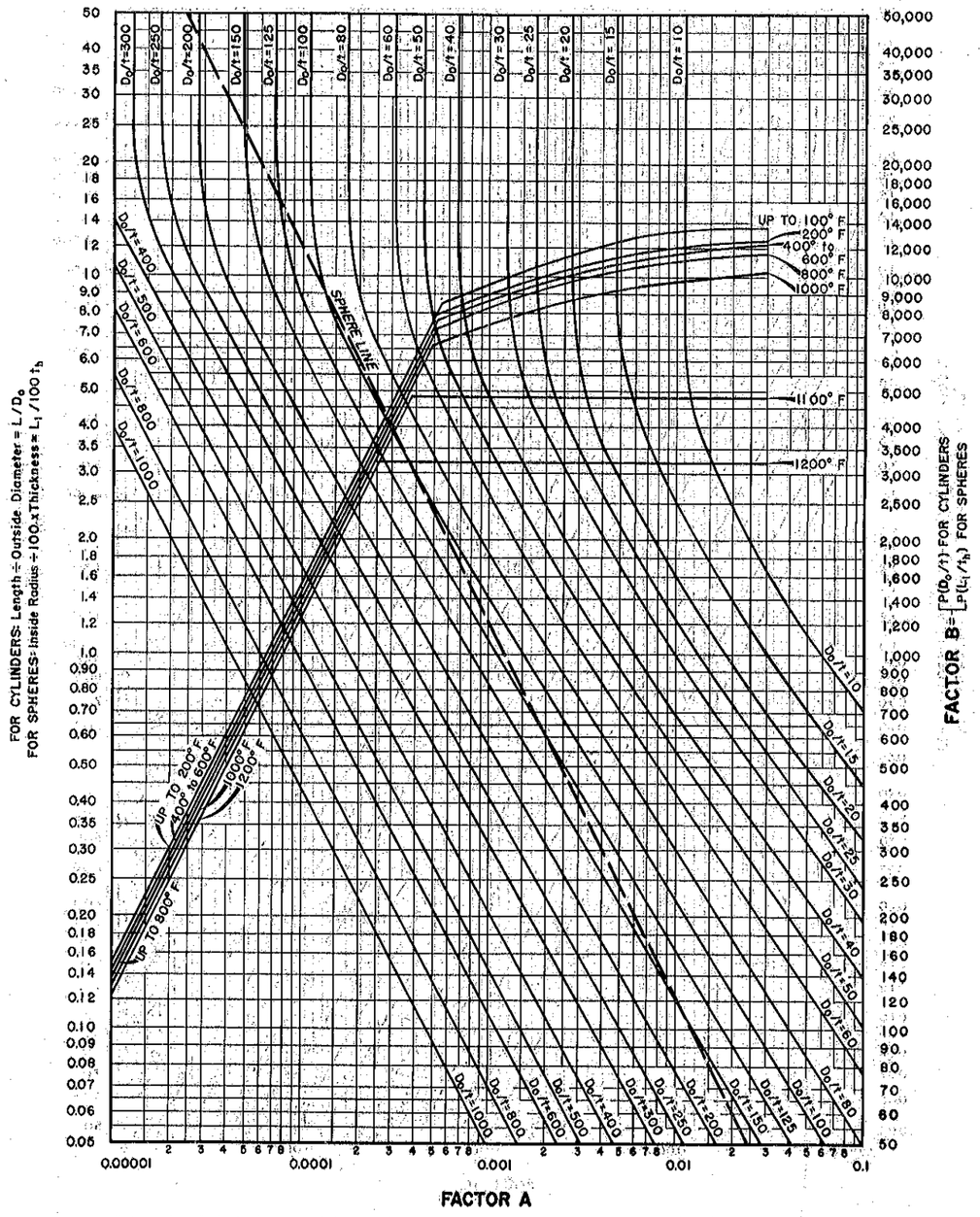


FIG. UNF-28.8 CHART FOR DETERMINING SHELL THICKNESS OF CYLINDRICAL AND SPHERICAL VESSELS UNDER EXTERNAL PRESSURE WHEN CONSTRUCTED OF ANNEALED NICKEL-CHROMIUM-IRON ALLOY

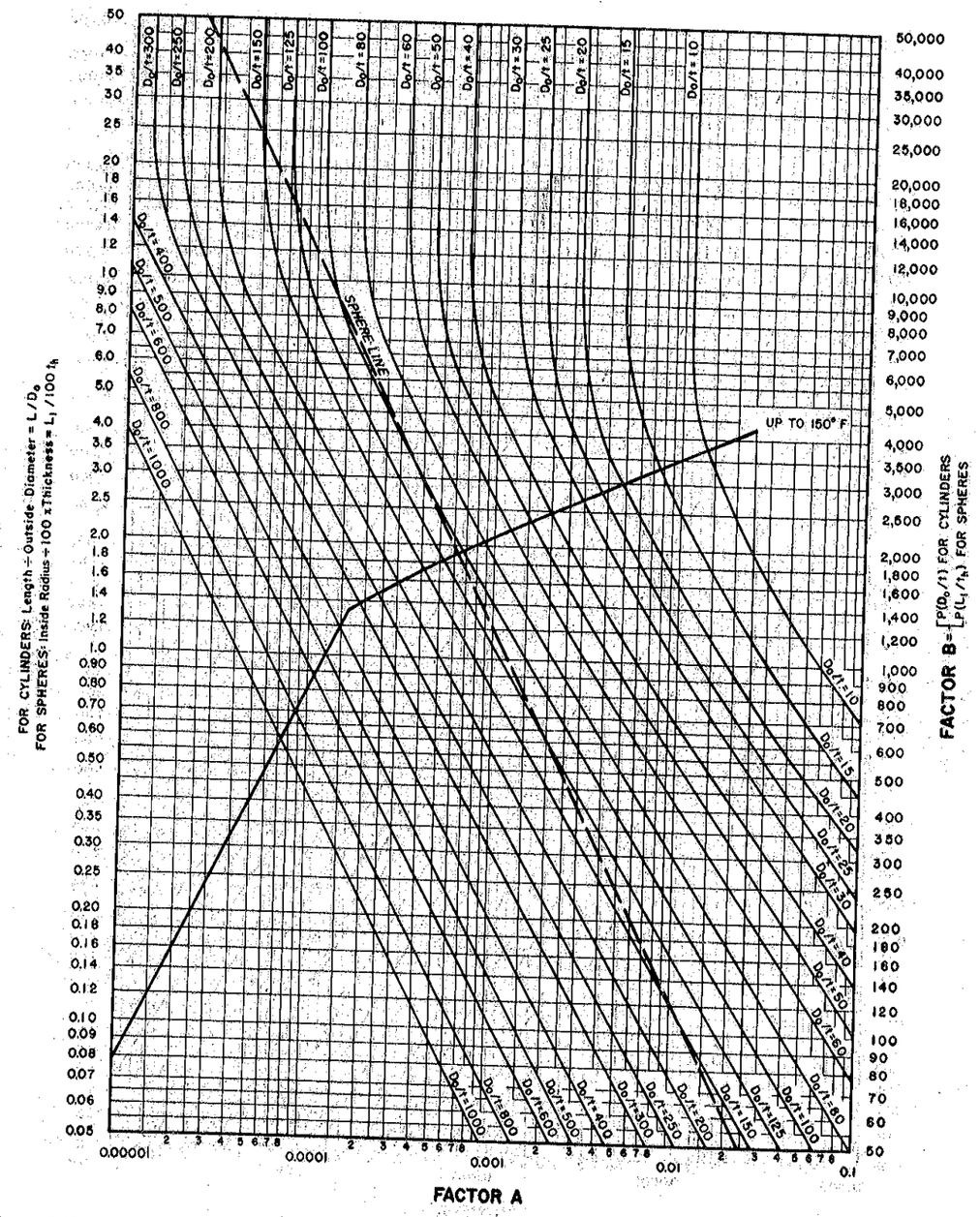


FIG. UNF-28.9 CHART FOR DETERMINING SHELL THICKNESS OF CYLINDRICAL AND SPHERICAL VESSELS UNDER EXTERNAL PRESSURE WHEN CONSTRUCTED OF ANNEALED COPPER, TYPE DHP

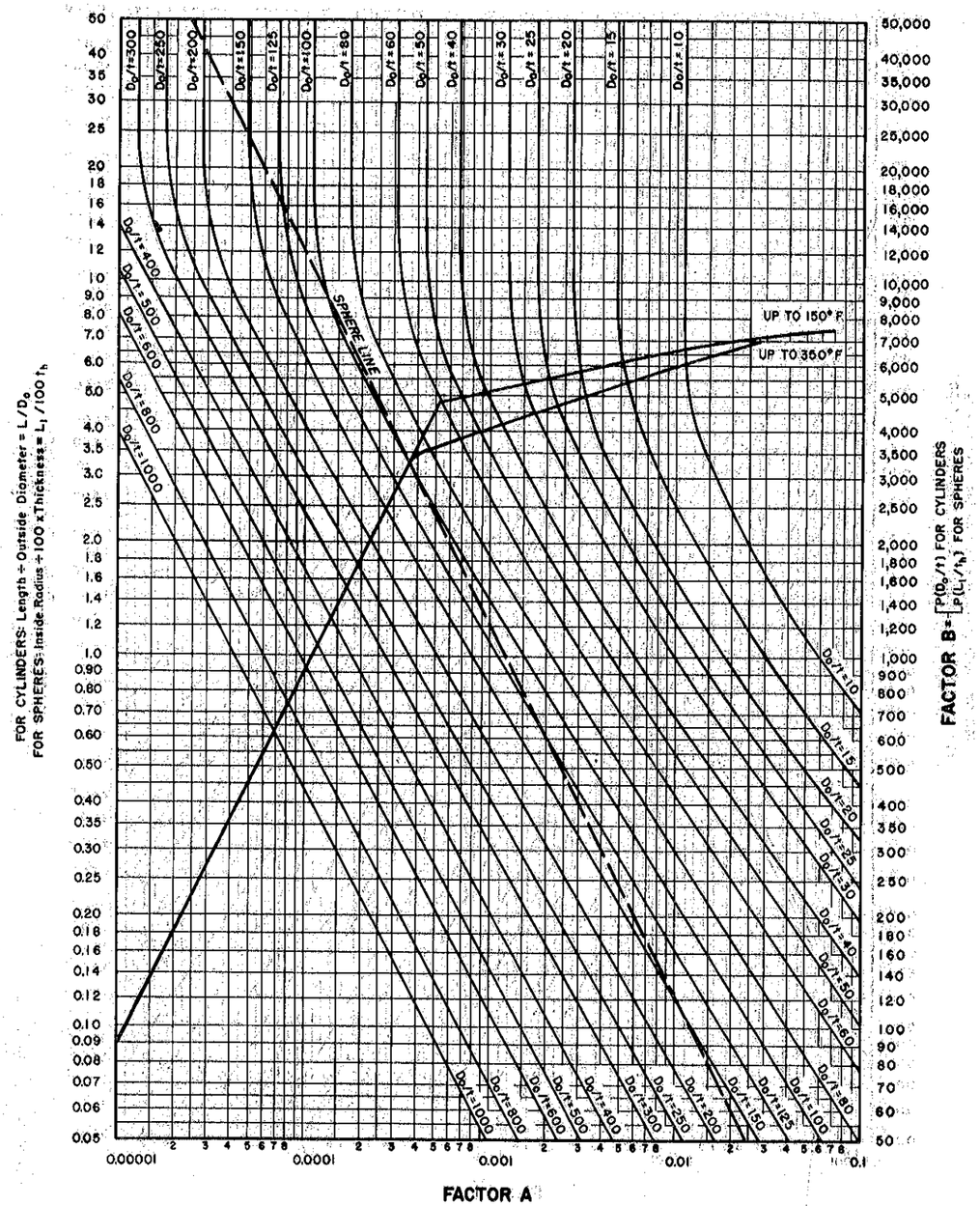


FIG. UNF-28.10 CHART FOR DETERMINING SHELL THICKNESS OF CYLINDRICAL AND SPHERICAL VESSELS UNDER EXTERNAL PRESSURE WHEN CONSTRUCTED OF COPPER SILICON ALLOYS A AND C

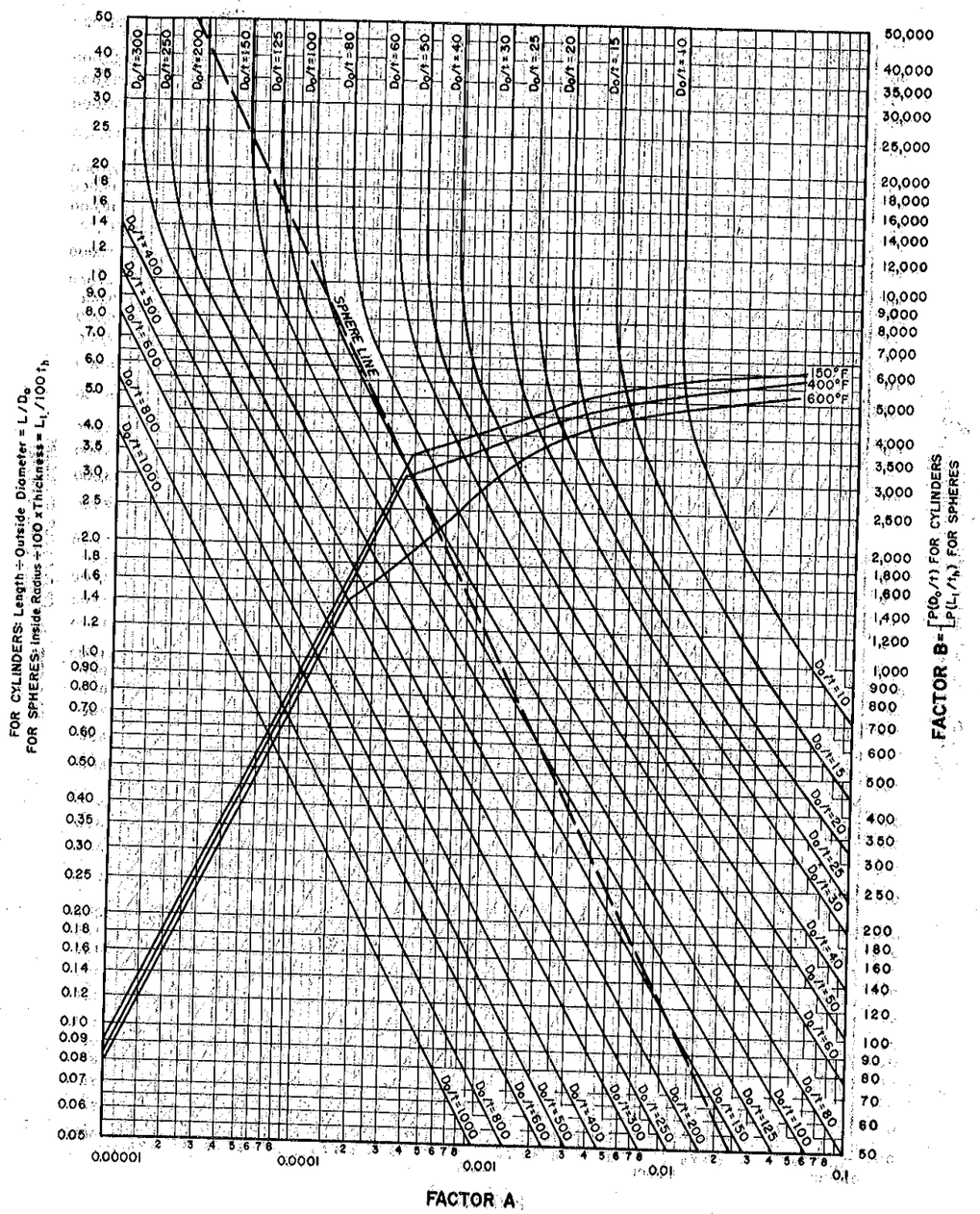


FIG. UNF-28.11 CHART FOR DETERMINING SHELL THICKNESS OF CYLINDRICAL AND SPHERICAL VESSELS UNDER EXTERNAL PRESSURE WHEN CONSTRUCTED OF ANNEALED 90-10 COPPER-NICKEL ALLOY

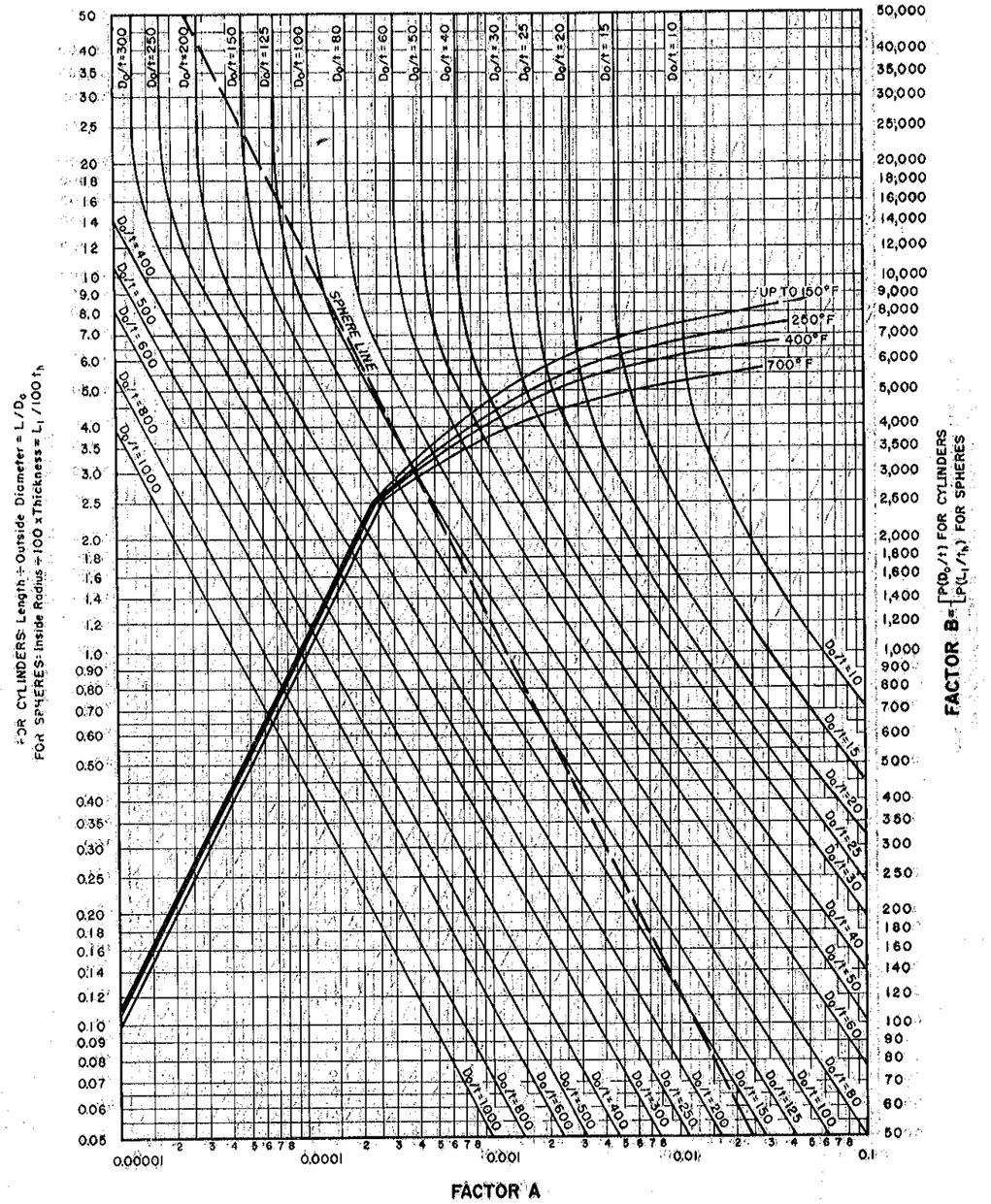


FIG. UNF-28.12 CHART FOR DETERMINING SHELL THICKNESS OF CYLINDRICAL AND SPHERICAL VESSELS UNDER EXTERNAL PRESSURE WHEN CONSTRUCTED OF ANNEALED 70-30 COPPER-NICKEL ALLOY

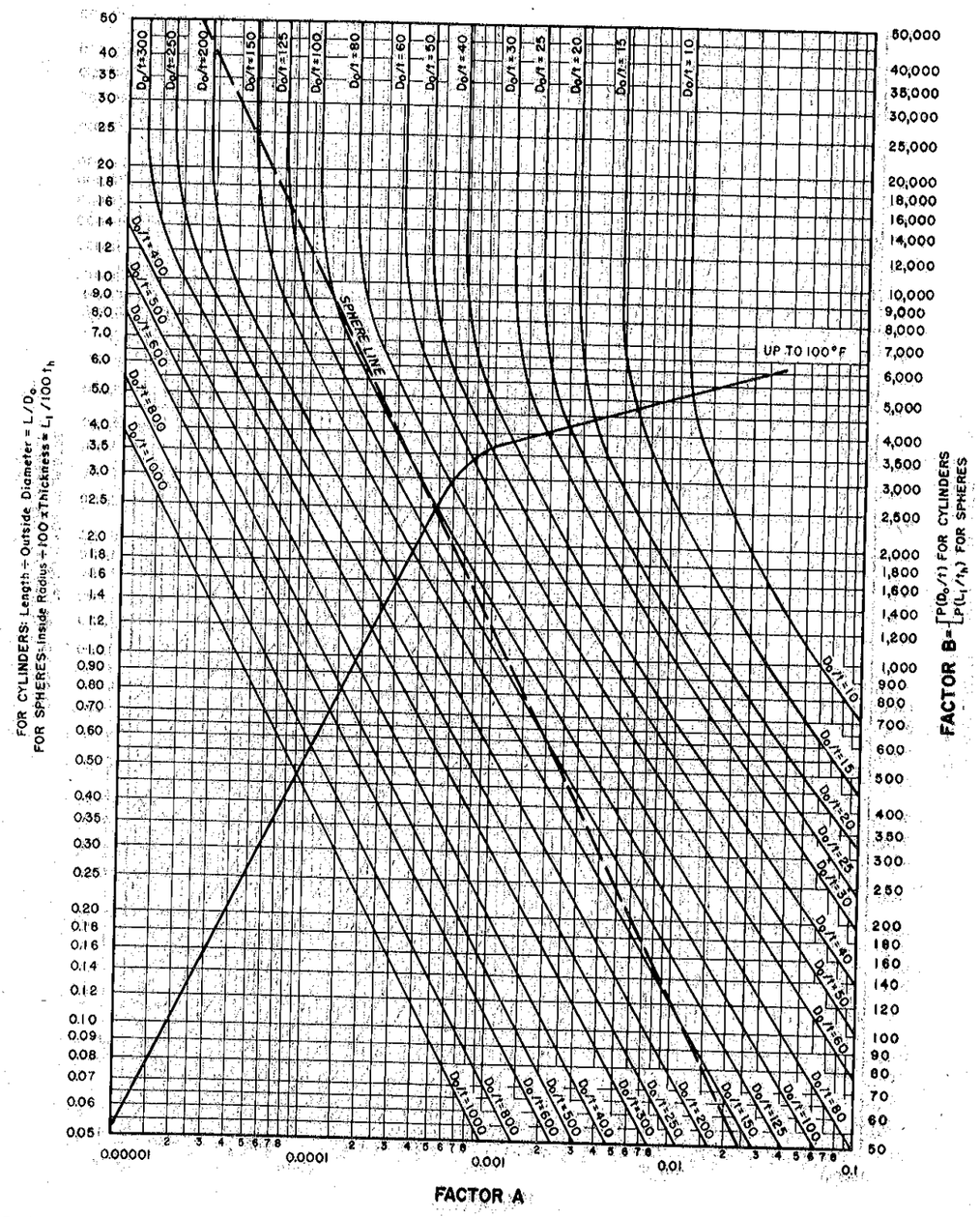


FIG. UNF-28.13 CHART FOR DETERMINING SHELL THICKNESS OF CYLINDRICAL AND SPHERICAL VESSELS UNDER EXTERNAL PRESSURE WHEN CONSTRUCTED OF ALUMINUM ALLOY 5154 IN O AND H112 TEMPER AND 5454 IN O, H32, H34, AND H112 TEMPER

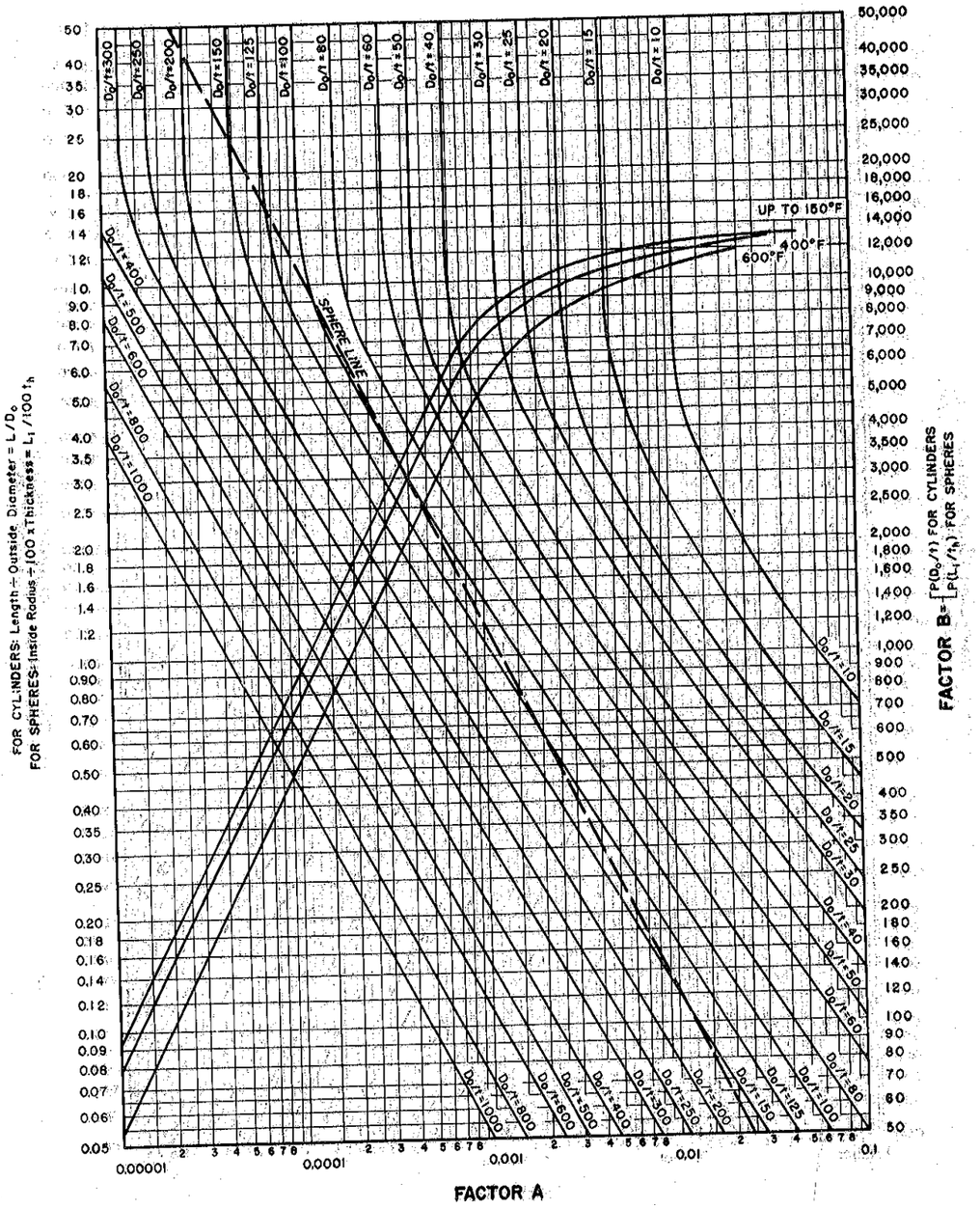


FIG. UNF-28.14 CHART FOR DETERMINING SHELL THICKNESS OF CYLINDRICAL AND SPHERICAL VESSELS UNDER EXTERNAL PRESSURE WHEN CONSTRUCTED OF ALUMINUM BRONZE SB-169 ALLOY D

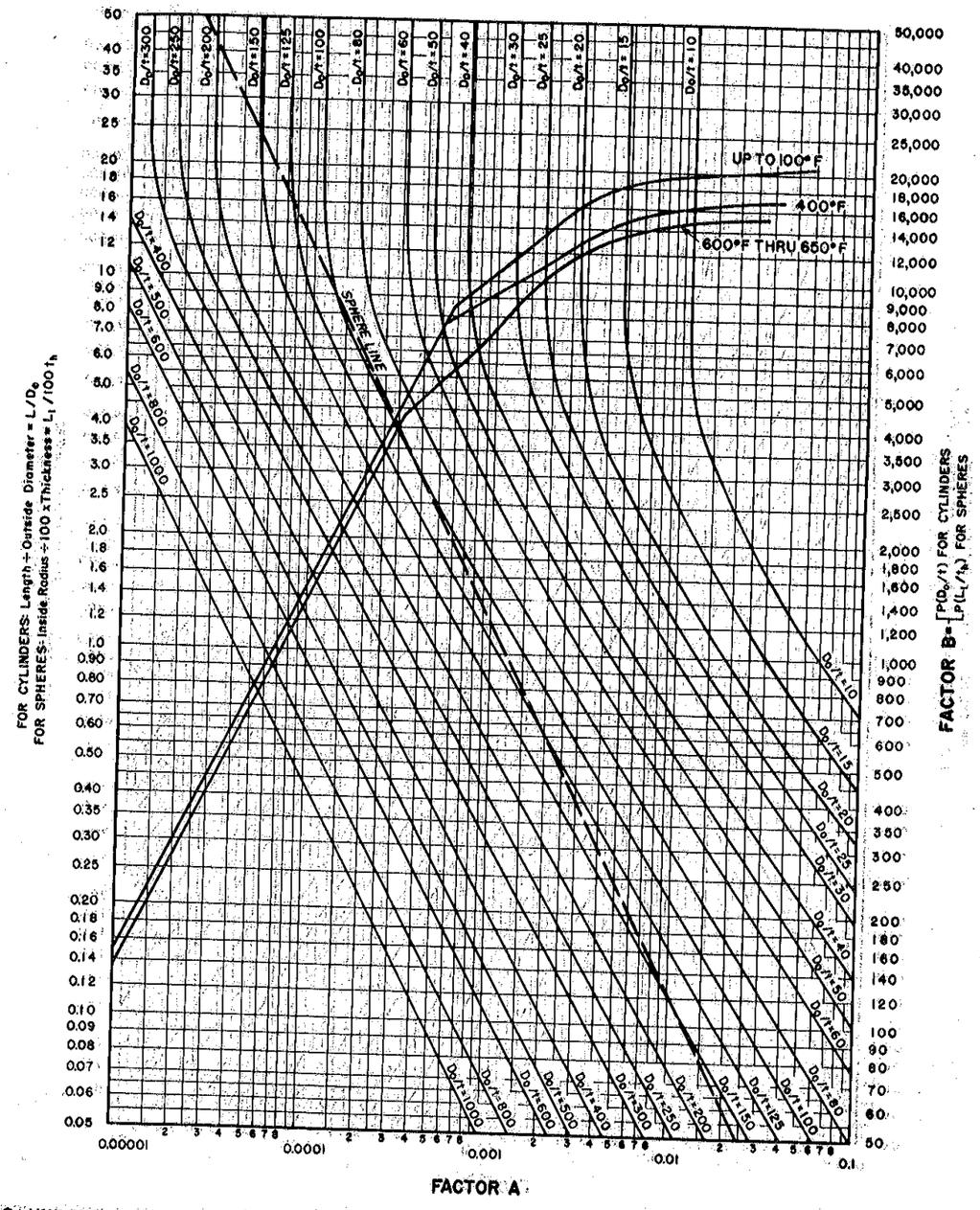


FIG. UNF-28.15 CHART FOR DETERMINING SHELL THICKNESS OF CYLINDRICAL AND SPHERICAL VESSELS UNDER EXTERNAL PRESSURE WHEN CONSTRUCTED OF NICKEL-MOLYBDENUM ALLOY

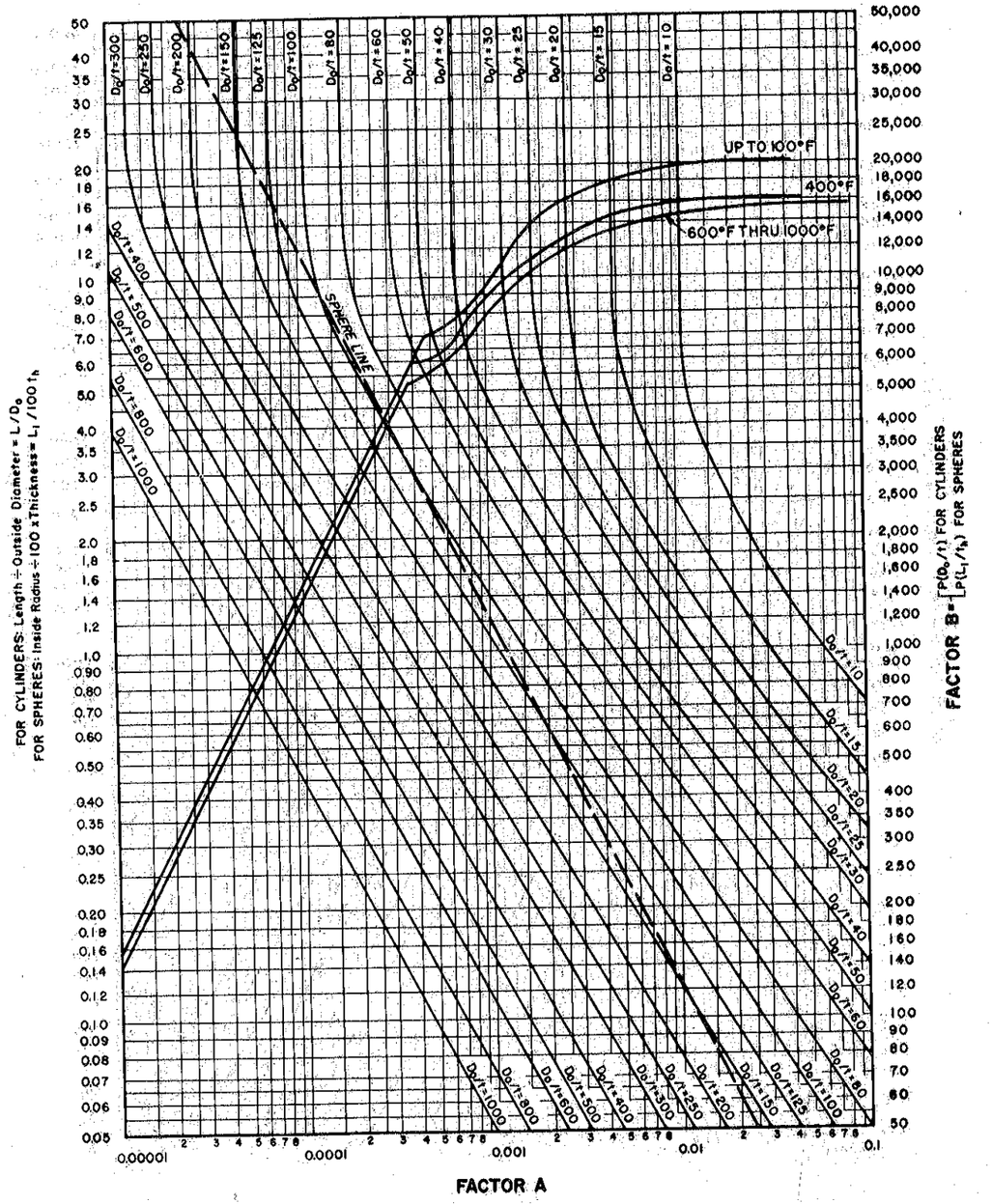


FIG. UNF-28.16 CHART FOR DETERMINING SHELL THICKNESS OF CYLINDRICAL AND SPHERICAL VESSELS UNDER EXTERNAL PRESSURE WHEN CONSTRUCTED OF NICKEL-CHROMIUM-MOLYBDENUM ALLOY

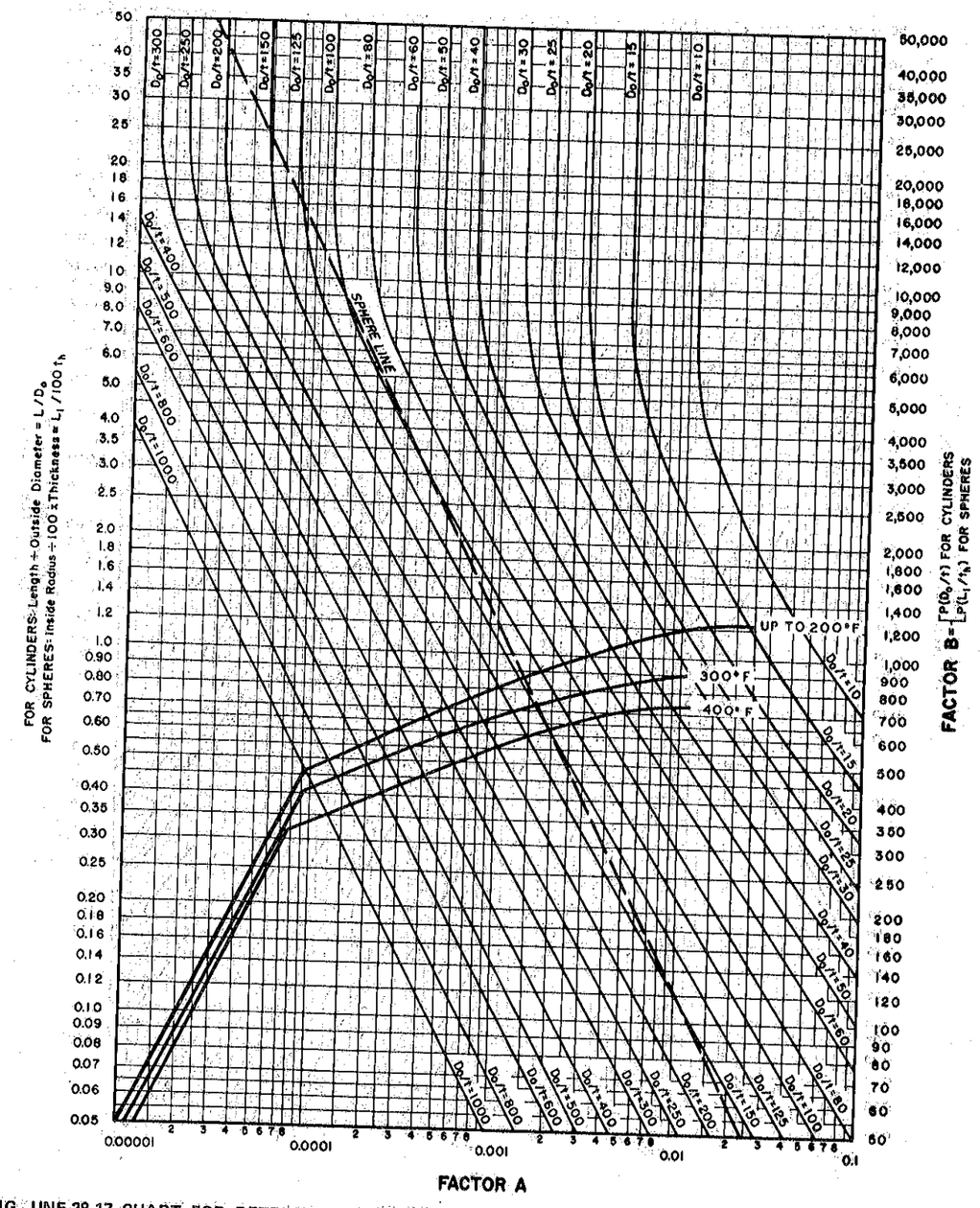


FIG. UNF-28.17 CHART FOR DETERMINING SHELL THICKNESS OF CYLINDRICAL AND SPHERICAL VESSELS UNDER EXTERNAL PRESSURE WHEN CONSTRUCTED OF ALUMINUM ALLOY 1060 IN 0 TEMPER

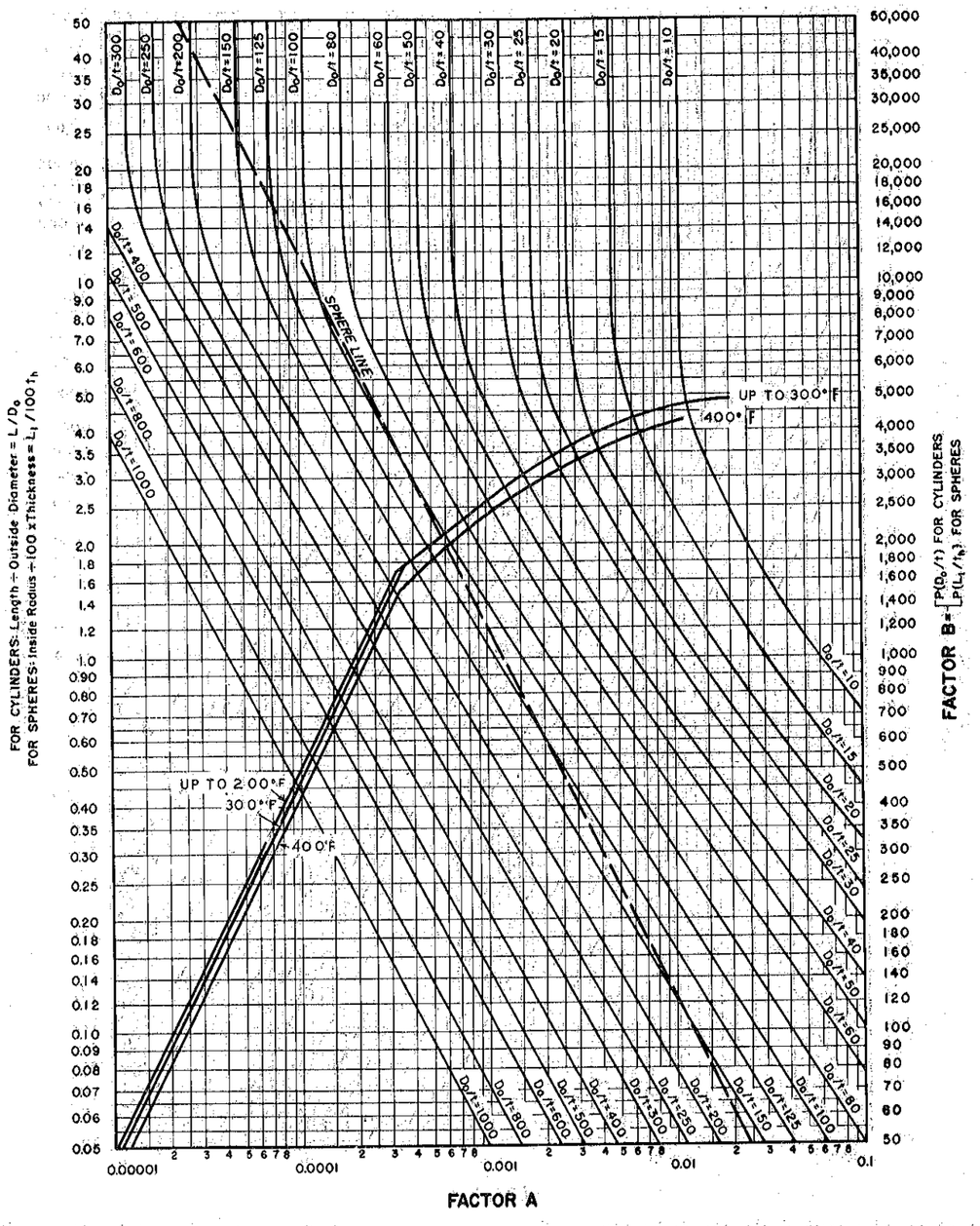


FIG. UNF-28.18 CHART FOR DETERMINING SHELL THICKNESS OF CYLINDRICAL AND SPHERICAL VESSELS UNDER EXTERNAL PRESSURE WHEN CONSTRUCTED OF ALUMINUM ALLOY 5052 IN 0 AND H112 TEMPER

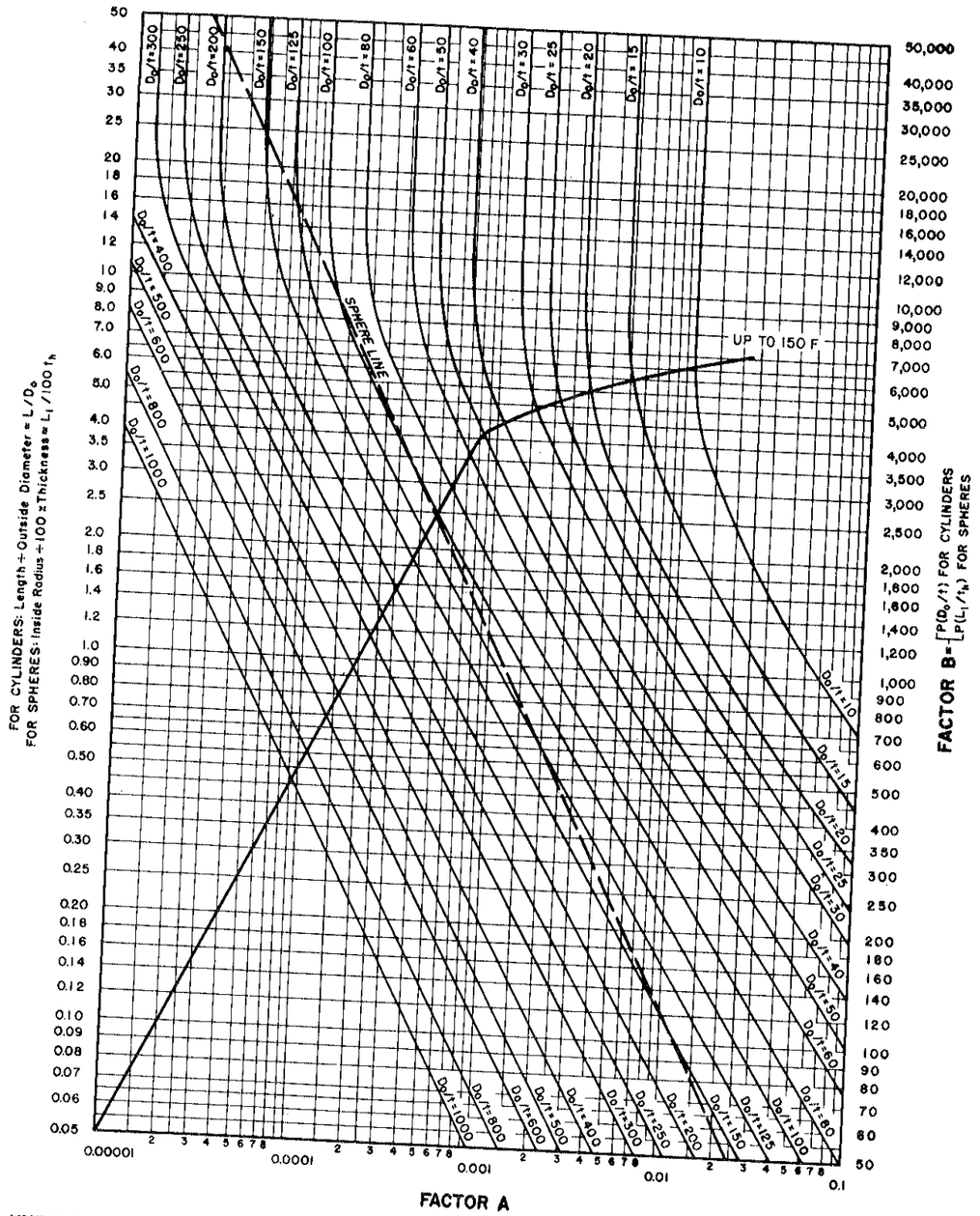


FIG. UNF-28.19 CHART FOR DETERMINING SHELL THICKNESS OF CYLINDRICAL AND SPHERICAL VESSELS UNDER EXTERNAL PRESSURE WHEN CONSTRUCTED OF ALUMINUM ALLOY 5086 IN 0 AND H112 TEMPER

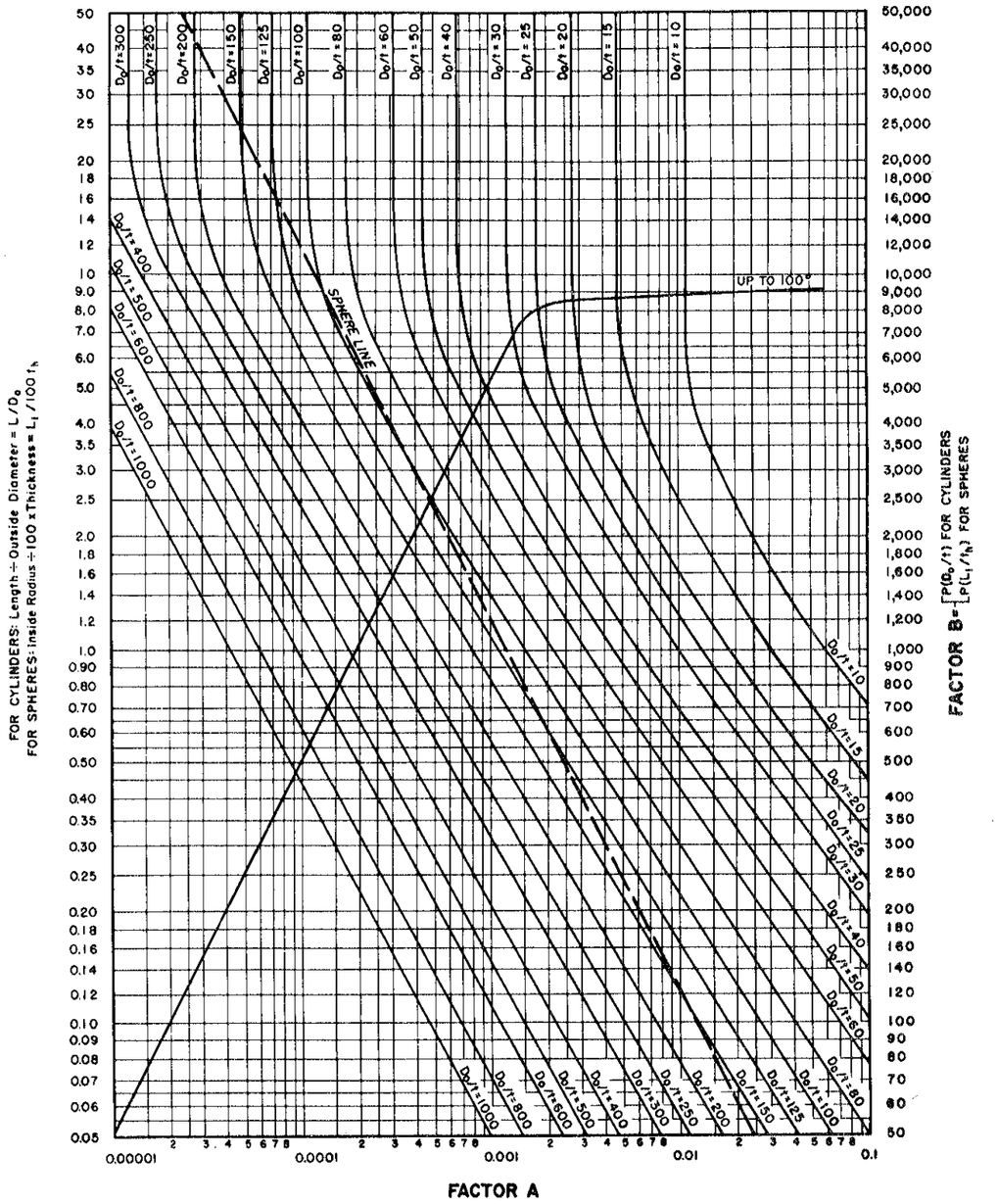


FIG. UNF-28.20 CHART FOR DETERMINING SHELL THICKNESS OF CYLINDRICAL AND SPHERICAL VESSELS UNDER EXTERNAL PRESSURE WHEN CONSTRUCTED OF ALUMINUM ALLOY 5456 IN 0 TEMPER

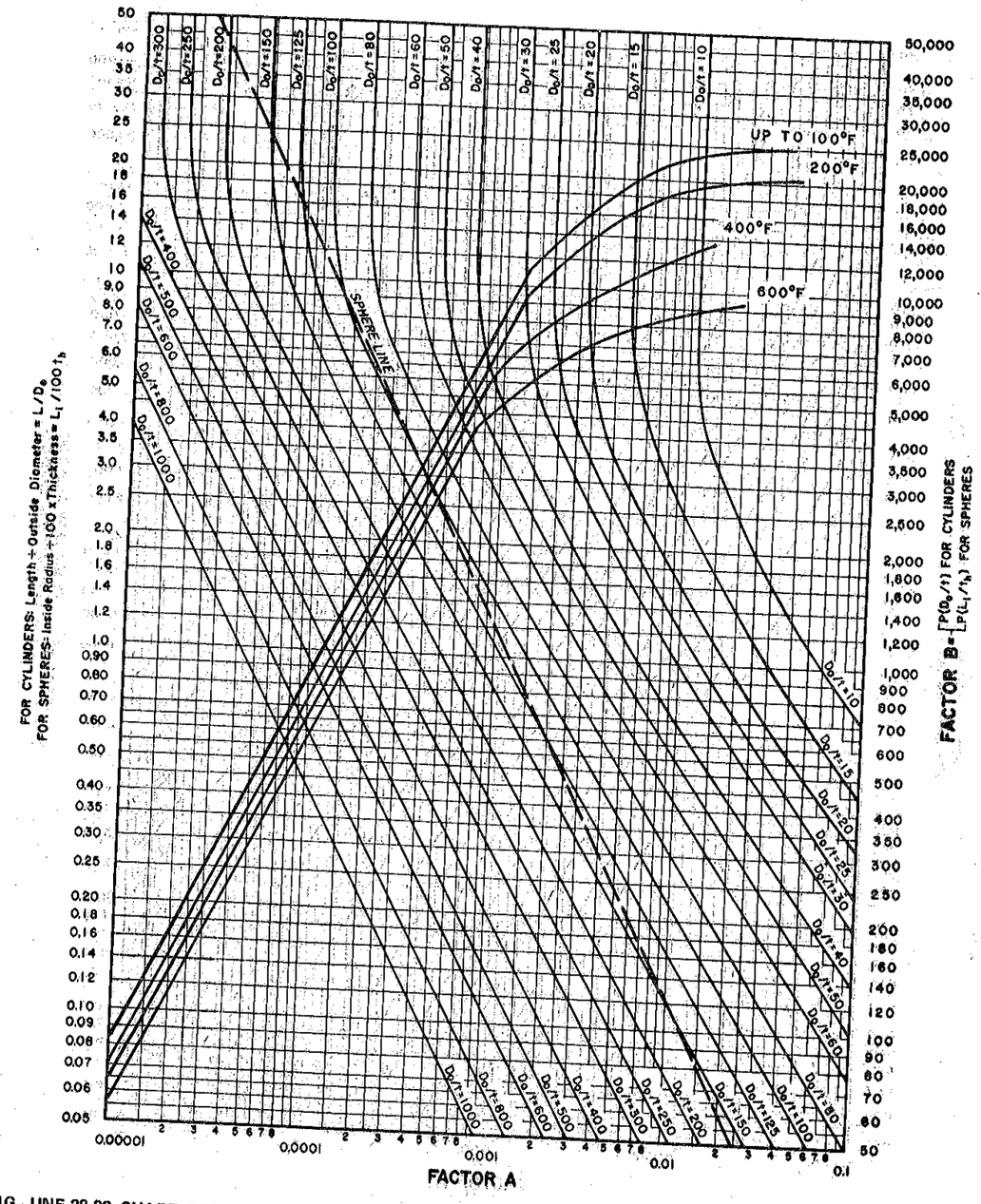


FIG. UNF-28.22 CHART FOR DETERMINING SHELL THICKNESS OF CYLINDRICAL AND SPHERICAL VESSELS UNDER EXTERNAL PRESSURE WHEN CONSTRUCTED OF UNALLOYED TITANIUM, GRADE 3

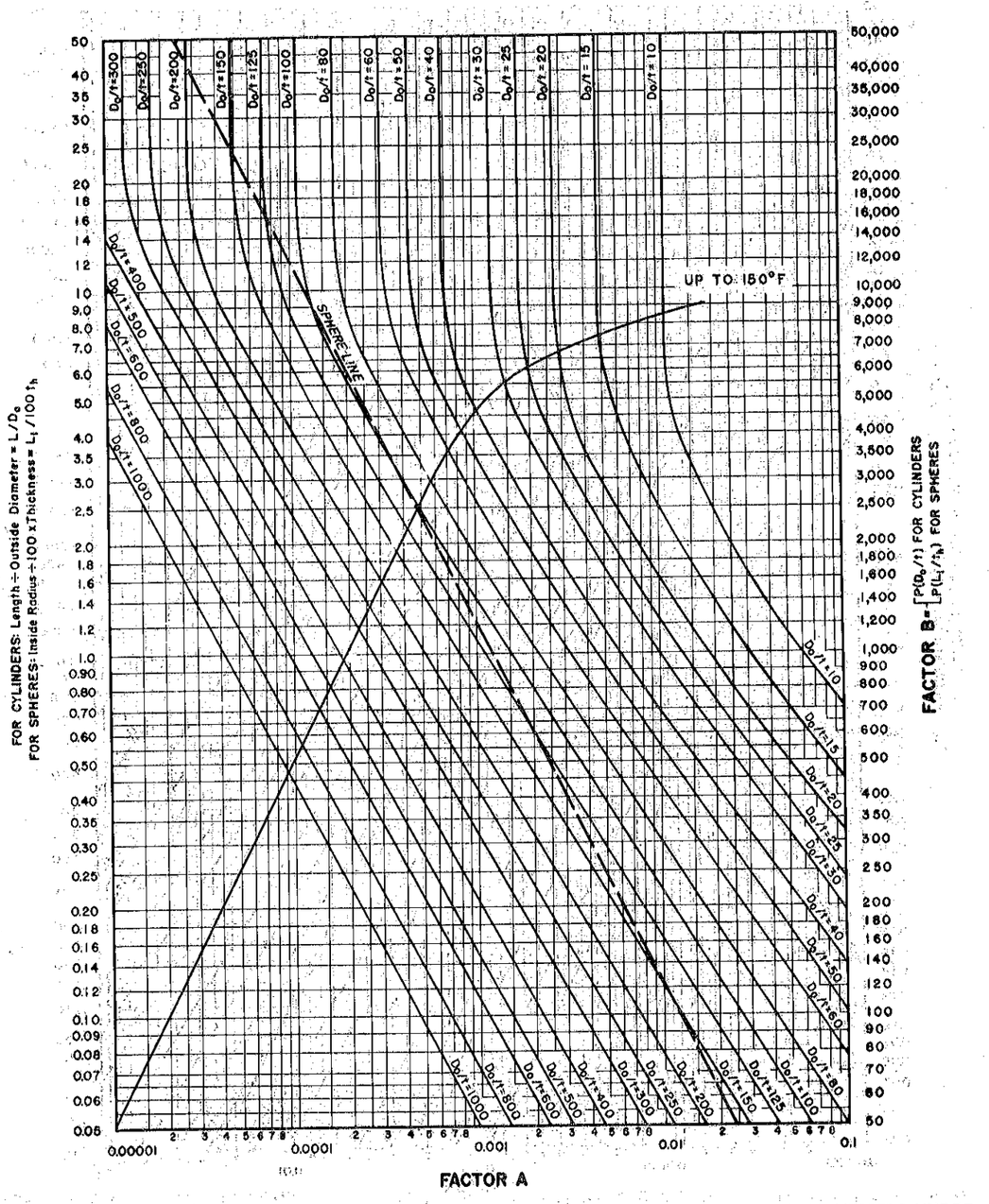


FIG. UNF-28.23 CHART FOR DETERMINING SHELL THICKNESS OF CYLINDRICAL AND SPHERICAL VESSELS UNDER EXTERNAL PRESSURE WHEN CONSTRUCTED OF ALUMINUM ALLOY 5083 IN O OR H-113 TEMPER (For material having a Yield Strength not less than 18,000 psi)

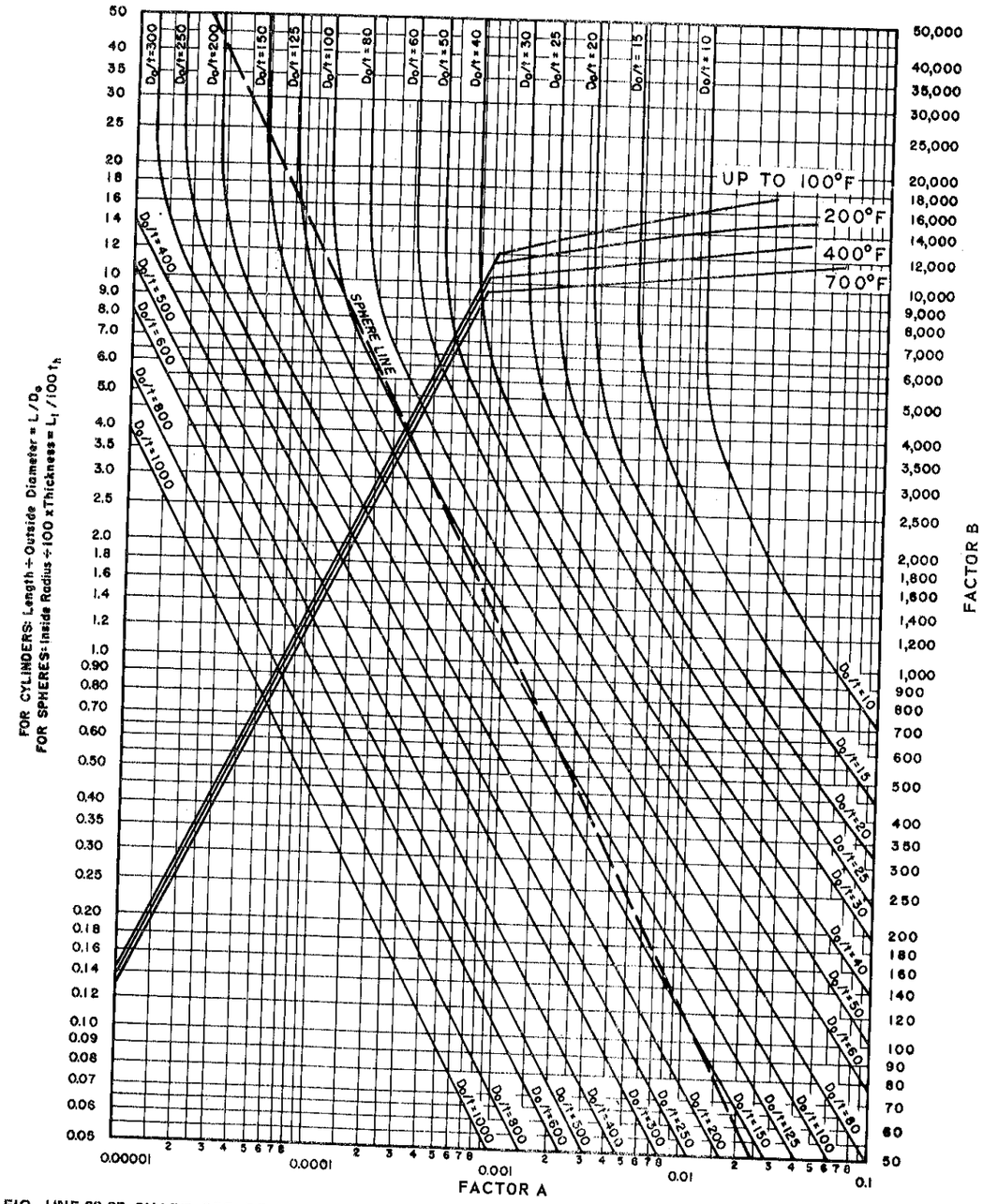


FIG. UNF-28.25 CHART FOR DETERMINING SHELL THICKNESS OF CYLINDRICAL AND SPHERICAL VESSELS UNDER EXTERNAL PRESSURE WHEN CONSTRUCTED OF NICKEL-IRON-CHROMIUM-MOLYBDENUM-COPPER ALLOY

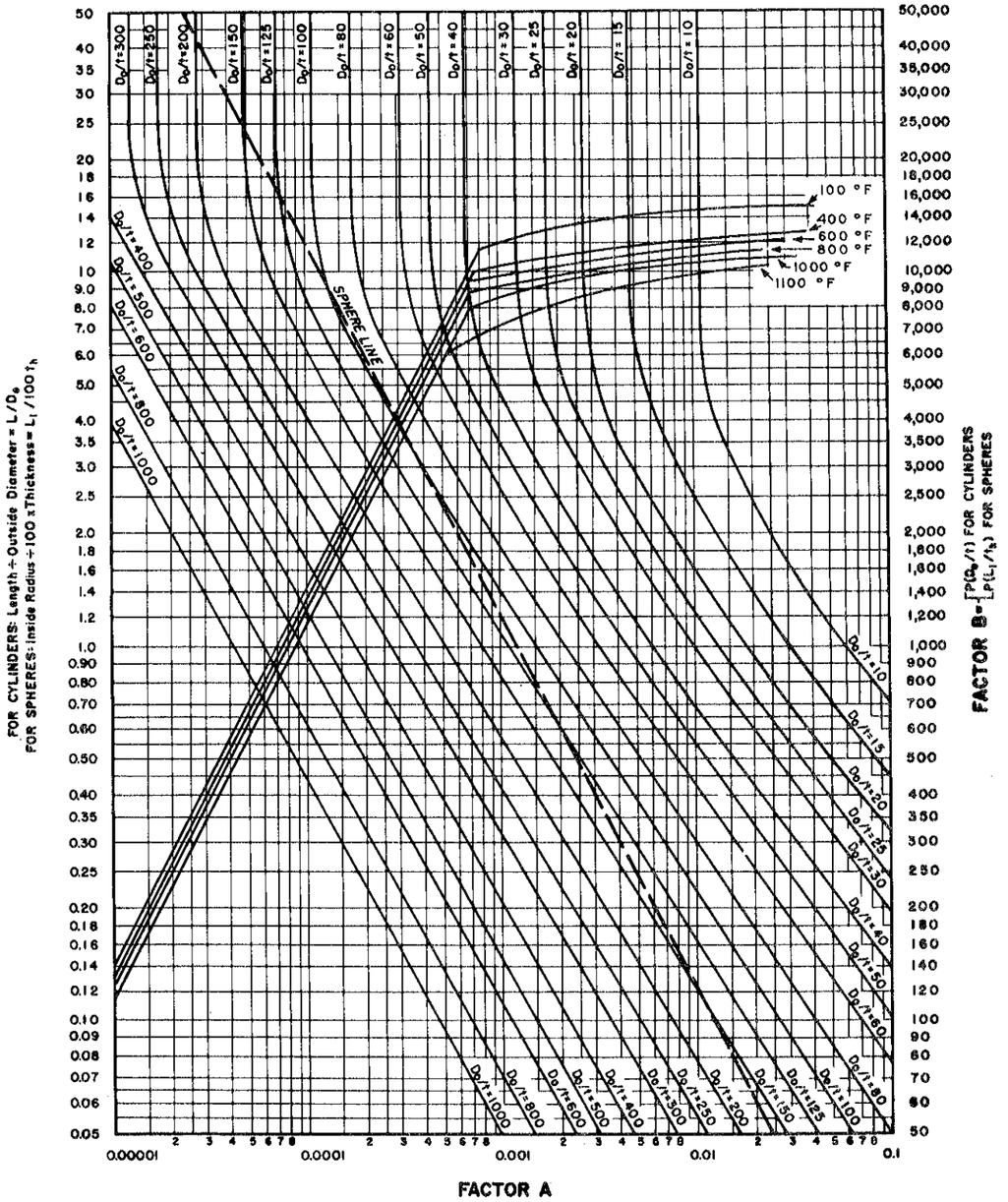


FIG. UNF-28.27 CHART FOR DETERMINING SHELL THICKNESS OF CYLINDRICAL AND SPHERICAL VESSELS UNDER EXTERNAL PRESSURE WHEN CONSTRUCTED OF NICKEL-IRON-CHROMIUM ALLOY, GRADE 1

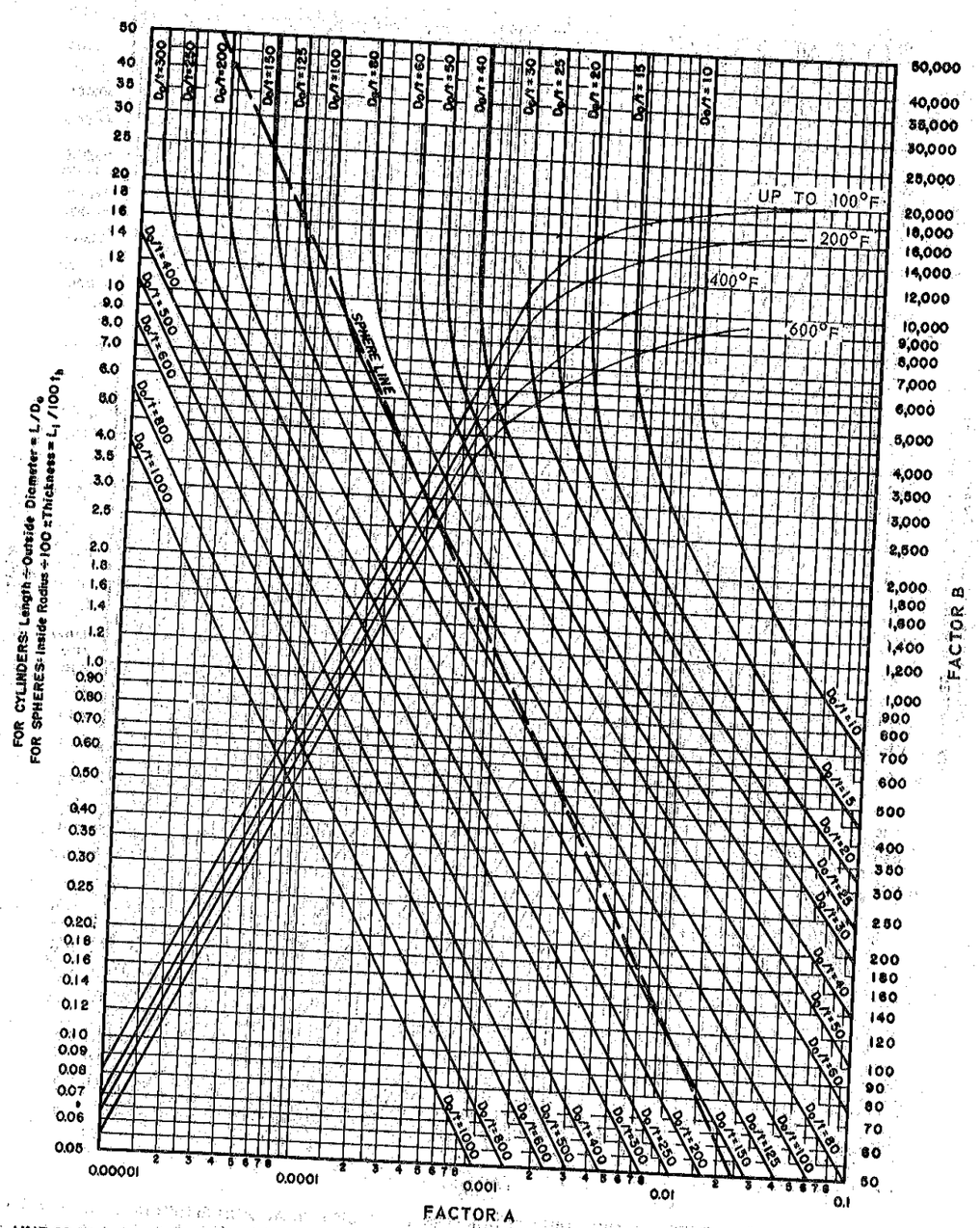


FIG. UNF-28.28 CHART FOR DETERMINING SHELL THICKNESS OF CYLINDRICAL AND SPHERICAL VESSELS UNDER EXTERNAL PRESSURE WHEN CONSTRUCTED OF UNALLOYED TITANIUM, GRADE 2

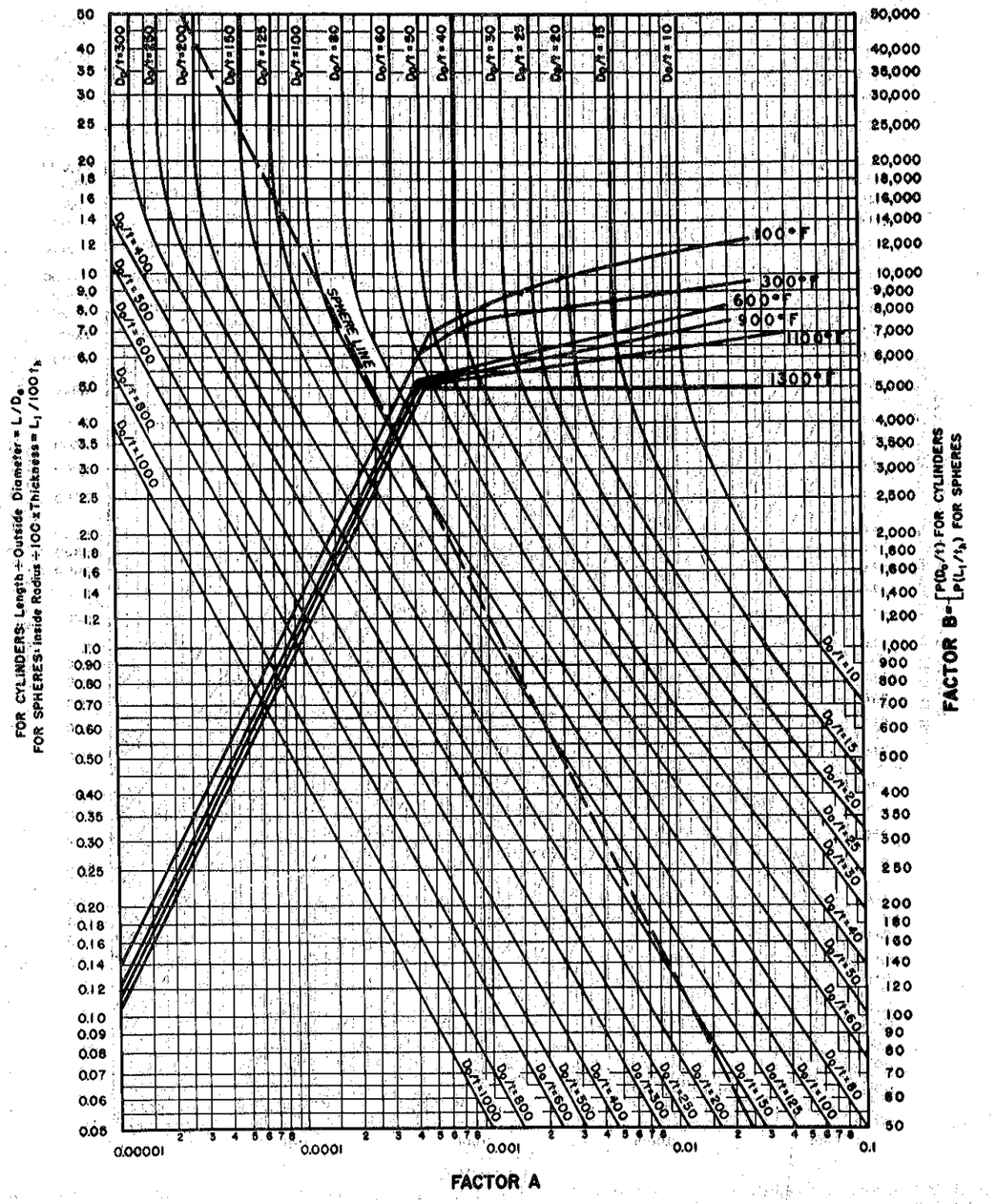


FIG. UNF-28.29 CHART FOR DETERMINING SHELL THICKNESS OF CYLINDRICAL AND SPHERICAL VESSELS UNDER EXTERNAL PRESSURE WHEN CONSTRUCTED OF NICKEL-IRON-CHROMIUM ALLOY, GRADE 2

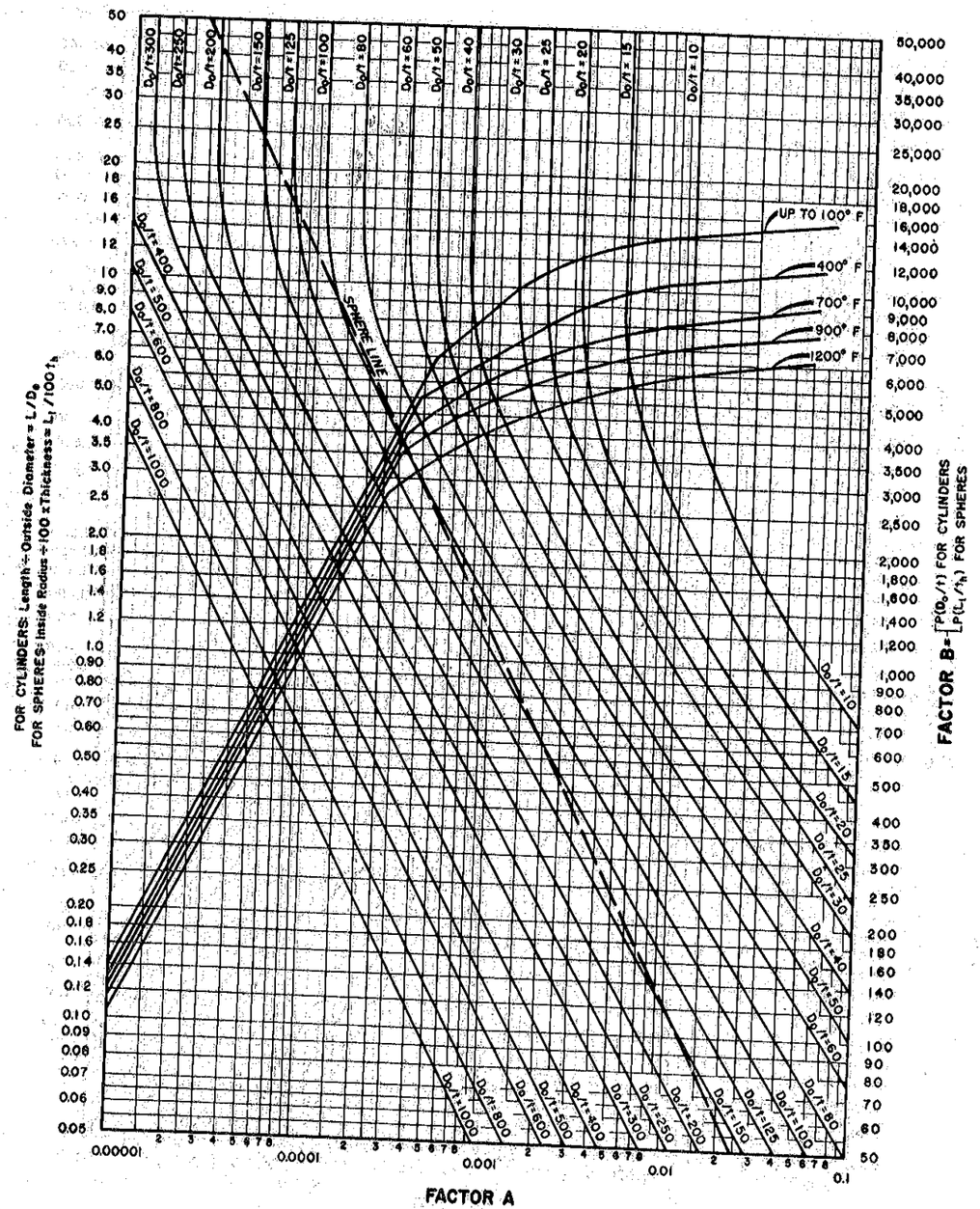


FIG. UHA-28.1 CHART FOR DETERMINING SHELL THICKNESS OF CYLINDRICAL AND SPHERICAL VESSELS UNDER EXTERNAL PRESSURE WHEN CONSTRUCTED OF AUSTENITIC STEEL (18 Cr-8 Ni, Type 304)

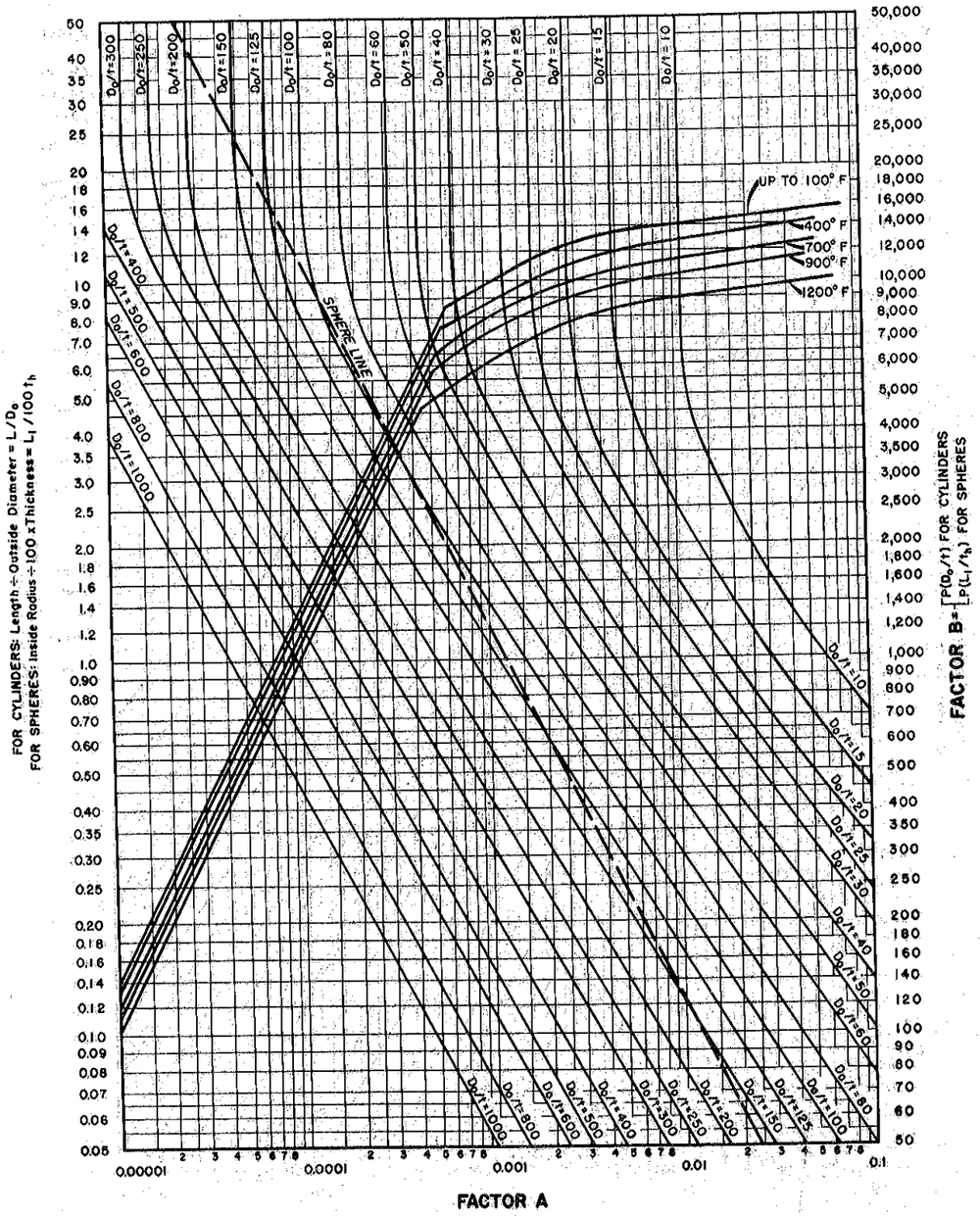


FIG. UHA-28.2 CHART FOR DETERMINING SHELL THICKNESS OF CYLINDRICAL AND SPHERICAL VESSELS UNDER EXTERNAL PRESSURE WHEN CONSTRUCTED OF AUSTENITIC STEELS (18 Cr-8 Ni + Mo, Type 316; 18 Cr-8 Ni + Ti, type 321; 18 Cr-8 Ni + Cb, Type 347; 25 Cr-12 Ni, Type 309 (Through 1100 F only); 25 Cr-20 NI, Type 310; and 17 Cr, Type 430B Stainless Steel (Through 700 F only)

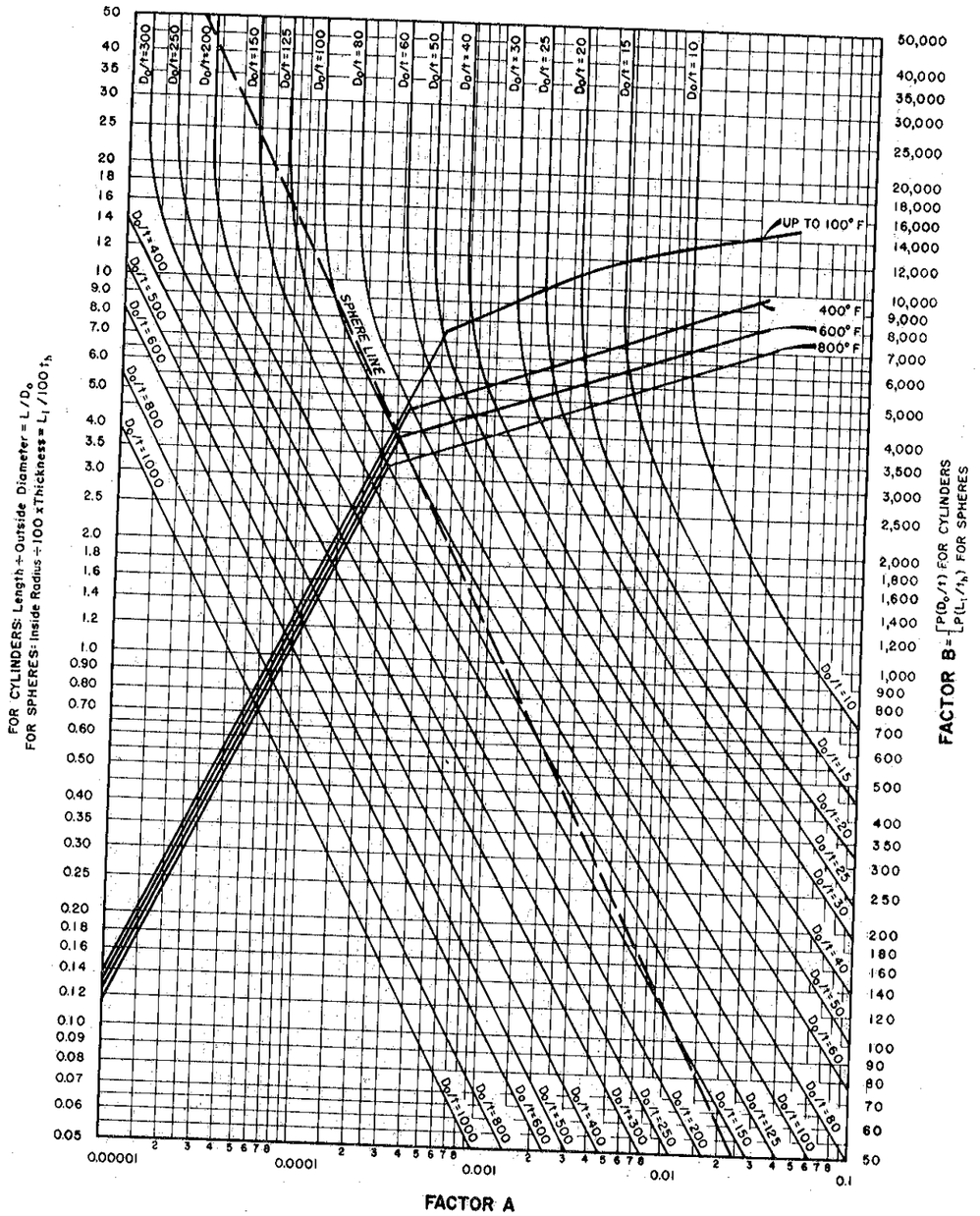


FIG. UHA-28.3 CHART FOR DETERMINING SHELL THICKNESS OF CYLINDRICAL AND SPHERICAL VESSELS UNDER EXTERNAL PRESSURE WHEN CONSTRUCTED OF AUSTENITIC STEEL (18 Cr-8 Ni-0.03 maximum carbon, Type 304L)

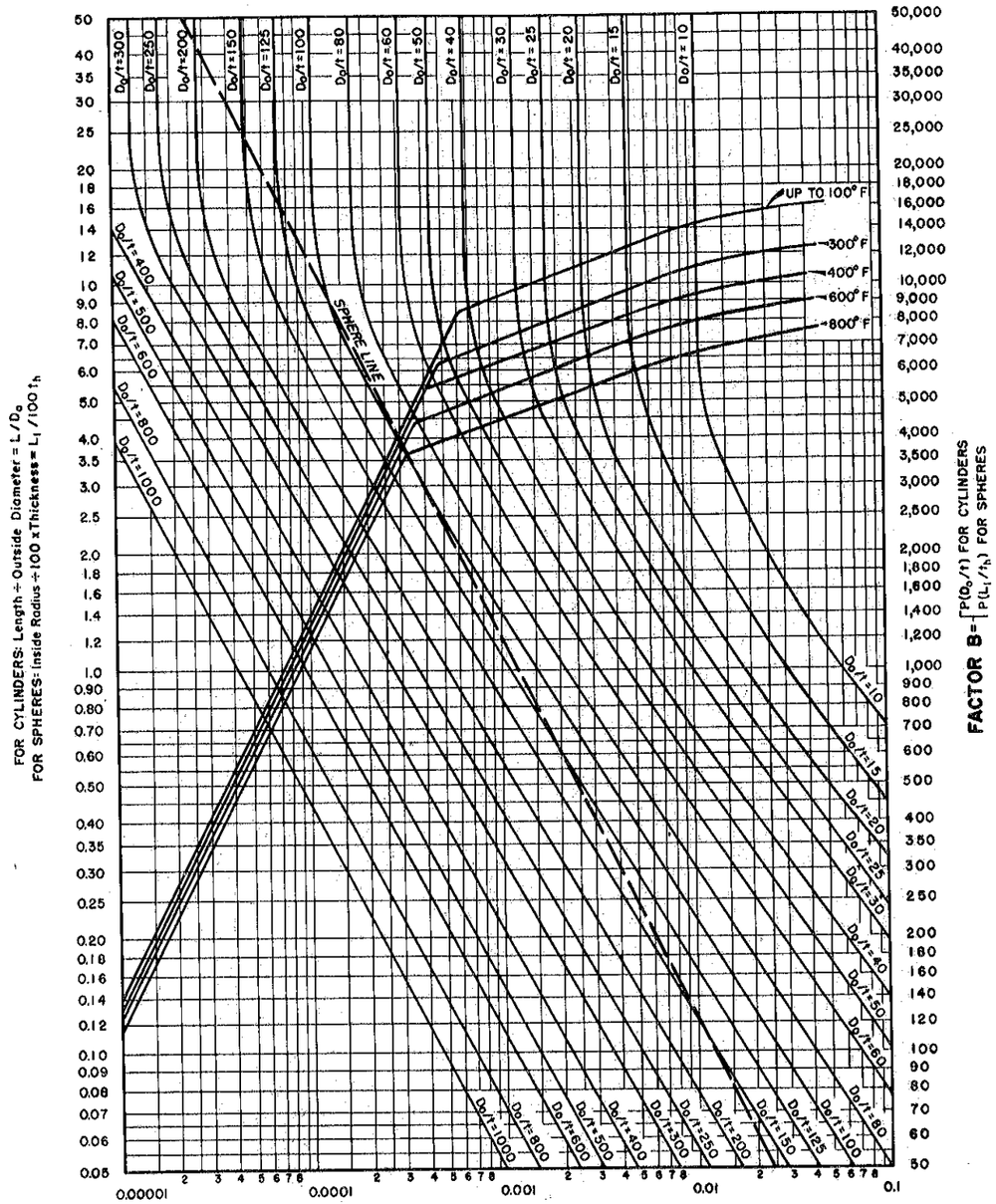


FIG. UHA-28.4 CHART FOR DETERMINING SHELL THICKNESS OF CYLINDRICAL AND SPHERICAL VESSELS UNDER EXTERNAL PRESSURE WHEN CONSTRUCTED OF AUSTENITIC STEEL (18 Cr-8 Ni + Mo-0.03 maximum carbon, Types 316L and 317L)

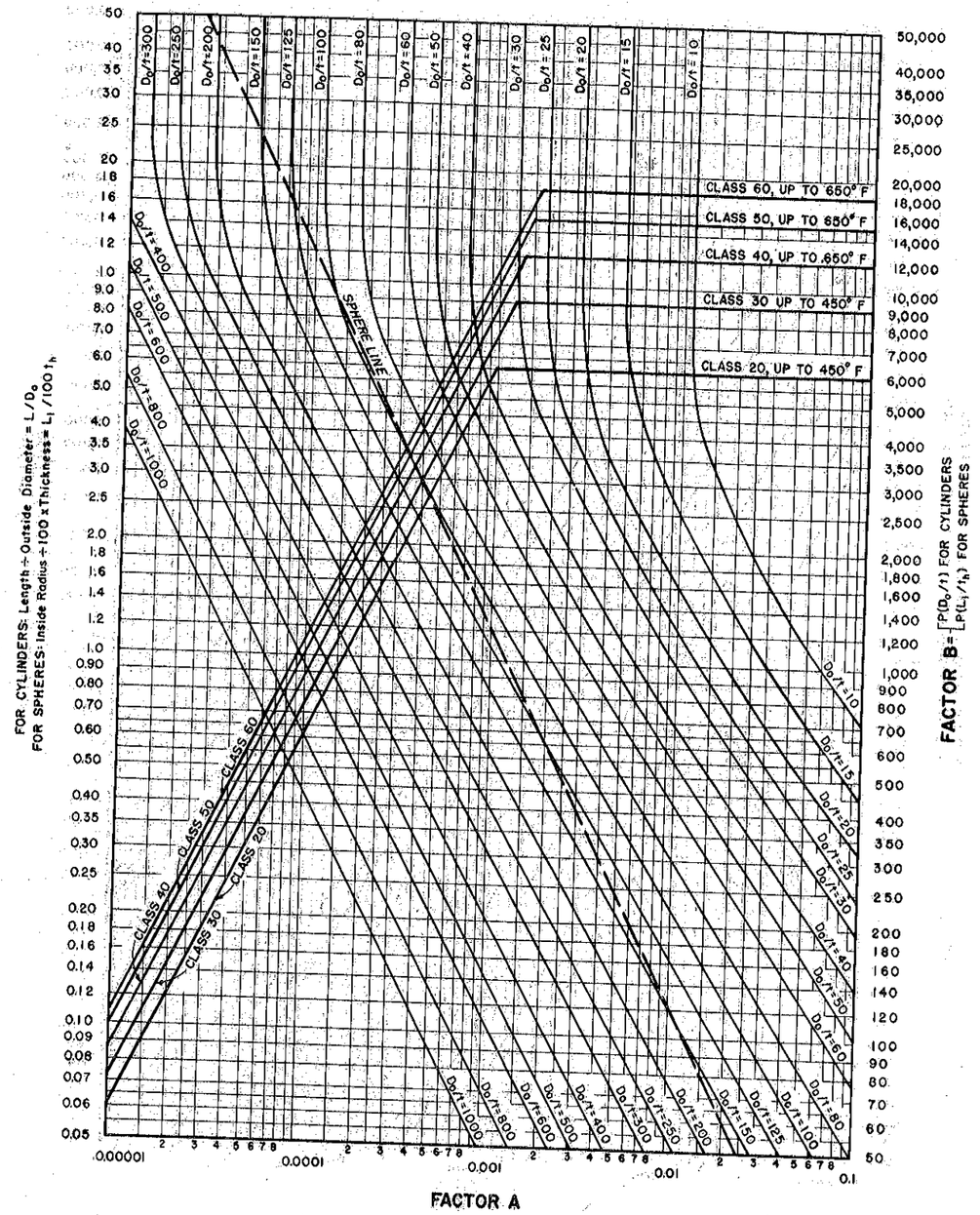


FIG. UCI-28 CHART FOR DETERMINING SHELL THICKNESS OF CYLINDRICAL AND SPHERICAL VESSELS UNDER EXTERNAL PRESSURE WHEN CONSTRUCTED OF CAST IRON

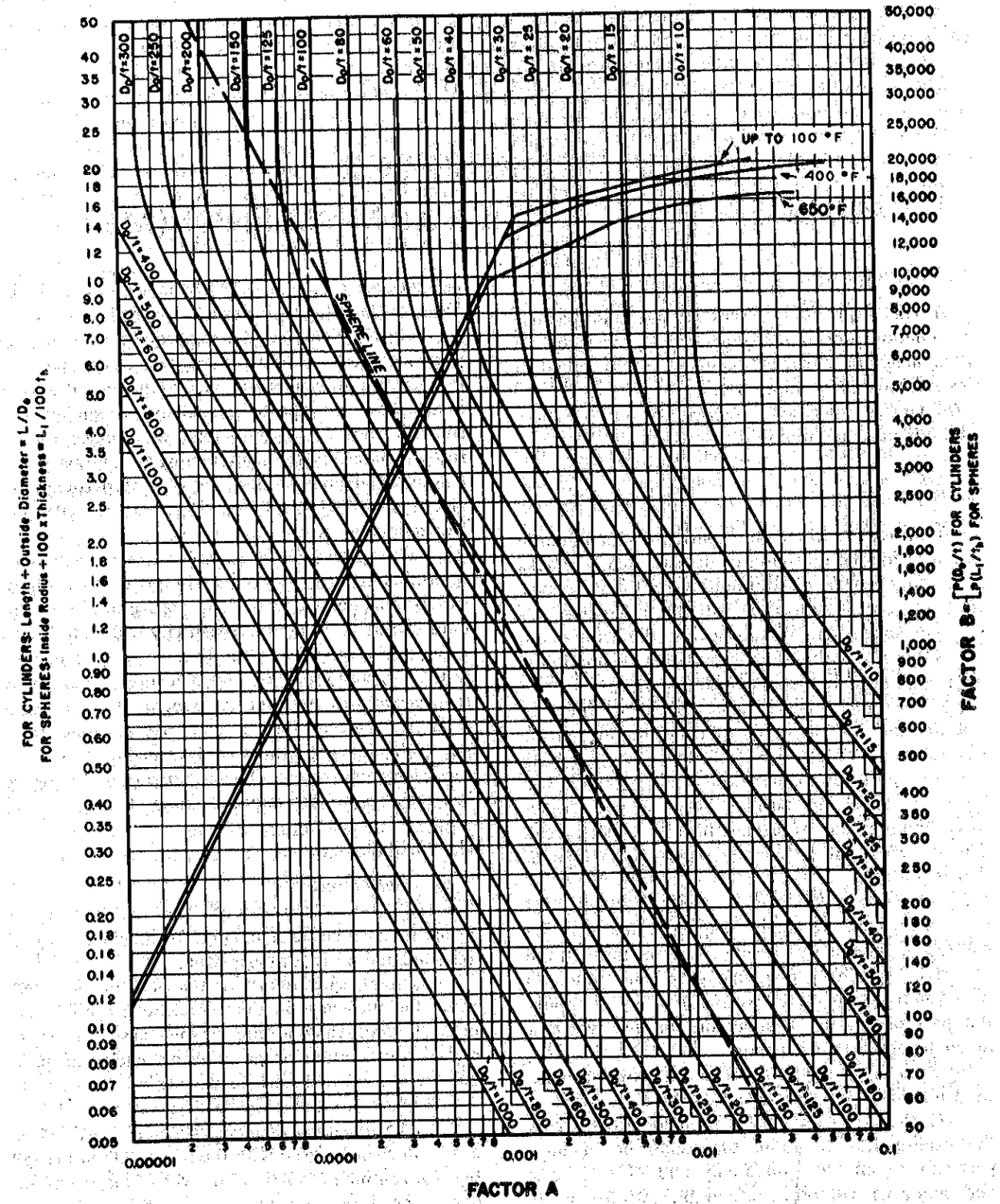


FIG. UCN-28 CHART FOR DETERMINING SHELL THICKNESS OF CYLINDRICAL AND SPHERICAL VESSELS UNDER EXTERNAL PRESSURE WHEN CONSTRUCTED OF CAST DUCTILE IRON WITH A SPECIFIED MINIMUM YIELD STRENGTH OF 40,000 PSI

APPENDIX VI

METHODS FOR MAGNETIC PARTICLE EXAMINATION (MT)

UA-70 Scope

(*a*) This Appendix describes magnetic particle examination procedures which are approved for use when magnetic particle examination is specified in this Division of Section VIII.

(*b*) Unless specified otherwise, any of these methods may be employed.

UA-71

(*a*) *General.* Magnetic particle examination provides for the detection of defects such as cracks and other linear discontinuities in welds, plates, forgings, and castings. Sensitivity is greatest for surface defects and diminishes rapidly with depth below the surface. Magnetic particle examination is applicable only to ferromagnetic materials.

(*b*) *Description of Method.* This method of examination consists of magnetizing the area to be examined to near saturation and then applying magnetic particles to the surface. The particles will be retained on the surface at cracks and other discontinuities due to leakage in the magnetic field. The patterns will be characteristic of the type of defect present.

(*c*) *Magnetization.* Any suitable means of establishing the necessary magnetic flux may be employed, such as by passing a current through the material, by using a magnetic yoke (the section to be examined being the "keeper") or by wrapping the part or surface with a coil through which a magnetizing current is passed.

(*d*) *Examination Medium.* The magnetic particles used for detection of defects shall be as follows:

(*1*) *Dry Particles.* If dry particles are used as the examination medium, they shall be of high permeability and low retentivity and of such size and shape as will produce suitable indications. It is desirable that the color be such as to provide adequate contrast with the background of the surface being examined. Amplified details on the use of dry particles are given in ASTM Specification E-109-63, Dry Powder Magnetic Particle Inspection.

(*2*) *Wet Particles.* If wet particles are used, the particles shall be red or black or, alternatively, may be fluorescent when viewed under ultraviolet illumination. The particles shall be suspended in a suitable liquid medium in the concentration recommended by the manufacturer of the particles. Amplified details on the use of wet particles are given in ASTM E-138-63, Wet Magnetic Particle Inspection.

(*e*) *Orientation of Defects.* Regardless of the manner of producing the magnetic flux, the greatest sensitivity will be to linear defects lying perpendicular to the lines of flux and the least sensitivity will be to linear defects lying parallel to the lines of flux. Hence, in order to insure most effective detection of defects, it is necessary to examine each area at least twice with the lines of flux in one case approximately perpendicular to the lines of flux in the other.

(*f*) *Demagnetization.* Demagnetization following inspection is neither required nor prohibited.

UA-72 Methods

(*a*) *Prod Method*

(*1*) *Surface Preparation.* The surface to be examined shall be clean and dry. It shall be free from oil, sand, loose rust, or loose scale.

In general, satisfactory results may be obtained when the surface is in the as-welded, as-rolled, as-cast, or as-forged condition. In some cases, however, surface preparation by grinding or machining may be necessary when surface irregularities otherwise would mask the indication of defects.

(*2*) *Examination Medium.* Magnetic particles in dry form shall be used with the prod method except that for routine production line type of inspection of parts such as castings, wet particles may be used.

(*3*) *Magnetizing Technique.* Magnetization is accomplished by the use of portable prod type electrical contacts pressed against the surface in the

area to be examined. A remote control switch, whcih may be built into the prod handles, shall be provided to permit the inspector to turn the current on after the prods have been properly positioned and to turn it off before the prods are removed in order to prevent arcing.

(*4*) *Prod Spacing.* Prod spacing shall be a maximum of 8 in. Shorter spacings may be used to meet the geometry of the area being examined or to increase sensitivity but prod spacing less than 3 in. usually is not feasible due to banding of the particles around the prods.

Care shall be taken to prevent local overheating or burning of the surface being examined, particularly on high-carbon or alloy materials, since this can cause hard spots or cracks. Lead or steel rather than copper-tipped prods are recommended where the magnetizing voltage is over 25 volts open circuit in order to avoid copper penetration.

(*5*) *Magnetizing Current.* Direct or rectified magnetizing current normally shall be used based on 100 to 125 amperes per inch of prod spacing.

(*6*) *Direction of Magnetization.* At least two separate examinations shall be carried out on each area. The prods shall be placed so that the magnetizing current during one is approximately perpendicular to the current during the other.

(*7*) *Procedure.* Prods are positioned on the surface to be examined and the magnetizing current turned on. The particles are then dusted lightly over the surface. Any excess may be removed with a gentle air stream. The air stream should not disturb or remove lightly held particle patterns. In order to recognize the broad, fuzzy, lightly held patterns produced by subsurface discontinuities, it is essential to observe carefully the formation of indications while the particles are being applied, and also while any excess is being removed. Proper lighting will facilitate observation of these patterns. Indications of defects are noted. The current is then turned off and the prods repositioned for the second examination of the area.

(*8*) *Evaluation of Indications.* Discontinuities and defects will be indicated by retention of the magnetic particles. All such indications are not necessarily defects, however, since excessive surface roughness, magnetic permeability variations (such as at the edge of heat affected zones), etc., may produce similar indications. If indications are believed to be nonrelevant, each type of indication shall be explored to determine if relevant linear discontinuities are present.

All linear discontinuities are unacceptable and shall be removed and repaired in accordance with applicable provisions of this Division of Section VIII. Where a linear discontinuity is removed by grinding or chipping, and subsequent welding is not necessary, care shall be taken to contour the surface so as to eliminate any sharp notches or corners. When a defect appears to be removed, the area shall be reexamined by the same method to verify that it has been removed completely. If repairs are made, the repaired area shall be examined by the same method.

(*b*) *Coil Method*

(*1*) The requirements of subparagraphs (1) "Surface Preparation" and (8) "Evaluation of Indications" of (a) shall apply.

(*2*) *Examination Medium.* Either dry or wet particles shall be used as the examination medium.

(*3*) *Magnetizing Technique.* Magnetization is developed by passing current through a multiturn coil looped around the part or section of the part that is to be examined. This produces a magnetic field parallel to the axis of the coil. The magnetic field strength of the coil shall be 3,000 to 10,000 ampere turns.

(*4*) *Magnetizing Current.* Direct or rectified current shall be used for magnetizing.

(*5*) *Direction of Magnetization.* At least two separate examinations shall be carried out on each area. The second examination shall be with current flow approximately at right angles to that used for the first examination in that area. A different means of magnetizing may be used for the second examination.

(*6*) *Procedure.* After the means of magnetization have been brought into the proper relationship with the surface to be examined, the magnetizing current is turned on. The examination medium is then applied to the area to be inspected. Dry particles are applied as described in (a)(7). If wet particles are used they are applied typically by spraying but other appropriate means may be employed. Indications of defects are noted and the second examination of the area is made in accordance with (5) above.

(*c*) *Yoke Method*

(*1*) The requirements of subparagraphs (1) "Surface Preparation" and (8) "Evaluation of Indications" of (a) shall apply.

(*2*) *Examination Medium.* Particles shall be used as the *examination* medium.

(*3*) *Magnetizing Technique*

(a) Alternating current electromagnetic yokes may be used to magnetize provided that the sensitivity to detect surface cracks is at least equivalent to

that of the prod method when a direct or rectified magnetizing current of 25 to 30 amperes per inch of prod spacing is used and the lifting power of the yoke is at least 10 lb with a pole spacing of 3 to 6 in.

(b) Permanent magnetic yokes may be used to magnetize provided that the sensitivity to detect surface cracks is at least equivalent to the prod method when a direct or rectified magnetizing current of 25 to 30 amperes per inch of prod spacing is used and the lfiting power of the yoke is at least 40 lb with a pole spacing of 3 to 6 in.

(*4*) *Direction of Magnetization.* At least two separate examinations shall be carried out on each area. The second examination shall be with the magnetic flux approximately at right angles to that used in the first inspection. A different means of magnetizing may be employed for the second examination of the area.

(*5*) *Procedure.* After the means of magnetizing have been brought into proper relationship with the surface to be examined, the magnetic particles shall be applied per (a)(7) and the examination and evaluation procedures carried out per reference paragraphs given in (1) above.

APPENDIX VII

EXAMINATION OF STEEL CASTINGS

UA-80 Scope

This Appendix covers examination requirements which shall be observed for all steel castings to which a 100 percent quality factor is to be applied in accordance with UG-24(a)(5). Those made to an accepted standard such as ANSI B16.5 are not required to comply with the provisions of this Appendix.

UA-81 Examination Techniques

Examination techniques shall be carried out in accordance with the following:

(*a*) Magnetic particle examinations shall be per Appendix VI except that acceptance standards shall be as given in UA-82(a)(3) of this Appendix.

(*b*) Liquid penetrant examinations shall be per Appendix VIII except that acceptance standards shall be as given in UA-82(a)(4) of this Appendix.

(*c*) Radiographic examinations shall be per ASTM Specification E94-62T, Tentative Recommended Practices for Radiographed Testing.

(*d*) Ultrasonic examinations shall be per ASTM Specification E114-63, Recommended Practice for Ultrasonic Testing.

UA-82 Examination Requirements

All steel castings shall be examined in accordance with (a) or (b) as applicable.

(*a*) All castings having a maximum body thickness less than $4^1/_2$ in. shall be examined as follows:

(*1*) All critical sections[1] shall be radiographed. For castings having radiographed thicknesses up to 2 in., the radiographs shall be compared to those in ASTM Specification E71-64, Reference Radiographs for Steel Castings. The maximum acceptable severity levels for defects shall be as follows:

MAXIMUM ACCEPTABLE SEVERITY LEVELS FOR CASTINGS UP TO 2 IN. THICKNESS

Defect Type	Thicknesses < 1 in.	Thicknesses 1 in. to < 2 in.
A–Gas and Blow Holes	1	2
B–Sand Spots and Inclusions	1	2
C–Internal Shrinkage	1	2
D–Hot Tears	0	0
E–Cracks	0	0
F–Useful Chaplets	0	0
G–Internal Chills	0	0

For castings having radiographed thicknesses from 2 to $4^1/_2$ in., the radiographs shall be compared to those in ASTM Specification E186-65T, Tentative Reference Radiographs for Heavy-Walled (2 to $4^1/_2$ in.) Steel Castings. The maximum acceptable severity levels for defects shall be as follows:

MAXIMUM ACCEPTABLE SEVERITY LEVELS FOR CASTINGS 2 TO 4½ IN. THICKNESS

Defect Type	Maximum Severity Level
A–Gas Porosity	2
B–Sand and Slag Inclusions	2
C–Shrinkage	
Type 1	1
Type 2	2
Type 3	3
D–Linear Discontinuities	0
E–Inserts	
Type 1	0
Type 2	0

(*2*) All surfaces including machined gasket seating surfaces shall be examined by the magnetic particle or the liquid penetrant method. When the casting specification requires heat treatment, these examinations shall be conducted after that heat treatment.

(*3*) Surface indications determined by magnetic

[1]Critical sections: For static castings, the sections where defects are usually encountered are abrupt changes in section and at the junctions or risers, gates, or feeders to the casting. For centrifugal castings, "critical sections" shall be interpreted to be any abrupt changes of section, the circumference for a distance of at least 3 in. from each end and one additional circumferential band at least 3 in. wide and including the area of the most severe indication detected by other examination methods.

particle examination shall be compared with those indicated in ASTM Specification E125-63, Standard Reference Photographs for Magnetic Particle Indications on Ferrous Castings, and shall be removed if they exceed the following limits:

Type	Degree
I. Linear Discontinuities (Hot Tears and Cracks)	All Indications
II. Shrinkage	2
III. Inclusions	3
IV. Chills and Chaplets	1
V. Porosity	1

(*4*) Surface indications determined by liquid penetrant examination shall be removed if they exceed the following limits:

(a) All cracks and hot tears

(b) Any group of more than six linear indications other than those in (a) in any rectangular area of $1\frac{1}{2}$ in. × 6 in. or less or any circular area having a diameter of $3\frac{1}{2}$ in. or less, these areas being taken in the most unfavorable location relative to the indications being evaluated.

(c) Other linear indications more than $\frac{1}{4}$ in. long for thicknesses up to $\frac{3}{4}$ in. inclusive, more than one-third of the thickness in length for thicknesses from $\frac{3}{4}$ in. to $2\frac{1}{4}$ in., and more than $\frac{3}{4}$ in. long for thicknesses over $2\frac{1}{4}$ in. (Aligned acceptable imperfections separated from one another by a distance equal to the length of the longer imperfection are acceptable.)

(d) All indications of nonlinear defects which have any dimension exceeding $\frac{3}{32}$ in.

(*5*) When more than one casting of a particular design is produced, each of the first five shall be examined to the full extent prescribed herein. When more than five castings are being produced, examinations as prescribed shall be performed on the first five and on one additional casting for each additional five castings produced. If any of these additional castings proves to be unacceptable, each of the remaining four castings of that group shall be examined fully.

(*b*) All castings having maximum body thickness $4\frac{1}{2}$ in. and greater and castings of lesser thickness which are intended for severe service applications[1] shall be examined as follows:

(*1*) Each casting shall be subjected to 100 percent visual examination and to complete surface examination by either the magnetic particle or the liquid penetrant method. When the casting specification requires heat treatment, these examinations shall be conducted after that heat treatment. Acceptability limits for surface defects shall be as given in UA-82(a) (3 and 4).

(*2*) All parts of castings up to 12 in. in thickness shall be subjected to radiographic examination and the radiographs compared to those given in ASTM Specification E280-65T, Tentative Reference Radiographs for Heavy-Wall ($4\frac{1}{2}$ to 12 in.) Steel Castings. The maximum acceptable severity levels for defects shall be as follows:

MAXIMUM ACCEPTABLE SEVERITY LEVELS FOR CASTINGS 4½ TO 12 IN. THICKNESS

Defect Type	Maximum Severity Level
A–Gas Porosity	2
B–Sand and Slag Inclusions	2
C–Shrinkage	
Type 1	2
Type 2	2
Type 3	2
D–Hot Tears and Cracks	0
E–Inserts	
Type 1	0
Type 2	0

(*3*) For castings having a maximum thickness in excess of 12 in., all thicknesses which are less than 12 in. shall be examined radiographically in accordance with the preceding paragraph. All parts of such castings having thicknesses in excess of 12 in. shall be examined ultrasonically in accordance with ASTM Specification E114-63. Any discontinuities having reflections which do not exceed 20 percent of the straight beam back reflection or do not reduce the height of the back reflection by more than 30 percent during a total movement of the transducer of 2 in. in any direction shall be considered acceptable. Defects having reflections exceeding these limits shall be repaired unless proved to be acceptable by other examination methods. The ultrasonic examination shall be conducted using transducers having approximately 1 sq in. of area.

UA-83 Repairs

(*a*) Whenever a discontinuity is removed, the excavated areas shall be examined by the magnetic particle or liquid penetrant method to ensure complete removal.

(*b*) Whenever a surface discontinuity is eliminated by removing less than 5 percent of the intended

[1]The Code as currently written provides minimum requirements for construction and it is recognized to be the responsibility of the designing engineer to determine when the intended service is of a nature that requires supplementary requirements to ensure safety; consequently, the designer should determine when the service warrants that this class of inspection be specified for steel castings of less than 4 in. nominal body thickness.

thickness of metal at that location, welding need not be employed in making repairs. Where this is the case, the excavated area shall be blended into the surrounding surface so as to avoid any sharp contours.

(*c*) Castings of nonweldable materials which contain defects in excess of acceptable limits as given in UA-82 shall be rejected.

(*d*) For any type of defect, if the repair will entail removal of more than 75 percent of the thickness or a length in any direction of 6 in. or more, approval of the purchaser of the casting shall be obtained prior to making repairs.

(*e*) The finished surface of all repair welds shall be examined by the magnetic particle or liquid penetrant method. When subsequent heat treatment is required, this examination of the repaired area shall be conducted after heat treatment.

(*f*) All weld repairs of depth exceeding 1 in. or 20 percent of the section thickness, whichever is the lesser, shall be inspected by radiography.

Where the depth of repairs is less than 20 percent of the section thickness, or 1 in., whichever is the lesser, and where the repaired section cannot be radiographed effectively, the first layer of each $\frac{1}{4}$ in. thickness of deposited weld metal shall be examined by the magnetic particle or the liquid penetrant method. Weld repairs which are made as a result of ultrasonic examination shall be reexamined by the same method when completed.

(*g*) When repair welding is done after the casting has been heat treated and when required by either the rules of this Section or the requirements of the casting specification, the repaired casting shall be postweld heat treated. Serious defects shall be the basis of rejection of the casting. The inspector shall have the right to demand a similar examination of any number of additional castings from the same heat until acceptable castings are consistently produced where a 90 or 100 percent quality factor is used. Where defects not impairing the strength of the casting have been repaired by welding, the completed repair shall be subject to reexamination and, when required by either the rules of this Section or the requirements of the castings specification, the repaired casting shall be postweld heat treated and to obtain a 90 or 100 percent factor, the repaired casting shall be stress relieved.

(*h*) All welding shall be performed using procedure qualifications in accordance with Section IX. The procedure qualification shall be performed on a test specimen of the cast material of the same specification that has been subjected to the same heat treatment both before and after welding as will be applied to the production casting. All welders and operators performing this welding shall be qualified in accordance with Section IX.

UA-84 Identification and Marking

Each casting shall be marked with the manufacturer's name and casting identification, including material designation. The manufacturer shall furnish reports of the chemical and mechanical properties and certification that each casting conforms to all applicable requirements of this Appendix.

APPENDIX VIII

METHODS FOR LIQUID PENETRANT EXAMINATION (PT)

NOTE: Satisfactory application of this method of examination requires special skills in the techniques involved and in interpreting the results. The requirements specified herein presume application by suitably experienced personnel.

UA-91 Scope

(*a*) This Appendix describes methods which shall be employed whenever liquid penetrant examination is specified in this Division of Section VIII. The procedures are substantially in conformance with ASTM Specification E-165-65, Methods for Liquid Penetrant Inspection, and reference to this standard may be made for additional details on procedures given herein.

(*b*) Two basic methods are approved for use, each with three choices of type of penetrant. Unless specified otherwise, any of the methods described may be employed.

UA-92 Description of Method

Liquid penetrant examination is a method of nondestructive examination which provides for the detection of discontinuities open to the surface in ferrous and nonferrous materials which are are nonporous. Typical discontinuities detectable by this method are cracks, seams, laps, cold shuts, and laminations.

A liquid penetrant is applied to the surface to be examined and allowed to enter such openings after which excess liquid is removed. A developer is then applied which is wetted or otherwise affected by the penetrant entrapped in the discontinuities. This increases the evidence of the discontinuities so that they may be seen either directly or by use of "black light."

UA-93 Approved Methods

(*a*) Either a visible dye penetrant or a fluorescent penetrant may be used. In each case, there are three types:

(*1*) Water washable penetrants
(*2*) Post emulsifying penetrants
(*3*) Solvent removable penetrants

(*b*) *Visible Dye Penetrants* contain a dye, the constrasting color of which can be seen readily in daylight or under normal interior illumination.

(*c*) *Fluorescent Penetrants* carry a dye that fluoresces under "black light."

UA-94 Procedures

(*a*) *Cleaning.* It is essential that the part or surface to be examined be clean. Since the success of the method depends upon entry of the penetrant into any defects present, the requirement for cleanliness is paramount. Cleanliness in this application shall be interpreted to include the removal of all rust, scale, welding flux, spatter, grease, oily films, water, dirt, etc., not only from the surface but, more particularly, from any defects present.

Typical cleaning facilities applicable for this purpose are detergents, organic solvents, descaling solutions or paint removers, and vapor degreasing, abrasive blasting, or ultrasonic cleaning methods.

(*b*) *Drying.* It is essential that the part or surface to be examined be sufficiently dried prior to application of penetrant so that no trace of water or cleaning agent remains in any defects that are present.

(*c*) *Penetrant Application.* The penetrant is applied by dipping, brushing, or spraying. Penetration time is critical. In general, the finer and tighter the discontinuity, the longer the penetration time should be. The penetration time shall be at least 3 minutes but this minimum time may have to be extended under certain conditions such as when the temperature is below 60 F. At 40 F, for example, twice the time required above 60 F is suggested.

As a standard technique, the temperature of the surface or part to be examined, the liquid penetrant, the rinse, and the developer shall not be below 40 F nor above 125 F throughout the examination

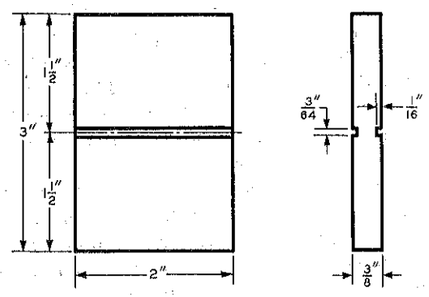


FIG. UA-99 LIQUID PENETRANT COMPARATOR

period. Local heating or cooling is permitted provided temperatures remain in the range of 40–125 F during the examination. Where it is impracticable to comply with the foregoing temperature limitations, other temperatures and times may be used providing that the procedure is qualified by use of a liquid penetrant comparator prepared and used as described in UA-99.

(*d*) *Excess Penetrant Removal.* After suitable penetration time has elapsed, any penetrant remaining on the surface shall be removed. Insufficient removal will leave a background which will interefere with subsequent indication of defects. Care must be exercised that penetrant in any defects is not removed.

(*1*) With water washable penetrants, it is recommended that the excess be removed with a water spray. Water pressures over 50 psi or water temperatures over 110 F should not be employed.

(*2*) With postemulsifying penetrants, an additional step is required. This is the application of a liquid emulsifier prior to the rinsing operation. The emulsifier may be applied by spraying or dipping. The emulsifying time is critical and depends on surface roughness and type of defects sought. It may vary from 10 sec to 5 min. The usual time is 2 to 3 min. After emulsification, the mixture is removed by a water spray, using the same procedure as for water washable liquid penetrants.

(*3*) With solvent removable penetrants, excess penetrant may be removed from the surface by wiping with rags or cloths moistened with the solvent. Care should be employed not to use an excess of the solvent in order to avoid removing penetrant from defects. On smooth surfaces it may be possible sometimes to remove excess penetrant merely by wiping the surface with clean dry rags or cloth.

(*e*) *Developing.* There are two types of developer, dry and wet, either of which may be used.

(*1*) The dry developer is a powder that is applied by a soft brush, a hand powder bulb, or a powder gun. Other means more suitable to the size and geometry of the specimen may be used provided the objective is accomplished. This is to deposit a film of developer on the surface to be examined. The surface should be dried before application of the powder, preferably by warm air. The normal developing time required to draw penetrant in the discontinuities into the powder on the surface is about one-half the time allowed for penetration.

(*2*) The liquid developer is a suspension of powder in water or a volatile solvent. It is applied by dipping, spraying, or brushing. In any case, when the developer dries, a film of powder is left on the surface. Where a water suspension developer is used, drying time may be decreased by the use of warm air.

UA-95 Examination

The true size and type of defect are difficult to appraise if the dye diffuses excessively in the developer. Consequently, it is good practice to conduct the examination soon after applying the developer. In no case shall the examination be made later than 30 min after the developer has dried.

(*a*) *With Visible Penetrants,* the developer forms a more or less even white coating. Surface defects are indicated by bleeding out of the penetrant, which is normally of a deep red color. Adequate illumination shall be provided since otherwise sensitivity will be diminished.

(*b*) *With Fluorescent Penetrants,* the mechanism is essentially the same except that the examination is conducted in a darkened area using "black light." A "black light" filter shall be used so that the light emitted shall be essentially in the 3650 Angstrom wavelength band. An intensity of illumination of 90 to 100 foot candles measured with the filter in place is required for satisfactory indication of defects.

UA-96 Evaluation of Indications

(*a*) *Linear Indications* are those indications in which the length is more than twice the width.

(*b*) *Rounded Indications* are indications which are circular or elliptical with the length less than twice the width.

(*c*) Any questionable or doubtful indications shall be retested to verify whether or not actual defects are present.

(*d*) General broad areas of pigment penetration shall be interpreted as indicative of improper processing. Such areas shall be retested with a suitably modified procedure.

UA-97 Acceptance Standards

All surfaces required to be examined shall be free of linear defects (cracks, laps, fissures, etc.) and of four or more rounded defects in a line separated by $^{1}/_{16}$ in. or less (edge to edge) except where the specification for the material establishes different requirements for acceptance so far as defects are concerned.

UA-98 Defect Removal and Repair

Unacceptable defects shall be removed and a reexamination made to assure the complete removal. Whenever a defect is removed and subsequent repair by welding is not required, the excavated area shall be blended into the surrounding surface so as to avoid sharp notches, crevices, or corners. Where welding is required after removal of a defect, the area shall be cleaned and welding performed in accordance with a qualified welding procedure. Completed repairs shall be reexamined by the method originally used for detection of the defect.

UA-99 Qualification of Procedures for Nonstandard Temperatures

(*a*) *General.* When it is impracticable to conduct a liquid penetrant examination within the temperature range of 40 to 125 F, the examination procedure at the proposed temperature must be qualified. This is accomplished by producing quench cracks in an aluminum block, which for this purpose is designated as a liquid penetrant comparator, and then examining one section of the block at the proposed temperature and the other section of the block at a temperature in the range of 60 to 90 F.

(*b*) *The liquid penetrant comparator* shall be made of aluminum SB-211, Type 2024, as rolled, $^{3}/_{8}$ in. thick and shall have a face dimension of 2 in. × 3 in. At the center of each face, an area approximately 1 in. in diameter shall be marked with a 950 F temperature indicating crayon or paint. The marked area shall be heated by a blow torch, a Bunsen burner or a similar device to a temperature of 950 to 975 F. The specimen is then quenched in cold water, which will produce a network of fine cracks on each of the faces. The block shall then be dried by heating to 300 F, after which a groove shall be machined across the center of each face $^{1}/_{16}$ in. deep and $^{3}/_{64}$ in. wide. One-half of the specimen shall be designated as "A" and the other as "B" for identification in subsequent procedures. Figure UA-99 shows the comparator after the grooves have been cut.

(*c*) If it is desired to qualify a liquid penetrant examination procedure at a temperature less than 40 F, for example, the proposed procedure shall be applied to area "B" after the block and all testing materials have been cooled to the proposed examination temperature. The block then shall be allowed to warm to 60 to 90 F and area "A" examined in a manner which has been demonstrated to be suitable for use in this temperature range.

The indications of cracks shall be compared for areas "A" and "B". If the indications obtained under the proposed conditions are essentially the same as those obtained under the examination at 60 to 90 F, the proposed procedure may be considered qualified for use.

(*d*) If the proposed temperature for the examination is above 125 F, then only the block need be held at this temperature throughout the examination of the "B" section.

APPENDIX IX
JACKETED VESSELS

UA-100 Scope

(*a*) The rules in Appendix IX cover minimum requirements for the design, fabrication, and inspection of the jacketed portion of a pressure vessel. The jacketed portion of the vessel is defined as the inner and outer walls, the closure devices, and all other penetrations or parts within the jacket which are subjected to pressure stresses. Parts such as nozzle closure members and stiffening or stay rings are included.

(*b*) All other Parts of this Section of the Code shall apply unless otherwise stated in this Appendix.

(*c*) Where the internal pressure is 15 psi or less, any combination of pressures and vacuum in the vessel and jacket which will produce a total external pressure greater than 15 psi on the inner vessel wall, the entire jacket shall be interpreted as within the scope of this part.

(*d*) For the purpose of this Part, jackets are assumed to be integral pressure chambers, attached to a vessel for one or more purposes such as,

(*1*) To heat the vessel and its contents

(*2*) To cool the vessel and its contents

(*3*) To provide a sealed insulation chamber for the vessel

(*e*) As stated in U-2, the Code does not contain rules to cover all details of design and construction. These rules are therefore established to cover most common jacket types, but are not intended to limit configurations to those illustrated or otherwise described herein.

UA-101 Types of Jacketed Vessels

This Appendix shall apply to jacketed vessels having jackets which cover the shell or heads as illustrated in Fig. UA-101 and partial jackets as illustrated in Fig. UA-106. Jackets, as shown in Fig. UA-101, shall be continuous circumferentially for Types 1, 2, 4, or 5 shown and shall be circular in cross section for Type 3. The use of any combination of the Types shown is permitted on any one vessel provided the individual requirements for each are met. Dimpled jackets are not covered in this Appendix (See UW-19).

UA-102 Materials

Materials used in the fabrication of jackets shall be in accordance with Subsection A.

UA-103 Design of Jacket Shells and Jacket Heads

Design shall comply with the applicable requirements of Subsection A except where otherwise provided for in this Appendix.

(*a*) Shell and head thickness shall be determined by the appropriate formula given in Subsection A. In consideration of the loadings given in UG-22, particular attention to the effects of local internal and external loads and expansion differentials at design temperatures shall be given. Where vessel supports are attached to the jacket, consideration shall be given to the transfer of the supported load of the inner vessel and contents.

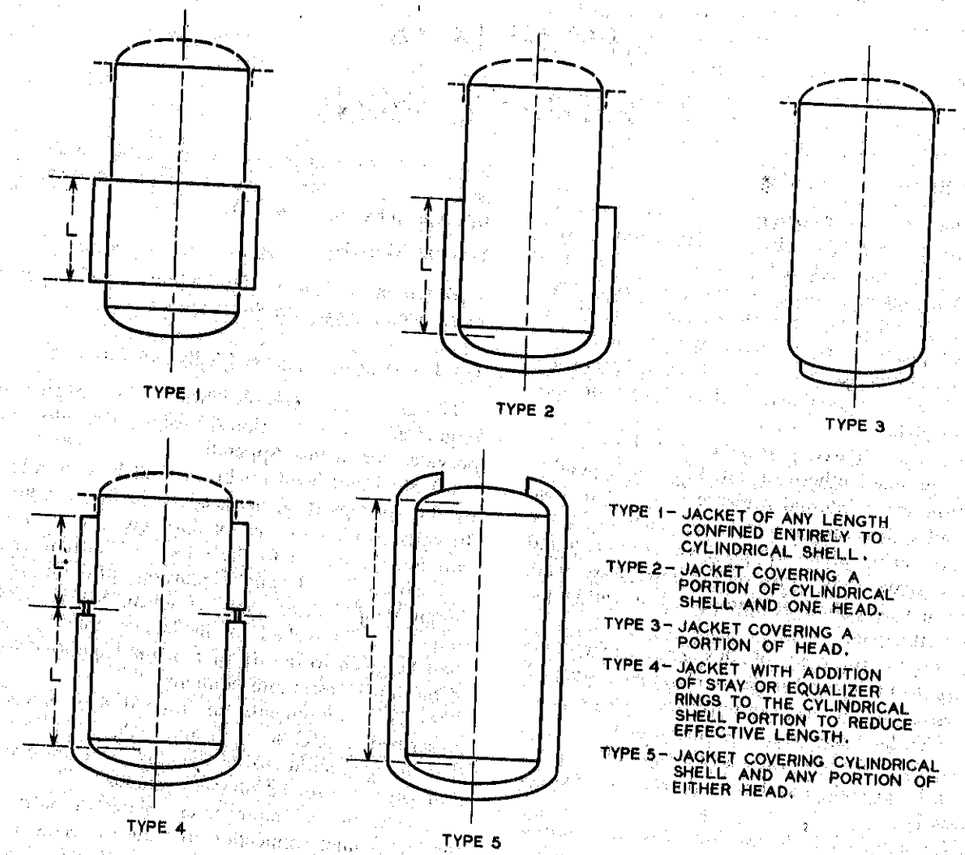
(*b*) The requirements for inspection openings as prescribed in UG-46 shall apply to jackets except that the maximum size of opening need not exceed 2-in. pipe size for all diameter vessels.

(*c*) The use of impingement plates or baffles at the jacket inlet connection to reduce erosion of the inner wall shall be considered for media where vapors are condensed, i.e., steam.

(*d*) Jacketed vessels may be designed utilizing braced and stayed surfaces as given in UG-47 provided the jacket wall in addition to meeting the requirements of UG-47(a) also meets the applicable requirements of UG-27(c) and (d) and UG-32. This paragraph is not intended to apply to dimpled jackets. (See UW-19.)

UA-104 Design of Closure Member of Jacket to Vessel

(*a*) This paragraph gives rules for the design of closure members shown herein. Closures of



TYPE 1 – JACKET OF ANY LENGTH CONFINED ENTIRELY TO CYLINDRICAL SHELL.

TYPE 2 – JACKET COVERING A PORTION OF CYLINDRICAL SHELL AND ONE HEAD.

TYPE 3 – JACKET COVERING A PORTION OF HEAD.

TYPE 4 – JACKET WITH ADDITION OF STAY OR EQUALIZER RINGS TO THE CYLINDRICAL SHELL PORTION TO REDUCE EFFECTIVE LENGTH.

TYPE 5 – JACKET COVERING CYLINDRICAL SHELL AND ANY PORTION OF EITHER HEAD.

FIG. UA-101 SOME ACCEPTABLE TYPES OF JACKETED VESSELS

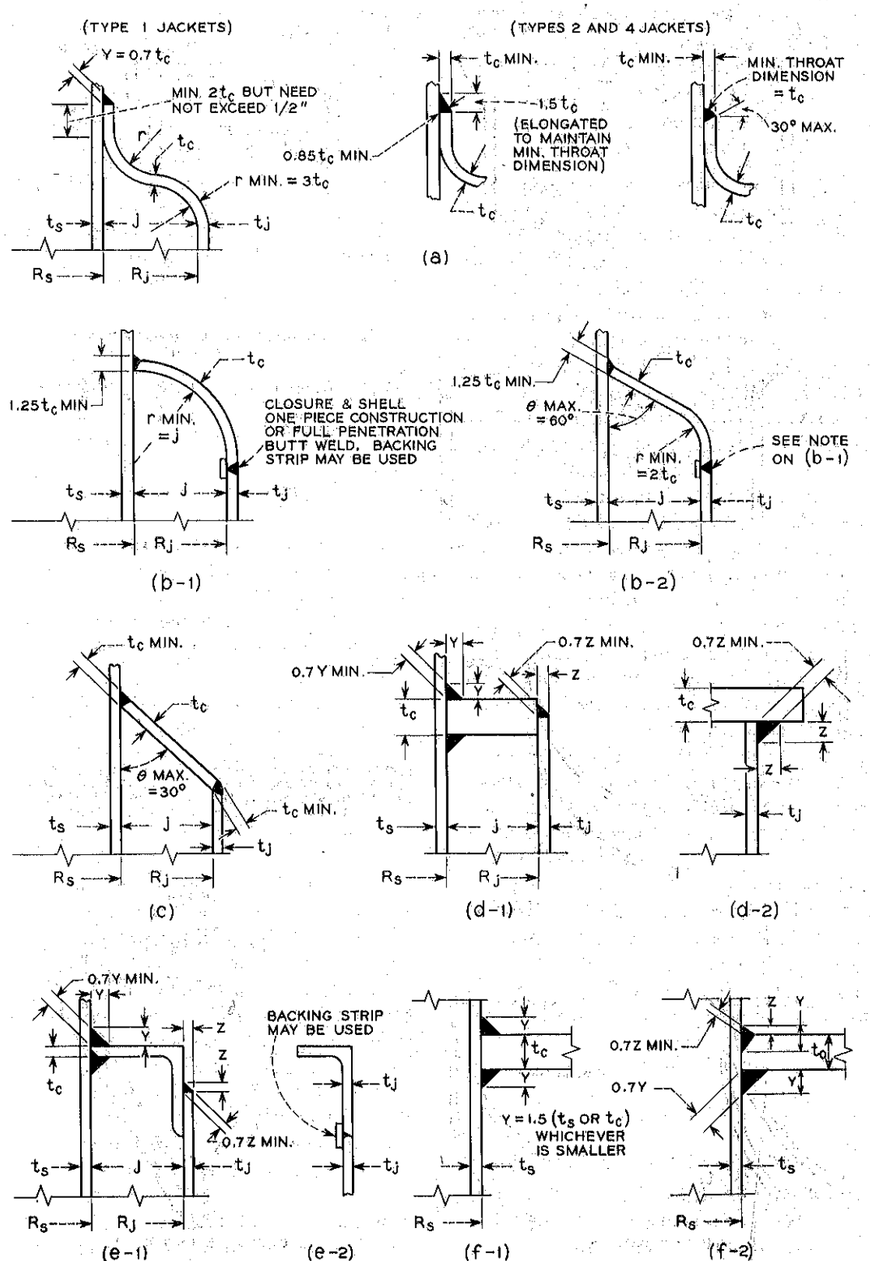


FIG. UA-104 SOME ACCEPTABLE TYPES OF JACKET CLOSURES

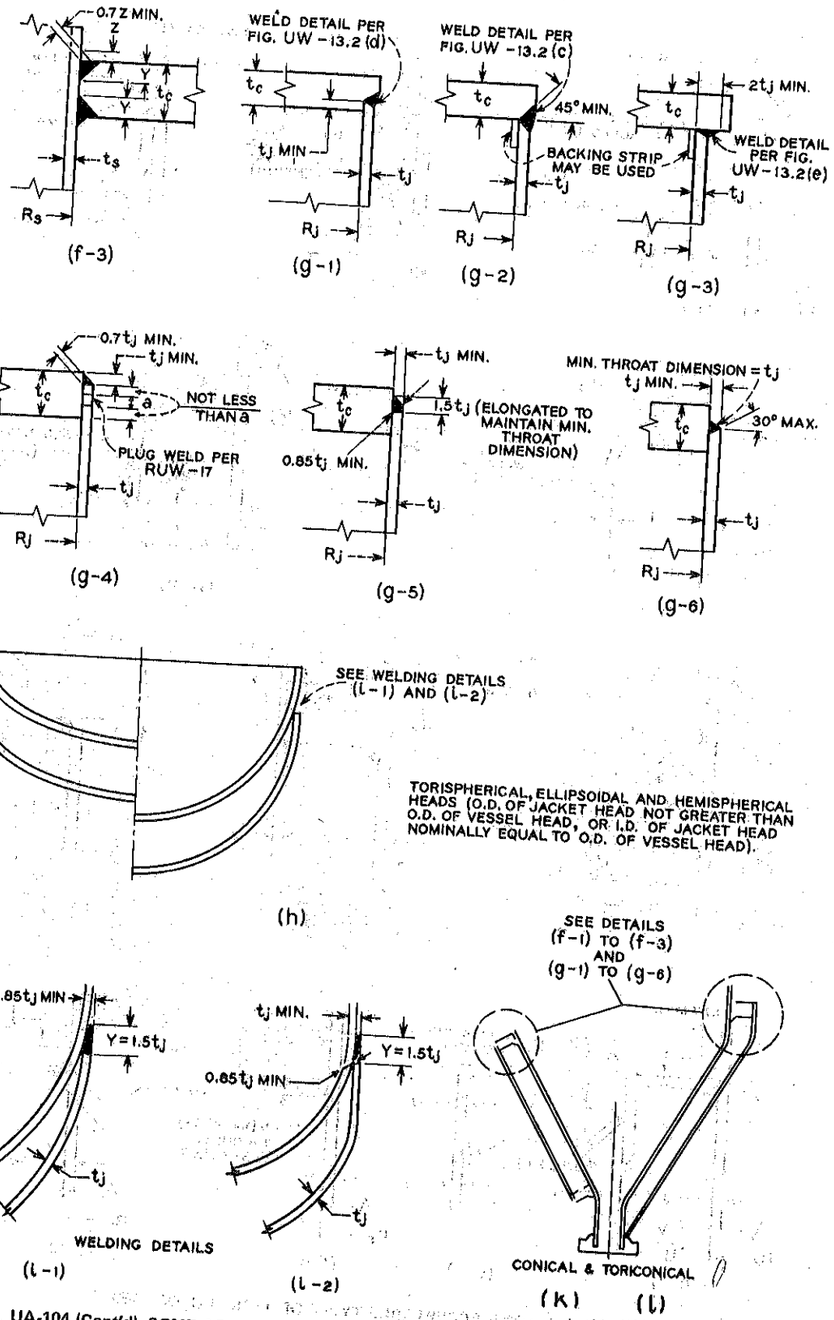


FIG. UA-104 (Cont'd) SOME ACCEPTABLE TYPES OF JACKET CLOSURES (see text for limitations)

geometries other than those illustrated may be used if the strength requirements of UG-101 are met.

(*b*) Symbols used in UA-104 and UA-105 are as follows:

t_s = actual thickness of inner vessel wall, inches

t_{rj} = required minimum thickness of outer jacket wall exclusive of corrosion allowance, inches

t_{ro} = required minimum thickness exclusive of corrosion allowance of closure member as determined herein, inches

t_o = actual thickness of closure member, inches

t_j = actual thickness of outer jacket wall, inches

t_n = nominal thickness of nozzle wall, inches

r = corner radius of torus closures, inches

R_s = outside radius of inner vessel, inches

R_j = inside radius of jacket, inches

R_p = radius of opening in the jacket at the jacket penetration

P = design pressure in jacket chamber, psig

P_v = design vacuum in inner vessel, psig

S = maximum allowable stress value, psi, from applicable table of stress values in Subsection C

j = jacket space, inches. Inside radius of jacket minus outside radius of inner vessel

a, b, c, Y, Z = minimum weld dimensions for attachment of closure member to inner vessel measured as shown in Figs. UA-104 and UA-105, inches

L = design length of a jacket section as shown in Fig. UA-101. This length is determined as follows:

(1) The distance between inner vessel head-bend lines plus one-third of the depth of each inner vessel head if there are no stiffening rings nor jacket closures between the head-bend lines;

(2) the center-to-center distance between any two adjacent stiffening rings or jacket closures; or

(3) the distance from the center of the first stiffening ring or the jacket closure to the jacketed inner head-bend line plus one-third of the inner vessel head, all measured parallel to the axis of the vessel, inches

For the design of a closure member or stiffening ring, the greater adjacent L shall be used

(*c*) Jacket closures shown in Fig. UA-104 shall conform to the following requirements:

(*1*) Closures of the type shown in Fig. UA-104(a) that are used on Types 1, 2, and 4 jacketed vessels as shown in Fig. UA-101, shall have t_{ro} at least equal to t_{rj} and corner radius r shall not be less than $3t_o$. This closure design is limited to a maximum thickness, t_{ro}, of ⅝ in. When this construction is used on Type 1 jacketed vessels, the weld dimension Y shall be not less than 0.7 t_o, and when used on Types 2 and 4 jacketed vessels, the weld dimension Y shall be not less than .85 t_o.

(*2*) Closures of the type shown in Fig. UA-104 (b-1) and (b-2) shall have t_{ro} at least equal to t_{rj}. A groove weld attaching the closure to the inner vessel and fully penetrating the closure thickness, t_o, may be used with any of the types of jacketed vessels shown in Fig. UA-101. However, a fillet weld having a minimum throat dimension of 0.7 t_o may also be used to join the closure of the inner vessel on Type 1 jacketed vessels of Fig. UA-101.

(*3*) Closures of the type shown in Fig. UA-104 (c) shall be used only on Type 1 jacketed vessels shown in Fig. UA-101. The closure thickness, t_{ro}, shall be determined by Formula (4) of UG-32(g), but shall be not less than t_{rj}. The angle θ shall be limited to 30 deg maximum.

(*4*) Closures of the types shown in Fig. UA-104 (d-1), (d-2), (e-1), and (e-2), shall be used only on Type 1 jacketed vessels as shown in Fig. UA-101 and with the further limitation that t_{rj} does not exceed ⅝ in. The required minimum thickness for the closure bar shall be the greater of the following:

$$t_{ro} = 2(t_{rj})$$

$$t_{ro} = 0.866\, j \sqrt{\frac{P}{S}}$$

Fillet weld sizes shall be as follows:

Y shall be not less than the smaller of t_o or t_s

Z shall not be less than t_j

(*5*) Closure bar and closure bar to inner vessel welds of the types shown in Fig. UA-104 (f-1), (f-2), and (f-3) may be used on any of the types of jacketed vessels shown in Fig. UA-101. The required

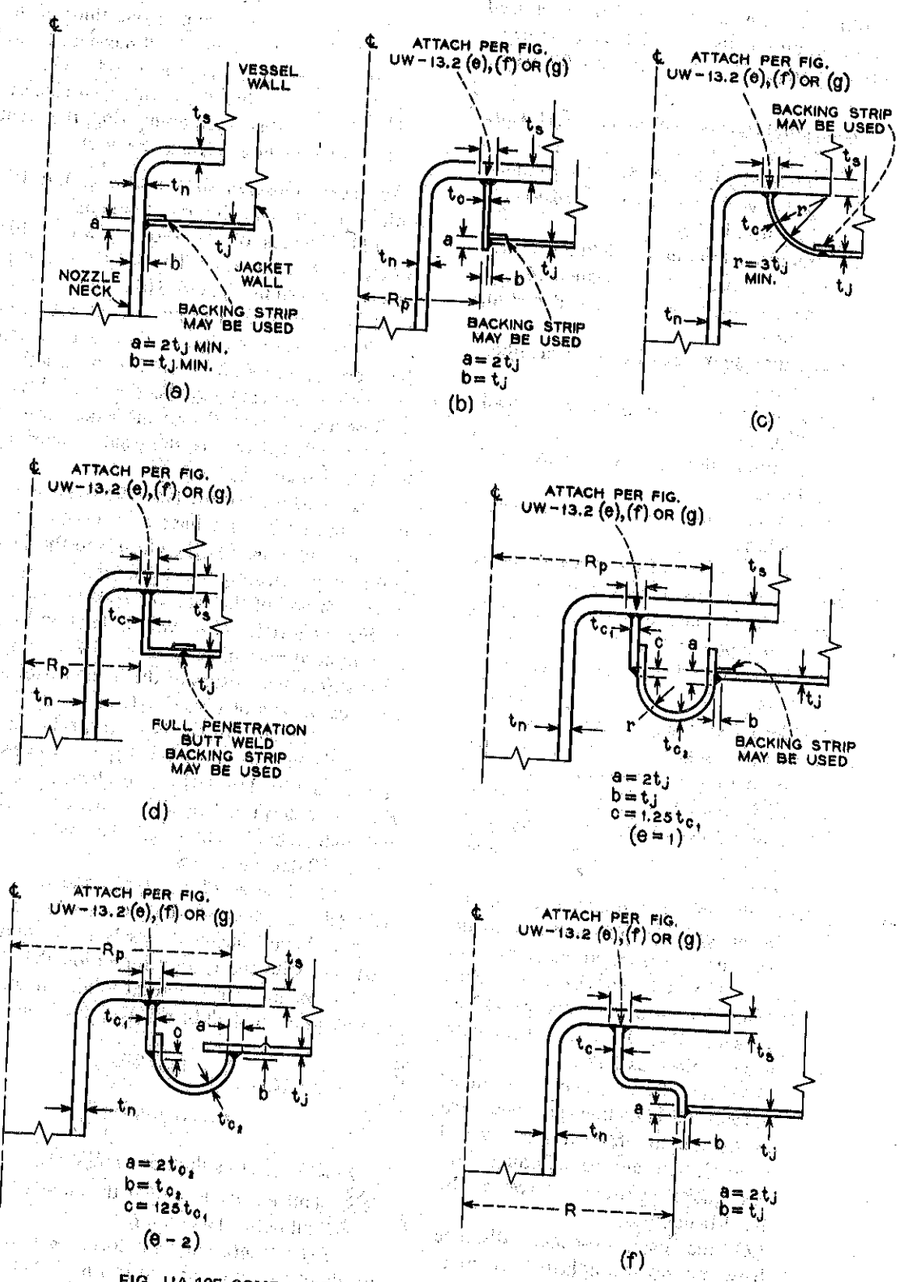


FIG. UA-105 SOME ACCEPTABLE TYPES OF PENETRATION DETAILS

minimum closure bar thickness shall be determined from the following formula:

$$t_{ro} = 1.732\sqrt{\frac{PR_{oj}}{S}}$$

The width of the jacket space shall not exceed the value given by the following formula:

$$j = \frac{2St_s^2}{PRj} - 0.5(t_s + t_j)$$

Weld sizes connecting the closure bar to the inner vessel shall be as follows:

Y shall be not less than the smaller of 1.5 t_o or 1.5 t_s.

Z = minimum fillet size necessary when used in conjunction with a groove to maintain minimum Y dimension.

(6) Jacket to closure bar attachment welds shown in Fig. UA-104 (g-1), (g-2), and (g-3) may be used on any of the types of jacketed vessels shown in Fig. UA-101. Attachment welds shown in Fig. UA-104 (g-4), (g-5), and (g-6) may be used on any of the types of jacketed vessels shown in Fig. UA-101 where t_{rj} does not exceed ⅝ in.

(7) Closures shown in Fig. UA-104(h) used on Type 3 jacketed vessels shown in Fig. UA-101 shall have attachment welds in accordance with Fig. UA-104 (i-1) or (i-2). This construction is limited to jackets where t_{rj} does not exceed ⅝ in.

(8) Closures for conical or toriconical jackets shown in Fig. UA-104(k) and (l) shall comply with the requirements for Type 2 jacketed vessels shown in Fig. UA-101.

(d) Any radial welds in closure members shall be butt-welded joints penetrating through the full thickness of the member and shall be ground flush where attachment welds are to be made.

(e) Where the inner vessel must meet the requirements of UW-2, the attachment welds of the jacket to the inner vessel need not be welded for their full thickness nor radiographed. These attachment welds shall be postweld heat treated where required by UW-2 except as may be exempted by the notes to Table UCS-56. The remainder of the jacket need not comply with UW-2 when the inner vessel alone is subjected to the service restrictions. The diameter limitations of UW-12 and UW-13 do not apply to the jacket attachment welds.

(f) Closures for any type of staybolted jacket may be designed in accordance with the requirements of Type 1 jackets shown in Fig. UA-101 provided the entire jacket is staybolted to compensate for pressure end forces.

UA-105 Design of Penetrations Through Jackets

(a) The design of openings through the jacket space shall be in accordance with the rules given in UG-36 through UG-45.

(b) Reinforcements of the opening in the jacket shall not be required for penetrations shown in Fig. UA-105 since the opening is stayed by virtue of the nozzle or neck of the closure member.

(c) The jacket penetration closure member minimum thickness considers only pressure membrane loading. Axial pressure loadings and secondary loadings given in UG-22 shall be considered in the design (see UA-105(d)(6)).

(d) Jacket penetration closure member designs shown in Fig. UA-105 shall conform to the following requirements:

(1) The nozzle wall may be used as the closure member as shown in Fig. UA-105(a), where jacket is welded to nozzle wall.

(2) The minimum required thickness, t_{ro}, for designs Fig. UA-105(b) and (d) shall be calculated as a shell under external pressure per UG-28.

(3) The minimum required thickness, t_{ro}, for design Fig. UA-105(c) shall be equal to t_{rj}.

(4) For designs Fig. UA-105 (e-1) and (e-2), the thickness required of the closure member attached to the inner vessel, t_{ro1}, shall be calculated as a shell under external pressure per UG-28. The required thickness of the flexible member, t_{ro2}, shall be determined from one of the following expressions:

$$t_{ro2} = \frac{Pr}{SE - 0.6p}$$ (when no tubular section exists between jacket and torus)

$$t_{ro2} = \frac{PR_p}{SE - 0.6p}$$ (when tubular section exists between jacket and torus)

where E = weld efficiency from Table UW-12 for circumferential weld in the torus for equation using r, or for any weld in opening closure member for equation using R_p, radius of penetration.

(5) The minimum thickness, t_{ro}, for design *(f)* shall be calculated as a shell of radius R_p under external pressure per UG-28.

(6) Designs (b), (c), (d), and (e) of Fig. UA-105 provide for some flexibility and are designed on a similar basis to that of expansion joints under the conditions of U-2(g) in combination with UG-22 and UG-23. Only pressure membrane loading is considered in establishing the minimum thickness of the penetration closure member, and it is not the intent that the combination of direct localized and secondary bending stress need be held to the Code-tabulated allowable stress values. It is recognized by

footnote 2 to UG-23(b) that high localized and secondary bending stresses may exist in code vessels.

(*e*) All radial welds in opening sealer membranes shall be butt-welded joints penetrating through the full thickness of the member.

(*f*) Closure member wells shall be circular, elliptical, or obround in shape where possible. Rectangular member wells are permissible provided that corners are rounded to a suitable radius.

UA-106 Design of Partial Jackets

(*a*) Partial jackets are jackets which encompass less than the full circumference of the vessel. Some variations are shown in Fig. UA-106.

(*b*) The rules for construction of jacketed vessels given in preceding paragraphs shall apply to partial jackets with following exceptions.

(*1*) Stayed partial jackets shall be designed and constructed in accordance with UG-47. Closure members shall conform to UA-104.

(*2*) Partial jackets which by virtue of their service or configuration do not lend themselves to staybolt construction may be fabricated by other means providing they are designed using appropriate stress values and are proof tested in accordance with UG-101(p).

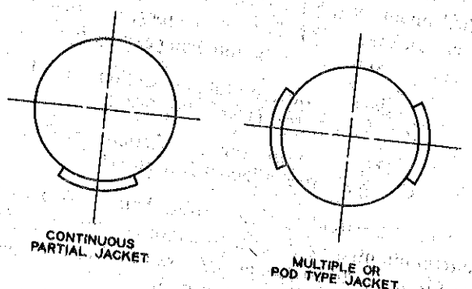


FIG. UA-106

UA-107 Fabrication

(*a*) Fabrication of vessels shall be in accordance with applicable Parts of Subsection A and Subsection B, Part UW. The requirements of UW-13(e) do not apply to closure rings.

(*b*) This Part covers fabrication of jacketed vessels by welding. Other methods of fabrication are permitted provided the requirements of applicable parts of this Section are met.

(*c*) Where only the inner vessel is subjected to lethal service, the requirements of UW-2 shall apply only to welds in the inner vessel and those welds attaching the jacket to the inner vessel. Welds attaching the jacket to the inner vessel need not be radiographed and may be fillet welded. Postweld heat treatment shall be as required by Table UCS-56.

UA-108 Heat Treatment of Enameled (Glass Lined) Vessels

The heat treatment provided in the normalizing temperature range during the enameling process may be used in lieu of the postweld heat treatment requirements of UW-40 and UCS-56 provided that the weld qualification test specimens required by UW-28 and Section IX have been subjected to this total enameling heat treatment. Inner vessels which are so heat treated need not be again postweld heat treated after the attachment to the jacket if the joining welds do not require postweld heat treatment.

UA-109 Inspection

Inspection and testing shall be carried out as stated in Subsection A except that the test pressure for jackets of enameled vessels shall be at least equal to, but need not exceed, the maximum allowable pressure of the jacket.

NONMANDATORY APPENDICES

APPENDIX A
(NONMANDATORY APPENDIX A NOW MANDATORY APPENDIX IV)

APPENDIX B
APPROVAL OF NEW MATERIALS UNDER THE ASME BOILER AND PRESSURE VESSEL CODE

UA-110 Code Policy

(*a*) It is the policy of the ASME Boiler and Pressure Vessel Committee to adopt for inclusion in Section II of the Code only such specifications as have been adopted by the American Society for Testing and Materials.

(*b*) It is expected that requests for Code approval will normally be for materials for which there is an ASTM Specification. For other materials, request should be made to ASTM to develop a specification which can be presented to the Code Committee.

UA-111 Mechanical Properties

(*a*) Together with the Specification for the material, the inquirer shall furnish the Committee with adequate data on which to base allowable stress values for inclusion in the applicable stress table. The data shall include values of ultimate strength, yield strength, reduction of area, elongation, creep strength, and stress-rupture strength of base metal and welded joints over the range of temperatures at which the material is to be used. Any heat treatment that is required to produce the tensile properties should be fully described. Adequate data on the notch toughness in the proposed range of service temperatures must be furnished. Service experience in the temperature range contemplated will be useful to the Committee.

(*b*) If the material is to be used in vessels to operate umder external pressure, stress-strain curves (tension or compression) shall be furnished for a range of design temperature desired.

UA-112 Weldability

The inquirer shall furnish complete data on the weldability of material intended for weldability of material intended for welding including data on procedure and performance qualification tests made in accordance with the requirements of Section IX of the Code. Welding tests shall be made over the full range of thickness in which the material is to be used. Pertinent information, such as heat treatment required, susceptibility to air hardening, and the amount of experience in welding the material shall be given.

UA-113 Physical Changes

It is important to know the structural stability characteristics and the degree of retention of properties with exposure at temperature of new materials. The influence of fabrication practices such as forming, welding, and thermal treatments of the mechanical properties, ductility, and microstructure of the material are important, particularly where a degradation in properties may be encountered. Where particular temperature ranges of exposure or heat

footnote 2 to UG-23(b) that high localized and secondary bending stresses may exist in code vessels.

(*e*) All radial welds in opening sealer membranes shall be butt-welded joints penetrating through the full thickness of the member.

(*f*) Closure member wells shall be circular, elliptical, or obround in shape where possible. Rectangular member wells are permissible provided that corners are rounded to a suitable radius.

UA-106 Design of Partial Jackets

(*a*) Partial jackets are jackets which encompass less than the full circumference of the vessel. Some variations are shown in Fig. UA-106.

(*b*) The rules for construction of jacketed vessels given in preceding paragraphs shall apply to partial jackets with following exceptions.

(*1*) Stayed partial jackets shall be designed and constructed in accordance with UG-47. Closure members shall conform to UA-104.

(*2*) Partial jackets which by virtue of their service or configuration do not lend themselves to staybolt construction may be fabricated by other means providing they are designed using appropriate stress values and are proof tested in accordance with UG-101(p).

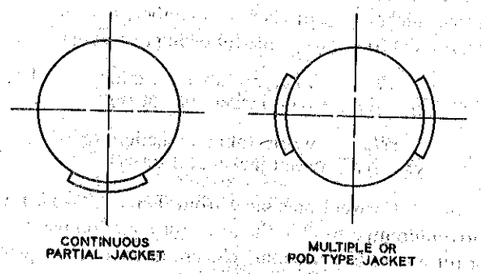


FIG. UA-106

UA-107 Fabrication

(*a*) Fabrication of vessels shall be in accordance with applicable Parts of Subsection A and Subsection B, Part UW. The requirements of UW-13(e) do not apply to closure rings.

(*b*) This Part covers fabrication of jacketed vessels by welding. Other methods of fabrication are permitted provided the requirements of applicable parts of this Section are met.

(*c*) Where only the inner vessel is subjected to lethal service, the requirements of UW-2 shall apply only to welds in the inner vessel and those welds attaching the jacket to the inner vessel. Welds attaching the jacket to the inner vessel need not be radiographed and may be fillet welded. Postweld heat treatment shall be as required by Table UCS-56.

UA-108 Heat Treatment of Enameled (Glass Lined) Vessels

The heat treatment provided in the normalizing temperature range during the enameling process may be used in lieu of the postweld heat treatment requirements of UW-40 and UCS-56 provided that the weld qualification test specimens required by UW-28 and Section IX have been subjected to this total enameling heat treatment. Inner vessels which are so heat treated need not be again postweld heat treated after the attachment to the jacket if the joining welds do not require postweld heat treatment.

UA-109 Inspection

Inspection and testing shall be carried out as stated in Subsection A except that the test pressure for jackets of enameled vessels shall be at least equal to, but need not exceed, the maximum allowable pressure of the jacket.

NONMANDATORY APPENDICES

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(NONMANDATORY APPENDIX A NOW MANDATORY APPENDIX IV)

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(*b*) It is expected that requests for Code approval will normally be for materials for which there is an ASTM Specification. For other materials, request should be made to ASTM to develop a specification which can be presented to the Code Committee.

UA-111 Mechanical Properties

(*a*) Together with the Specification for the material, the inquirer shall furnish the Committee with adequate data on which to base allowable stress values for inclusion in the applicable stress table. The data shall include values of ultimate strength, yield strength, reduction of area, elongation, creep strength, and stress-rupture strength of base metal and welded joints over the range of temperatures at which the material is to be used. Any heat treatment that is required to produce the tensile properties should be fully described. Adequate data on the notch toughness in the proposed range of service temperatures must be furnished. Service experience in the temperature range contemplated will be useful to the Committee.

(*b*) If the material is to be used in vessels to operate umder external pressure, stress-strain curves (tension or compression) shall be furnished for a range of design temperature desired.

UA-112 Weldability

The inquirer shall furnish complete data on the weldability of material intended for weldability of material intended for welding including data on procedure and performance qualification tests made in accordance with the requirements of Section IX of the Code. Welding tests shall be made over the full range of thickness in which the material is to be used. Pertinent information, such as heat treatment required, susceptibility to air hardening, and the amount of experience in welding the material shall be given.

UA-113 Physical Changes

It is important to know the structural stability characteristics and the degree of retention of properties with exposure at temperature of new materials. The influence of fabrication practices such as forming, welding, and thermal treatments of the mechanical properties, ductility, and microstructure of the material are important, particularly where a degradation in properties may be encountered. Where particular temperature ranges of exposure or heat

treatment, cooling rates, combinations of mechanical working and thermal treatments, fabrication practices, etc., cause significant changes in the mechanical properties, microstructure, resistance to brittle fracture, etc., it is of prime importance to call attention to those conditions which should be avoided in service or in the manufacture and fabrication of parts or vessels from the material.

UA-114 Patents

The inquirer shall state whether or not the material is covered by patents and whether or not it is licensed and if licensed the limitations on its manufacture.

UA-115 Code Case

In exceptional circumstances, the Code Committee will consider the issuance of a Code Case effective for a period of three years permitting the use of a material provided that the following conditions are met:

(*1*) The inquirer provides evidence that a specification for the material is before ASTM.

(*2*) The material is commercially available and can be purchased within the specified range of chemical and tensile requirements and other requirements described in UA-111.

(*3*) The inquirer shows that there will be a reasonable demand for the material by industry and that there exists an urgency for approval by means of a Code Case.

(*4*) The request for approval of the material shall clearly describe it in ASTM specification form, including such items as scope, process, manufacture, conditions for delivery, heat treatment, chemical and tensile requirements, bending properties, testing specifications and requirements, workmanship, finish, marking, inspection and rejection.

(*5*) The inquirer shall furnish the Code Committee with all the data specified in UA-111 to UA-114.

APPENDIX C

SUGGESTED METHODS FOR OBTAINING THE OPERATING TEMPERATURE OF VESSEL WALLS IN SERVICE

UA-130

At least three thermocouples shall be installed on vessels that are to have contents at temperatures above that at which the allowable stress value of the material is less than its allowable stress value at 100 F. One of the thermocouples shall be on the head that will be subject to the higher temperature, and the other two shall be on the shell in the zone of maximum temperature. For a number of vessels in similar service in the same plant, thermocouples need be attached to one vessel only of each group or battery, provided that each vessel has a suitable temperature measuring device to show the temperature of the entering fluid, in order that a comparison of the operation of the different vessels can be made and any abnormal operation immediately detected. Thermocouples shall be attached to the outside surface of the vessel by inserting the terminals separately in two small holes drilled into the shell approximately ½ in. center-to-center and firmly securing them therein, or by some other equally satisfactory method.

UA-131

In lieu of the provisions in the preceding paragraph, it shall be optional to provide a thermocouple or other temperature measuring device for obtaining the temperature of the fluid in the zone of the vessel having the highest temperature. In this case, the metal temperature shall be assumed to be the same as the maximum fluid temperature.

APPENDIX D

SUGGESTED GOOD PRACTICE REGARDING INTERNAL STRUCTURES

UA-140

Pressure vessels that have heavy internal structures such as trays and baffles are subject to damage due to failure of the connections that support the structures.

UA-141

The designer should have this possible hazard in mind and provide supports of sufficient strength with due allowance for corrosion.

UA-142

Following are some suggestions that should be considered in the design of internal structures:

(*1*) Connections to the vessel wall should be designed to prevent excessive tensile stress outward from the wall face due to the connection. (See UG-55).

(*2*) Structures should rest on top of their supports in preference to being suspended from them.

(*3*) Additional metal should be provided when corrosion is expected. The corrosion allowance need not be the same as in the vessel if the supports and structures can be replaced more readily and economically than the vessel.

(*4*) Corrosion resistant metals may be used in the fabrication of the structures and supports.

APPENDIX E

SUGGESTED GOOD PRACTICE REGARDING CORROSION ALLOWANCE[1]

UA-155

From the standpoint of corrosion, pressure vessels may be classified under one of the following groups:

(*1*) Vessels in which corrosion rates may be definitely established from information available to the designer regarding the chemical characteristics of the substances they are to contain. Such information may, in the case of standard commercial products, be obtained from published sources, or, where special processes are involved, from reliable records compiled from results of previous observations by the user or others under similar conditions of operation;

(*2*) Vessels in which corrosion rates, while known to be relatively high, are either variable or indeterminate in magnitude;

(*3*) Vessels in which corrosion rates, while indeterminate, are known to be relatively low;

(*4*) Vessels in which corrosion effects are known to be negligible or entirely absent.

UA-156

When the rate of corrosion is closely predictable, additional metal thickness over and above that required for the initial operating conditions should be provided, which should be at least equal to the expected corrosion loss during the desired life of the vessel.

UA-157

When corrosion effects are indeterminate prior to design of the vessel, although known to be inherent to some degree in the service for which the vessel is to be used, or when corrosion is incidental, localized, and/or variable in rate and extent, the designer

[1] When using high alloys and nonferrous materials either for solid wall or clad or lined vessels, refer to UHA-6, UCL-3, and UNF-4, as appropriate.

must exercise his best judgment in establishing a reasonable maximum excess shell thickness. This minimum allowance may, of course, be increased according to the designer's judgment.

UA-158

When corrosion effects can be shown to be negligible or entirely absent, no excess thickness need be provided.

UA-159

When a vessel goes into corrosive service without previous service experience, it is recommended that service inspections be made at frequent intervals until the nature and rate of corrosion in service can be definitely established. The data thus secured should determine the subsequent intervals between service inspections and the probable safe operating life of the vessel.

APPENDIX F

SUGGESTED GOOD PRACTICE REGARDING LININGS

UA-170

When protective linings are used, the amount of additional shell thickness provided to compensate for corrosion effects will depend largely on the nature of the protective material itself, as well as on the degree of knowledge available regarding its resistivity under the intended operating conditions.

UA-171

(*a*) When corrosion resistant metal linings are used, either as a surface layer integral with the shell plate, or in deposited form as applied with a so-called metal gun, or in sheet form mechanically attached, the base plate may be only as thick as required for design operating conditions, provided, however, the thickness of such lining is sufficient to afford an estimated life equal at least to twice the length of the initial inspection period and that application of the material is such as to preclude any possibility of contact between the corrosive agent and the steel shell by infiltration or seepage through or past the lining.

(*b*) Before strip lining or joint covering strips are applied to carbon steel base plate, the surface shall be closely inspected to assure that it is properly prepared and that it is free of all foreign matter, rust, scale, and moisture. It may be necessary to sand-blast or to hot-air dry the surface, or both.

UA-172

No paint of any type should be considered as a permanent protection. When paint is applied to the inside of a vessel, corrosion allowance should be added to the wall thickness of the vessel as if it were unprotected, the paint serving only to extend the life of the vessel if the protection is effective.

UA-173

When the test fluid seeps behind the applied liner, there is danger that the fluid will remain in place until the vessel is put in service. In cases where the operating temperature of the vessel is above the boiling point of the test fluid, the vessel should be heated slowly for a sufficient time to drive out all test fluid from behind the applied liner without damage to the liner. This heating operation may be performed at the vessel manufacturing plant or at the plant where the vessel is being installed. After the test fluid is driven out, the lining should be repaired by welding.

APPENDIX G

SUGGESTED GOOD PRACTICE REGARDING DESIGN OF SUPPORTS

UA-185

A vessel supported in a vertical or horizontal position will have concentrated loads imposed on the shell in the region where the supports are attached. When vessels are subject to internal pressure, lower secondary stresses may exist in the shell adjacent to the attachment of such supports than when the vessel is filled with water before any pressure is imposed other than that caused by the hydrostatic head. Calculations to resist the forces involved are not given here because they involve so many variables depending upon the size and weight of vessels, the temperature of service, the internal pressure, the arrangement of the supporting structure, and the piping attached to the vessel as installed.

UA-186

The details of supports should conform to good structural practice, bearing in mind the following items (see Manual of the American Institute of Steel Construction for 1957, "Steel Construction"):

(*1*) All supports should be designed to prevent excessive localized stresses due to temperature changes in the vessel or deformations produced by the internal pressure. Any arrangement of the structure which does not permit expansion and contraction of the shell will tend to weaken the vessel.

(*2*) External stays in ring girders, or any internal framing that may support other internal parts, may also exert a stiffening effect on the shell where exterior supporting members of the vessel are to be attached. This stiffening effect may be beneficial or harmful, depending upon the operating temperature and the location of the stiffening members.

(*3*) Columns supporting field assembled vessels and bearing loads which may produce high secondary stresses in the vessel wall should be so designed at the attachment to the wall that no high stress concentration can occur near changes in shape, gusset plates if any, or at ends of attachment welds. It is preferable to use details permitting continuous welds extending completely around the periphery of the attachment and to avoid intermittent or deadend welds at which there may be local stress concentration. A thicker wall plate at the support may serve to reduce secondary stresses and, if desired, a complete ring of thicker wall plates may be installed.

(*4*) When superimposed forces on the vessel wall occurring at the attachment for principal struts or gussets and supports of any kind can produce high bending stresses, and when thicker wall plates do not seem appropriate, an oval or circular reinforcing plate may be used. The attachment of such reinforcing plates should be designed to minimize flexing of the plate under forces normal to the surface of the vessel.

UA-187

Vertical vessels may be supported on a number of posts without substantial ring girder bracing them around the shell, provided they attach to the shell where the latter is reinforced in an equivalent manner by the head of the vessel or by an intermediate partition.

UA-188

Where vertical vessels are supported by lugs or brackets attached to the shell, the supporting members under these bearing attachments shall preferably be as close to the shell as clearances for insulation will permit. The choice between a number of brackets and a ring girder will depend upon the applicable conditions for each individual vessel.

UA-189

For large and heavy vertical vessels to be supported by skirts, the conditions of loading under hydrostatic tests, before pressure is applied, or for any possible combination of loadings (see UG-22) under the highest expected metal temperature in service for the normal operating pressure, shall be compared in determining the best location for the line of skirt attachment. In applying UG-22 and UG-23(a) to vertical vessels supported on skirts, the following shall be considered in addition to pressure effects:

(*1*) The skirt reaction:

(a) The weight of vessel and contents

transmitted in compression to the skirt by the shell above the level of the skirt attachment.

(b) The weight of vessel and contents transmitted to the skirt by the weight in the shell below the level of skirt attachment.

(c) The maximum load intensity due to externally applied moments and forces when these are a factor, e.g., wind, earthquake, or piping loads.

(2) The stress in the vessel wall due to the effects enumerated in (1). Localized longitudinal bending and circumferential compressive stresses of high order may exist in the metal of the shell and skirt near the circle of the skirt attachment if the skirt reaction is not substantially tangent to the vessel wall. When a cylindrical skirt is fillet welded to the shell above the head tangent line, the localized bending is similar to a lap girth joint and may be normally considered satisfactory. When the skirt is attached below the head tangent line, localized stresses are introduced in proportion to the component of the skirt reaction which is normal to the head surface at the point of attachment; when the mean diameter of skirt and shell approximately coincide and a generous knuckle radius is used (e.g., a 2:1 ellipsoidal head) the localized stresses are minimized and are not considered objectionable. In other cases an investigation of local effects may be warranted depending on the magnitude of the loading, location of skirt attachment, etc., and an additional thickness of vessel wall or compression rings may be necessary.

UA-190

Horizontal vessels may be supported by means of saddles or equivalent leg supports. For other than very small vessels, the bearing afforded by the saddles shall extend over at least one-third of the circumference of the shell.

UA-191

Supports should be as few in number as possible, preferably two in the length of the vessel. The vessel may be reinforced by stiffening rings at intermediate sections.[1]

UA-192

Large horizontal storage tanks for gases under pressure may be supported by any combination of hangers, with ring girders, stiffeners, and such other reinforcement as may be necessary to prevent stresses in the shell in excess of those allowed by UG-23 and to prevent excessive distortion due to the weight of the vessel when the internal pressure is near atmospheric.

[1] See Transactions ASCE, Volume 98—1931 "Design of Large Pipe Lines."

APPENDIX J

CAPACITY CONVERSIONS FOR SAFETY VALVES

UA-230

The capacity of a safety or relief valve in terms of a gas or vapor other than the medium for which the valve was officially rated may be determined by application of the following formulas: [1]

For steam:

$$W_s = 51.5KAP$$

For Air:

$$W_a = CKAP\sqrt{\frac{M}{T}}$$

$C = 356$

$M = 28.97$

$T = 520$ when W_a is the rated capacity

For any gas or vapor:

$$W = CKAP\sqrt{\frac{M}{T}}$$

where

W_s = rated capacity, pounds of steam per hour

W_a = rated capacity, converted to pounds of air per hour at 60 degrees Fahrenheit, inlet temperature

W = flow of any gas or vapor, pounds per hour

C = constant for gas or vapor which is a function of the ratio of specific heats, $k = c_p/c_v$ (see Fig. UA-230)

K = coefficient of discharge (see UG-131(d) and (e))

A = actual discharge area of the safety valve, square inches

P = (set pressure × 1.10) plus atmospheric pressure, pounds per square inch absolute

M = molecular weight

T = absolute temperature at inlet (degrees Fahrenheit plus 460)

[1] Knowing the official rating capacity of a safety valve which is stamped on the valve, it is possible to determine the overall value of KA in either of the following formulas in cases where the value of these individual terms is not known:

Official Rating in Steam $\quad KA = \frac{W_s}{51.5P}$

Official Rating in Air $\quad KA = \frac{W_a}{CP}\sqrt{\frac{T}{M}}$

This value for KA is then substituted in the above formulas to determine the capacity of the safety valve in terms of the new gas or vapor.

These formulas may also be used when the required flow of any gas or vapor is known and it is necessary to compute the rated capacity of steam or air.

Molecular weights of some of the common gases and vapors are given in Table UA-230.

For hydrocarbon vapors, where the actual value of k is not known, the conservative value, $k = 1.001$ has been commonly used and the formula becomes,

$$W = 315\,KAP\sqrt{\frac{M}{T}}$$

When desired, as in the case of light hydrocarbons, the compressibility factor, Z, may be included in the formulas for gases and vapors as follows:

$$W = CKAP\sqrt{\frac{M}{ZT}}$$

Example 1:

Given: A safety valve bears a certified capacity rating of 3020 lb of steam per hour for a pressure setting of 200 psi.

Problem: What is the relieving capacity of that valve in terms of air at 100 F for the same pressure setting?

Solution:

For steam:

$$W_s = 51.5\,KAP$$

$$3020 = 51.5\,KAP$$

$$KAP = \frac{3020}{51.5} = 58.5$$

For air:

$$W_a = CKAP\sqrt{\frac{M}{T}}$$

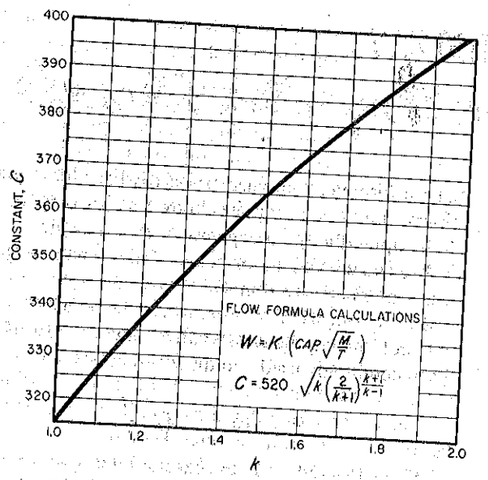
$$= 356\,KAP\sqrt{\frac{28.97}{460+100}}$$

$$= (356)(58.5)\sqrt{\frac{28.97}{560}}$$

$$= 4750 \text{ lb per hr}$$

Example 2:

Given: It is required to relieve 5000 lb of propane per hour from a pressure vessel through a safety valve set to relieve at a pressure of P_s, pounds per square inch, and with an inlet temperature of 125 F.



k	Constant C	k	Constant C	k	Constant C
1.00	315	1.26	343	1.52	366
1.02	318	1.28	345	1.54	368
1.04	320	1.30	347	1.56	369
1.06	322	1.32	349	1.58	371
1.08	324	1.34	351	1.60	372
1.10	327	1.36	352	1.62	374
1.12	329	1.38	354	1.64	376
1.14	331	1.40	356	1.66	377
1.16	333	1.42	358	1.68	379
1.18	335	1.44	359	1.70	380
1.20	337	1.46	361	2.00	400
1.22	339	1.48	363	2.20	412
1.24	341	1.50	364		

FIG. UA-230 CONSTANT C FOR GAS OR VAPOR RELATED TO RATIO OF SPECIFIC HEATS ($k = c_p/c_v$)

Problem: What total capacity in pounds of steam per hour in safety valves must be furnished?

Solution:
For propane:

$$W = CKAP\sqrt{\frac{M}{T}}$$

value of C is not definitely known. Use the conservative value, $C = 315$

$$5000 = 315\ KAP\sqrt{\frac{44.09}{460+125}}$$

$$KAP = 57.7$$

For steam:

$$W_s = 51.5\ KAP = (51.5)(57.7)$$
$$= 2790 \text{ pounds per hour set to relieve at } P_s \text{, pounds per square inch}$$

Example 3:

Given: It is required to relieve 1000 lb of ammonia per hour from a pressure vessel at 150 F.

Problem: What is the required total capacity in pounds of steam per hour at the same pressure setting?

Solution:
For ammonia:

$$W = CKAP\sqrt{\frac{M}{T}}$$

Manufacturer and user agree to use $k = 1.33$

From Fig. UA-230, $C = 350$

$$1000 = 350\ KAP\sqrt{\frac{17.03}{460+150}}$$

$$KAP = 17.10$$

For steam:

$$W_s = 51.5\ KAP = 51.5 \times 17.10$$
$$= 880 \text{ pounds per hour}$$

Example 4:

Given: A safety valve bearing a certified rating of 10,000 cu ft per minute of air at 60 F and 14.7 psia (atmospheric pressure).

Problem: What is the flow capacity of this safety valve in pounds of saturated steam per hour for the same pressure setting?

Solution:
For air:

Weight of dry air at 60 F and 14.7 psia is 0.0766 per cu ft.

$$W_a = 10{,}000 \times 0.0766 \times 60 = 45{,}960 \text{ lb per hour}$$

$$45{,}960 = 356\ KAP\sqrt{\frac{28.97}{460+60}}$$

$$KAP = 546$$

For steam:

$$W_s = 51.5\ KAP = (51.5)(546)$$
$$= 28200 \text{ pounds per hour}$$

TABLE UA-230
MOLECULAR WEIGHTS OF GASES AND VAPORS

Air	28.97	Freon 22	86.48
Acetylene	26.04	Freon 114	170.90
Ammonia	17.03	Hydrogen	2.02
Butane	58.12	Hydrogen Sulfide	34.08
Carbon Dioxide	44.01	Methane	16.04
Chlorine	70.91	Methyl Chloride	50.48
Ethane	30.07	Nitrogen	28.02
Ethylene	28.05	Oxygen	32.00
Freon 11	137.371	Propane	44.09
Freon 12	120.9	Sulfur Dioxide	64.06

APPENDIX K
SECTIONING OF WELDED JOINTS

(A) ETCH TESTS

UA-250

(*a*) *Carbon and Low-Alloy Steels.* Etching solutions suitable for carbon and low-alloy steels, together with directions for their use, are suggested as follows:

(*1*) *Hydrochloric Acid.* Hydrochloric (muriatic) acid and water equal parts by volume. The solution should be kept at or near the boiling temperature during the etching process. The specimens are to be immersed in the solution for a sufficient period of time to reveal all lack of soundness that might exist at their cross-sectional surfaces.

(*2*) *Ammonium Persulfate.* One part of ammonium persulfate to nine parts of water by weight. The solution should be used at room temperature and should be applied by vigorously rubbing the surface to be etched with a piece of cotton saturated with the solution. The etching process should be continued until there is a clear definition of the structure in the weld.

(*3*) *Iodine and Potassium Iodide.* One part of powdered iodine (solid form), two parts of powdered potassium iodide, and ten parts of water, all by weight. The solution should be used at room temperature and brushed on the surface to be etched until there is a clear definition of outline of the weld.

(*4*) *Nitric Acid.* One part of nitric acid and three parts of water by volume.

CAUTION: Always pour the acid into the water. Nitric acid causes bad stains and severe burns.

The solution may be used at room temperature and applied to the surface to be etched with a glass stirring rod. The specimens may also be placed in a boiling solution of the acid but the work should be done in a well-ventilated room. The etching process should be continued for a sufficient period of time to reveal all lack of soundness that might exist at the cross-sectional surfaces of the weld.

(*b*) The appearance of the etched specimens may be preserved by washing them in clear water after etching, removing the excess water, immersing them in ethyl alcohol, and then drying them. The etched surface may then be preserved by coating it with a thin clear lacquer.

(*c*) *Aluminum Alloy.* The following etching solution is suggested for revealing the macrostructure of welded aluminum alloy specimens:

Hydrochloric Acid (conc)	15 ml
Hydrofluoric Acid (48%)	10 ml
Water	85 ml

This solution is used at room temperature and etching is accomplished by either swabbing or immersion of the specimen. The surface to be etched should be smoothed by filing or machining or by grinding on No. 180 Aloxite paper. With different alloys and tempers the etching period will vary from 15 seconds to several minutes and should be continued until the desired contrast is obtained.

(B) CLOSURE OF OPENINGS RESULTING FROM SECTIONING

UA-251

(*a*) Holes in welded joints left by the removal of trepanned plug specimens may be closed by any welding method approved by the authorized inspector. Some suggested methods for closing round plug openings by welding are as follows:

(*1*) Insert and weld in special plugs of which some acceptable types are shown in Fig. UA-251. Type (a) is adapted to welding from both sides and should be used wherever that method is practicable, and Types (b) and (c) when access is possible only from one side. The diameter of the filler plug shall be such as to make a snug fit in the hole to be filled. Each layer of weld metal as deposited shall be thoroughly peened to reduce residual stresses. The $^1/_4$-in. hole in the center of the plugs shown in Fig. UA-251 may afterwards be closed by any reasonable method. Plain plugs without a hole may be used.

(*2*) For joints where the thickness of the thinner plate at the joint is not greater than one-third of the diameter of the hole, place a backing plate on the inside of the shell over the opening and fill the hole completely with weld metal applied from the outside of the shell. Rebuild fillet welds where cut.

(*3*) For joints where the thickness of the thinner plate at the joint is not less than one-third, nor greater than two-thirds the diameter of the hole, fill the hole completely with weld metal applied from both sides of the shell. Rebuild fillet welds where cut.

(*4*) For butt joints where the thickness of the thinner plate at the joint does not exceed $^7/_8$ in., chip a groove on one side of the plate each way along the seam from the hole. The groove at the opening shall have sufficient width to provide a taper to the bottom of the hole, and the length of the groove on each side of the opening is to have a slope of approximately 1 to 3. Use a backing plate on the side opposite that on which the chipping is done or a thin disk (not over $^1/_8$ in. thick) at the bottom of the hole and fill the groove and the hole with weld metal.

(*5*) For butt joints, and for plates of any thickness, chip a groove on both sides of the plate each way along the seam from the hole. The groove at the opening shall have sufficient width to provide a taper to the middle of the plate, and the length of the groove on each side of the opening is to have a slope of approximately 1 to 3. Place a thin disk (not over $^1/_8$ in. thick) in the hole at the middle of the plate and fill the grooves and the hole on both sides with weld metal.

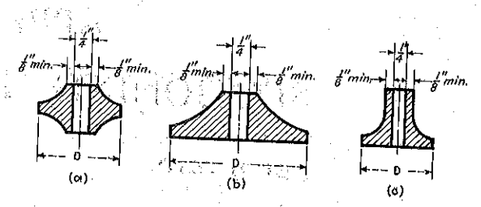


FIG. UA-251 SOME ACCEPTABLE TYPES OF FILLER PLUGS

(*b*) The following is a suggested method for closing openings cut with a spherical saw: For butt-welded joints place a backing plate, where necessary, on the inside of the vessel shell over the opening. For lap-welded joints, a part of the parent plate remaining opposite the removed weld will usually serve as a backing plate. Fill the opening completely with the weld metal. Rebuild fillet welds where cut.

UA-252

Where gas welding is employed, the area surrounding the plugs shall be preheated prior to welding.

APPENDIX L

EXAMPLES ILLUSTRATING THE APPLICATION OF CODE FORMULAS AND RULES

VESSELS UNDER EXTERNAL PRESSURE

NOTE: The lines on the charts representing the values for D_o/t and the sphere line are the same on all of the charts. These lines are based on the proportion or dimensions of the vessel.

The lines sloping upward and to the right represent the mechanical properties of the materials at the temperature indicated on the lines. They are different for the various materials and are referred to as the material lines.

In the use of these charts interpolations may be made between the D_o/t lines and the material lines.

UA-270

(*a*) *Cylindrical Shell Under External Pressure.* An example of the use of the rules in UG-28(c)

Given: A fractionating tower 14 ft inside diameter by 21 ft long, bend line to bend line, fitted with fractionating trays, and operating under a vacuum at 750 F. The tower to be constructed of SA-285 Grade C carbon steel.

Design length (due to removable-tray spacing)	$L=39$ in.
External design pressure	$P=15$ psi.
Inside diameter	$D=168$ in.

Required: Shell thickness, t.

Solution:

Step 1:

Assume a thickness	$t=0.3125$ in.
Assumed outside diameter	$D_o=168.625$ in.
Call outside diameter	$D_o=169$ in.

$$\frac{L}{D_o}=\frac{39}{169}=0.231$$

$$\frac{D_o}{t}=\frac{169}{0.3125}=540$$

Steps 2–5: Enter the chart in Fig. UCS-28.2 with $L/D_o=0.231$, move horizontally to intersect the diagonal line for $D_o/t=540$, then move vertically to the material line for 750 F (interpolated between the 700 F and 800 F material lines), and then move horizontally to the right-hand side of the chart and read $B=6100$.

Step 6: The maximum allowable pressure for the assumed shell thickness of 0.3125 in. is:

$$P_a=\frac{B}{D_o/t}=\frac{6100}{540}=11.30 \text{ psi}$$

Step 7: Since P_a is appreciably smaller than the design pressure P, it is necessary to assume a greater thickness for t and repeat the design procedure.

For a second trial (Step 1) assume $t=0.375$ in. The ratio L/D_o does not change but D_o/t becomes:

$$\frac{D_o}{t}=\frac{169}{0.375}=450$$

Proceeding as before (Steps 2–5) it is determined that $B=7000$.

Step 6: The maximum allowable pressure for the assumed shell thickness of 0.375 in. is:

$$P_a=\frac{7000}{450}=15.5 \text{ psi}$$

Step 7: Since P_a is greater than the design pressure P, the second assumed thickness should be satisfactory.

(*b*) *Spherical Shell Under External Pressure.* An example of the use of the rules in UG-28(d).

Given: A spherical vessel having an inside diameter of 72 in., made of an aluminum alloy conforming to Specification SB-209 Alloy 3003-0 to withstand an external pressure of 12 psi at 100 F.

Required: Shell thickness t_h.

Solution:

Step 1: Assume a shell thickness, $t_h=0.50$ in.

$$\frac{L_1}{t_h}=\frac{36}{0.5}=72$$

$$\frac{L_1}{100t_h}=\frac{36}{100\times 0.5}=0.72$$

Steps 2–5: Enter the chart in Fig. UNF-28.2 with $L_1/100t_h=0.72$, move horizontally to intersect the sphere line, then move vertically to the material line for 100 F, and then move horizontally to the right-hand side of the chart and read $B=1730$.

Step 6: The maximum allowable pressure for the assumed shell thickness of 0.5 in. is:

$$P_a=\frac{B}{L_1/t_h}=\frac{1730}{72}=24.0 \text{ psi}$$

Step 7: Since P_a is appreciably greater than the design pressure P, it appears that a lesser thickness would be satisfactory.

For a second trial (Step 1) assume $t_h=0.3125$ in., then:

$$\frac{L_1}{t_h}=\frac{36}{0.3125}=115$$

$$\frac{L_1}{100t_h}=\frac{36}{100\times0.3125}=1.15$$

Proceeding as before (Steps 2–5) it is determined that B=1600.

Step 6: The maximum allowable pressure for the assumed shell thickness 0.3125 in. is:

$$P_a=\frac{B}{L_1/t_h}=\frac{1600}{115}=13.9 \text{ psi}$$

Step 7: Since P_a is greater than the design pressure P, the second assumed thickness should be satisfactory.

UA-271 Maximum Out-of-Roundness Permitted for Vessels Under External Pressure

An example of the use of the rules in UG-80(b).

Given: The same vessel considered in UA-270(a).

Required: Maximum out-of-roundness permitted.

Solution: By the requirement in UG-80(b)(1), the difference between the maximum diameter, D_{max} and the minimum diameter, D_{min} (see Fig. UG-80.2), in any plane perpendicular to the longitudinal axis of the vessel shall not exceed one percent of the nominal diameter; that is, $0.01\times169=1.69$ in.

By the requirement in UG-80(b)(2) the maximum deviation from a circular form for $D_o/t=450$ and $L/D_o=0.231$ as determined from Fig. UG-80.1 is:

$$e=0.80t=0.80\times0.375=0.300 \text{ in.}$$

From Fig. UG-29.2, for the same values of D_o/t and L/D_o the arc length is found to be $0.05D_o$. The reference chord then becomes:

$$2\times0.05\times169=16.90 \text{ in.}$$

Thus, in a chord length of 16.90 in., the maximum plus-or-minus deviation from the true circular form shall not exceed 0.30 in.

UA-272 Design of Circumferential Stiffening Ring for a Shell Under External Pressure

An example of the use of the rules in UG-29(a).

Given: The same vessel considered in UA-270(a).

Required: A structural steel member to act as a circular stiffening ring.

Solution:

Step 1: Select a 6-in. channel, 10.5 lb per ft for the stiffening ring.

$$A_s=3.07 \text{ sq in.}$$
$$I=15.1 \text{ in.}^4$$

$$B=\frac{PD_o}{t+\frac{A_s}{L_s}}=\frac{15\times169}{0.375+\frac{3.07}{39}}=5600$$

Steps 2–4: Enter the right-hand side of the chart in Fig. UCS-28.2 with the value of $B=5600$, move horizontally to the material line for 750 F and then move vertically to the bottom of the chart and read $A=0.00047$.

Step 5: Compute the value for I_s.

$$I_s=\frac{169^2\times39\left\{0.375+\frac{3.07}{39}\right\}0.00047}{14}=16.90 \text{ in.}^4$$

Step 6: The required I_s is greater than I for the section selected, therefore a selection of a heavier section must be made.

For a second trial (Step 1) select a 7-in. channel, 9.8 lb per ft.

$$A_s=2.85 \text{ sq in.}$$
$$I=21.1 \text{ in.}^4$$

$$B=\frac{15\times169}{0.375+\frac{2.85}{39}}=5650$$

Proceeding as before (Steps 2–4) it is determined that $A=0.00047$.

Step 5:

$$I_s=\frac{169^2\times39\left\{0.375+\frac{2.85}{39}\right\}0.00047}{14}=16.70 \text{ in.}^4$$

Step 6: The required I_s is smaller than I for the second section selected; therefore it should be satisfactory.

UA-274

(a) Cylindrical Shell Under Internal Pressure with Supplementary Loading. An example of the use of the rules in UG-27(c).

Given: A packed column 24 in. inside diameter and 43 ft long, bend line to bend line, operating under 200 psi internal at 212 F with a longitudinal bending moment of 665,000 in.-lb. The column is to be constructed of SA-285 Grade C carbon steel. Longitudinal joint efficiency $E=0.85$, Circumferential joint efficiency, $E=0.80$.

Required: Shell thickness, t, required with no longitudinal stiffeners.

Solution:

Minimum thickness due to pressure, circumferential stress governing

$$t=\frac{PR}{SE-0.6P}$$

$$=\frac{200\times12}{13{,}750\times0.85-(0.6\times200)}=0.207 \text{ in.}$$

Thickness due to pressure, longitudinal stress governing

$$=\frac{PR}{2SE+0.4P}$$

$$=\frac{200\times12}{2\times13{,}750\times0.80+(0.4\times200)}=0.109 \text{ in.}$$

Thickness due to longitudinal bending moment, assuming I/C for thin cylinder $=\pi R^2t$

$$t=\frac{M}{\pi R^2SE}$$

$$=\frac{665{,}000}{\pi\times12^2\times13{,}750\times0.80}=0.134 \text{ in.}$$

Total required thickness, longitudinal stress governing

$$t=0.109+0.134=0.243 \text{ in.}$$

Since 0.243 in., required thickness when longitudinal stress governs, is greater than 0.207 in. required thickness when circumferential stress governs, the minimum shell thickness is 0.243 in.

(b) Cylindrical Shell Under Internal Pressure With Supplementary Loading. An example of the use of the rules in UG-27(c).

Given: Same vessel considered in UA-274-(a) with an actual thickness of 5/16 in.

Required: Maximum allowable working pressure, P.

Solution:

Maximum allowable working pressure, circumferential stress governing:

$$P=\frac{SEt}{R+0.6t}$$

$$P=\frac{13{,}750\times0.85\times0.313}{12+(0.6\times0.313)}=300 \text{ psi}$$

Thickness available to support pressure, longitudinal stress governing

$$t=0.313-0.134=0.179 \text{ in.}$$

(0.134 in. equals thickness required for longitudinal bending. See UA-274(a)).

Maximum allowable working pressure, longitudinal stress governing

$$P=\frac{2SEt}{R-0.4t}$$

$$P=\frac{2\times13{,}750\times0.80\times0.179}{12-(0.4\times0.179)}=330 \text{ psi}$$

Since 300 psi allowable pressure when circumferential stress governs, is less than 330 psi, allowable pressure when longitudinal stress governs, the maximum allowable working pressure for the vessel is 300 psi.

UA-276 Required Thickness for Formed Head With Pressure on the Convex Side

(a) Ellipsoidal Head. An example of the use of the rules in UG-33(d).

Given: The same vessel considered in UA-270(a). The head to have a major-to-minor axis ratio of 2:1.

Required: Head thickness t_h.

Solution:

Equivalent spherical radius	$L_1=K_1D_o$
From Table UG-37, $(D/2h=2)$	$K_1=0.90$
Outside diameter	$D_o=169$ in.

$$L_1=0.90\times169=152.1 \text{ in.}$$

Step 1: Assume a head thickness $t_h=0.5625$ in.

$$\frac{L_1}{100t_h}=\frac{152.1}{100\times0.5625}=2.71$$

$$\frac{L_1}{t_h}=\frac{152.1}{0.5625}=271$$

Steps 2-5: Enter the left-hand side of the chart in Fig. UCS-28.2 with the value for $L_1/100t_h=2.71$, move horizontally to the sphere line, then move ver-

tically to the material line for 750F, and then move horizontally to the right-hand side of the chart and read $B=5100$.

Step 6: The maximum allowable pressure for the assumed head thickness of 0.5625 in. is:

$$P_a=\frac{B}{L_1/t_h}=\frac{5100}{271}=18.8 \text{ psi}$$

Step 7: Since P_a is greater than the design pressure, P, the assumed thickness should be satisfactory.

(b) Torispherical Head. An example of the use of the rules in UG-33(e).

Given: The same vessel considered in UA-270 (a). The head to have a crown radius equal to the diameter of the vessel and a knuckle radius equal to 6 percent of the vessel diameter.

Required: Head thickness, t_h

Solution:

Spherical radius $L_1=D_0=169$ in.

Step 1: Assume a head thickness, $t_h=0.50$ in.

$$\frac{L_1}{100t_h}=\frac{169}{100\times 0.50}=3.38$$

$$\frac{L_1}{t_h}=\frac{169}{0.50}=338$$

Steps 2-5: Enter the left-hand side of the chart in Fig. UCS-28.2 with the value for $L_1/100t_h=3.38$, move horizontally to the sphere line, then move vertically to the material line for 750 F, and then move horizontally to the right-hand side of the chart and read $B=4300$.

Step 6: The maximum allowable pressure for the assumed head thickness of 0.50 in. is:

$$P_a=\frac{B}{L_1/t_h}=\frac{4300}{338}=12.7 \text{ psi}$$

Step 7: Since P_a is smaller than the design pressure P, it is necessary to assume a greater thickness t_h and repeat the design procedure.

For a second trial (Step 1) assume $t_h=0.5625$ in.

$$\frac{L_1}{100t_h}=\frac{169}{100\times 0.5625}=3.00$$

$$\frac{L_1}{t_h}=\frac{169}{0.5625}=300$$

Proceeding as before (Steps 2-5) it is determined that $B=4700$.

Step 6: The maximum allowable pressure for the assumed head thickness of 0.5625 in. is:

$$P_a=\frac{B}{L_1/t_h}=\frac{4700}{300}=15.7 \text{ psi}$$

Step 7: Since P_a is greater than the design pressure P, the second assumed thickness should be satisfactory.

(c) Hemispherical Head. An example of the use of the rules in UG-33(c).

Given: The same vessel considered in UA-270 (a). The head to have a hemispherical shape.

Required: Head thickness, t_h.

Solution:

Spherical radius $L_1=D_0=84.5$ in.

Step 1: Assume a head thickness, $t_h=0.3125$ in.

$$\frac{L_1}{100t_h}=\frac{84.5}{100\times 0.3125}=2.70$$

$$\frac{L_1}{t_h}=\frac{84.5}{0.3125}=270$$

Steps 2–5: Enter the left-hand side of the chart in Fig. UCS-28.2 with the value for $L_1/100t_h=2.70$, move horizontally to the sphere line, then move vertically to the material line for 750 F, and then move horizontally to the right-hand side of the chart and read $B=5200$.

Step 6: The maximum allowable pressure for the assumed head thickness of 0.3125 in. is:

$$P_a=\frac{B}{L_1/t_h}=\frac{5200}{270}=19.3 \text{ psi}$$

Step 7: Since P_a is greater than the design pressure P, the assumed thickness should be satisfactory.

(d) Conical Head. An example of the use of the rules in UG-33(f)(1).

Given: The same vessel considered in UA-270(a). The head to be of a conical shape with a 45-deg included (apex) angle. There are to be no stiffening rings in the head.

Required: Head thickness, t.

Solution:

Outside diameter $D_0=169$ in.

One-half the included angle $\alpha=22\frac{1}{2}$ deg

Length $L=\frac{D_0/2}{\tan\alpha}=\frac{84.5}{0.4142}=204$ in.

Step 1: Assume a head thickness, $t=1.0$ in.

$$\frac{L}{D_0}=\frac{204}{169}=1.21$$

$$\frac{D_0}{t}=\frac{169}{1}=169$$

Steps 2–5: Enter the chart in Fig. UCS-28.2 with $L/D_0=1.21$, move horizontally to intersect the diagonal line for $D_0/t=169$, then move vertically to the material line for 750 F, and then move horizontally to the right-hand side of the chart and read $B=6200$.

Step 6: The maximum allowable pressure for the assumed cone thickness of 1.0 in. is:

$$P_a=\frac{B}{D_0/t}=\frac{6200}{169}=36.7 \text{ psi}$$

Step 7: Since P_a is appreciably greater than the design pressure P, a lesser thickness t may be selected.

For a second trial (Step 1) assume $t=0.75$ in. The ratio L/D_0 does not change but D_0/t becomes:

$$\frac{D_0}{t}=\frac{169}{0.75}=225$$

Proceeding as before (Steps 2–5) it is determined that $B=4100$.

Step 6: The maximum allowable pressure for the assumed cone thickness of 0.75 in. is:

$$P_a=\frac{B}{D_0/t}=\frac{4100}{225}=18.2 \text{ psi}$$

Step 7: Since P_a is greater than the design pressure P, the second assumed thickness should be satisfactory.

OPENINGS AND REINFORCEMENTS

UA-280 Welded Connections

The symbols used in this paragraph are defined as follows:

A = total cross-sectional area of reinforcement required in the plane under consideration, square inches (see Fig. UA-280 and Par. UG-37)

A_1 = area in excess thickness in the vessel wall available for reinforcement, square inches (see Fig. UA-280 and Par. UG-40)

A_2 = area in excess thickness in the nozzle wall available for reinforcement, square inches (see Fig. UA-280 and Par. UG-40)

A_8 = area available for reinforcement when the nozzle wall extends inside the vessel wall, square inches (see Fig. UA-280 and Par. UG-40)

A_4 = cross-sectional area of welds available for reinforcement, square inches (see Fig. UA-280 and Par. UG-40)

A_5 = cross-sectional area of material added as reinforcement, square inches (see Fig. UA-280 and Pars. UG-40 and UG-41)

c = corrosion allowance, inches

D_p = outside diameter of reinforcing element, inches (actual size of reinforcing element may exceed the limits of available reinforcement established by UG-40; however, credit cannot be taken for any material outside these limits)

d = diameter in the plane under consideration of the finished opening in its corroded condition, inches (see UG-37(b) and Fig. UG-40)

$E=1$ (see definitions for t_r and t_{rn});

$E_1=1$ when an opening is in the solid plate or when the opening passes through a circumferential joint in a shell or cone (exclusive of head-to-shell joints);

or

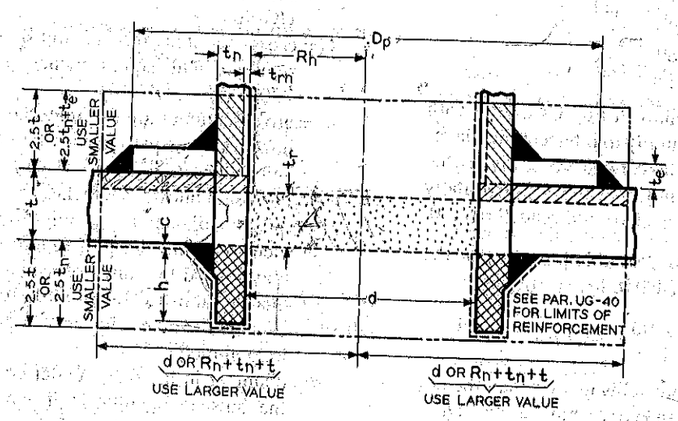
E_1 = the joint efficiency obtained from Table UW-12 when any part of the opening passes through any other welded joint;

F = a correction factor which compensates for the variation in pressure stresses on different planes with respect to the axis of a vessel. A value of 1.00 shall be used for all configurations except that Fig. UG-37 may be used for integrally reinforced openings in cylindrical shells and cones.

h = distance nozzle projects beyond the inner or outer surface of the vessel wall, before corrosion allowance is added, inches (the extension of the nozzle beyond the inside or outside surface of the vessel wall is not limited; however, for reinforcement calculations the dimension shall not exceed the smaller of $2.5t$ or $2.5t_n$ without a reinforcing element and the smaller of $2.5t$ or $2.5t_n+t_e$ with a reinforcing element or integral compensation)

P = design pressure, pounds per square inch (or maximum allowable working pressure for existing pressure vessels)

R = inside radius of the shell course under consideration, before corrosion allowance is added, inches



WITHOUT REINFORCING ELEMENT

$A = d \times t_r \times F$

$A_1 \begin{cases} = (E_1 t - F t_r)(d - R_n)\,2 = (E_1 t - F t_r)\,d \\ \text{or} \\ = (E_1 t - F t_r)(R_n + t_n + t - R_n)\,2 = (E_1 t - F t_r)(t_n + t)\,2 \end{cases}$

$A_2 \begin{cases} = (t_n - t_{rn})\,2.5\,t \times 2 = (t_n - t_{rn})\,5t \\ \text{or} \\ = (t_n - t_{rn})\,2.5\,t_n \times 2 = (t_n - t_{rn})\,5t_n \end{cases}$

$A_3 = (t_n - c)\,h \times 2 = (t_n - c)\,2h$*

A_4 = Area of welds

Area of reinforcement required.

(1a) (1b) Larger value is area of shell available for reinforcement.

(2a) (2b) Smaller value is area of nozzle wall available for reinforcement.

If $A_1 + A_2 + A_3 + A_4 \geq A$ Opening is adequately reinforced.

If $A_1 + A_2 + A_3 + A_4 < A$ The difference must be supplied by reinforcing element or otherwise.

WITH REINFORCING ELEMENT

A, A_1, A_2, A_3, A_4, same as without reinforcing element.

With a reinforcing element, $2.5\,t_n$ is measured from the top surface of the reinforcing element.

A_2 becomes the smaller of $(t_n - t_{rn})\,5t$ or $(t_n - t_{rn})\,(2.5t_n + t_e)\,2$.

Area of reinforcing element $= (D_p - d - 2t_n)\,t_e = A_5$.

If $A_1 + A_2 + A_3 + A_4 + A_5 \geq A$ opening is adequately reinforced.

*The nozzle projection will not corrode back of any attaching fillet, hence the term $(t_n - c)$ is slightly conservative.

FIG. UA-280 EXAMPLE OF A REINFORCED OPENING
(This figure illustrates a common nozzle configuration and is not intended to prohibit other configurations permitted by the Code.)

R_n = inside radius of the nozzle under consideration, before corrosion allowance is added, inches

S = allowable stress value as given in the applicable part of Subsection C, pounds per square inch; except vessels designed under UW-12(c) and Column (c) of Table UW-12 must have the applicable stress value multiplied by 0.8

t = nominal thickness of the vessel wall, less corrosion allowance, inches

t_r = required thickness of a seamless shell or head as defined in UG-37, inches

t_n = nominal thickness of nozzle wall, less corrosion allowance, inches

t_{rn} = required thickness of a seamless nozzle wall, inches

t_o = weld dimensions (see Fig. UW-16.1 and UW-16)

t_{min} = weld dimensions (see Fig. UW-16.1 and UW-16)

t_w = weld dimensions (see Fig. UW-16.1 and UW-16)

t_e = thickness or height of reinforcing element, inches (see UG-40 and UG-41 and Fig. UG-40)

W = total load to be carried by attachment welds, pounds (see UG-41)

$\pi = 3.1416$

NOTE: In the examples which follow, the calculations have been carried out in detail to assist in the following of the procedure; however, slide rule accuracy is acceptable for design purposes.

Also, F has been taken as 1 for all planes through openings in cylindrical shells although Fig. UG-37 permits smaller values of a magnitude dependent upon the plane under consideration.

Example 1:

A 4-in. ID, ¾-in. wall, nozzle conforming to Specification SA-181, Grade I, is attached by welding to a vessel that has an inside diameter of 30 in. and a shell thickness of ⅜ in. The shell material conforms to Specification SA-285, Grade C. The vessel operates at 250 lb per sq in. and 150 F. There is no allowance for corrosion. Spot examination requirements of UW-52 are to be met. The opening does not pass through the main seams. Check the construction for full penetration groove-weld and for the ⅜-in. fillet cover-weld shown in Fig. UA-280.1.

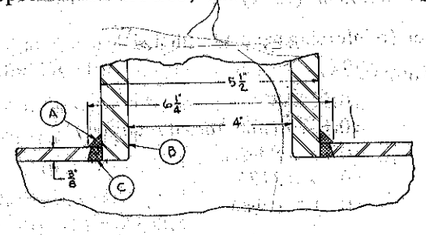


FIG. UA-280.1 EXAMPLE OF REINFORCED OPENING

Wall thicknesses required

Shell $t_r = \dfrac{PR}{SE - 0.6P}$

$= \dfrac{250 \times 15}{13{,}750 \times 1.0 - 0.6 \times 250}$

$= 0.276$ in.

Nozzle $t_{rn} = \dfrac{PR_n}{SE - 0.6P}$

$= \dfrac{250 \times 2}{15{,}000 \times 1.0 - 0.6 \times 250}$

$= 0.034$ in.

Size of weld required (UW-16(d), Fig. UW-16.1(c)

t_o = not less than the smaller of ¼ in. or $0.7t_{min}$.

$= 0.7 \times 0.75$ or 0.7×0.375

0.263 in.; therefore throat must be at least 0.25 in.

$= 0.7 \times$ weld size

$= 0.7 \times 0.375$

$= 0.263$ (exist)

Cover-weld satisfactory

Area of reinforcement required

$A = d \times t_r \times F$

$= 4 \times 0.276 \times 1$

$= 1.104$ 1.104 sq in.

Area of reinforcement available

A_1 = larger of following

$= (E_1 t - F t_r)\,d$

$= (1 \times 0.375 - 1 \times 0.276)\,4$

$= 0.396$ 0.396 sq in.

or

$= (E_1 T - F t_r)\,(t_n + t)\,2$

$= (1 \times 0.375 - 1 \times 0.276)\,(0.75 + 0.375)\,2$

$= 0.223$

A_2 = smaller of following

$= (t_n - t_{rn})\,5t$

$= (0.75 - 0.034)\,(5)\,(0.375)$

$= 1.342$ 1.342 sq in.

or

$= (t_n - t_{rn})\,5t_n$

$= (0.75 - 0.034)\,(5)\,(0.75)$

$= 2.685$

$A_4 = 2 \times 0.5 \times 0.375^2$
$= 0.141$ 0.141 sq in.

Area provided by $A_1 + A_2 + A_4 = 1.879$ sq in.

This is greater than the required area so a reinforcing element is not needed.

Load to be carried by welds (UG-41(b)(2))

$W = (A - A_1)\, S$
$= (1.104 - 0.396)\ 13{,}750 = 9{,}735$ lb

Unit stresses (UW-15(b))

Fillet-weld shear $= 0.49 \times 13{,}750$
$= 6{,}738$ psi
Groove-weld tension $= 0.74 \times 13{,}750$
$= 10{,}175$ psi
Nozzle-wall shear $= 0.70 \times 13{,}750$ [1]
$= 9{,}625$ psi

Strength of connection elements

(A) Fillet-weld shear
$= \pi/2 \times$ nozzle OD $\times$ weld leg $\times\ 6{,}738$
$= 1.57 \times 5.5 \times 0.375 \times 6{,}738$
$= 21{,}818$ lb

(B) Nozzle-wall shear
$= \pi/2 \times$ mean nozzle diam $\times\, t_n \times 9{,}625$
$= 1.57 \times 4.75 \times 0.75 \times 9{,}625$
$= 53{,}834$ lb

(C) Groove-weld tension
$= \pi/2 \times$ nozzle OD $\times$ weld leg $\times\ 10{,}175$
$= 1.57 \times 5.5 \times 0.375 \times 10{,}175$
$= 32{,}948$ lb

Possible paths of failure

(1) Through (A) and (B)
$21{,}818 + 53{,}834 = 75{,}652$ lb
(2) Through (A) and (C)
$21{,}818 + 32{,}948 = 54{,}766$ lb

Both paths are stronger than the required strength of 9,735 lb.

Example 2:

A 11¾-in. ID, ½-in. wall, nozzle conforming to Specification SA-105, Grade I, is attached by welding to a vessel that has an inside diameter of 60 in. Shell thickness ¾ in.; reinforcing element thickness ⅜ in. Shell plate to conform to Specification SA-201, Grade B, and the reinforcing element to conform to Specification SA-285, Grade C. Spot examination requirements of UW-52 are to be met and the opening does not pass through a main seam. The vessel is to operate at 250 psi and 700 F. There is to be no allowance for corrosion. Check the adequacy of the reinforcing element and the attachment welds shown in Fig. UA-280.2.

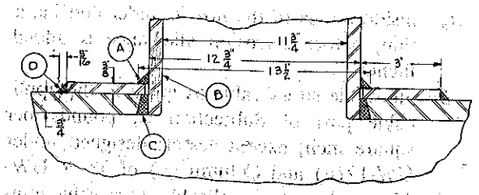


FIG. UA-280.2 EXAMPLE OF REINFORCED OPENING

Wall thicknesses required

Shell $t_s = \dfrac{PR}{SE - 0.6P}$

$= \dfrac{250 \times 30}{14{,}350 \times 1.0 - 0.6 \times 250}$

$= 0.529$ in.

Nozzle $t_{rn} = \dfrac{PR_n}{SE - 0.6 \times P}$

$= \dfrac{250 \times 5.875}{14{,}350 \times 1.0 - 0.6 \times 250}$

$= 0.104$ in.

Size of weld required (UW-16(e), Fig. UW-16.1 (m))

Inner (reinforcing element) fillet weld

$t_w = 0.7\ t_{\min}$
$= 0.7 \times 0.375$
$= 0.263$ in. (min. throat required)
$t_w = 0.7 \times$ weld size
$= \dfrac{0.7\ (13.5 - 12.75)}{2}$
$= 0.263$ in. (exist)

Outer (reinforcing element) fillet weld

Throat $= \frac{1}{2}\, t_{\min}$
$= 0.5 \times 0.375$
$= 0.1875$ (min. throat required)
$= 0.7 \times$ weld size
$= 0.7 \times 0.3125$
$= 0.219$ (exist)

Weld sizes are satisfactory.

[1] No credit can be taken for additional stength of any reinforcement having a higher allowable stress value than the material in the vessel wall (see UG-41(a)).

Area of reinforcement required

$A = d \times t_r \times F$
$= 11.75 \times 0.529 \times 1$
$= 6.216$ 6.216 sq in.

Area of reinforcement available

A_1 = larger of following
$= (E_1 t - F t_r)\, d$
$= (1 \times 0.75 - 1 \times 0.529)\ 11.75$
$= 2.596$ 2.596 sq in.

or

$= (E_1 t - F t_r)\, (t_n + t)\ 2$
$= (1 \times 0.75 - 1 \times 0.529)\, (0.5 + 0.75)\ 2$
$= 0.552$

A_2 = smaller of the following
$= (t_n - t_{rn})\ 5t$
$= (0.5 - 0.104)\, (5)\, (0.75)$
$= 1.485$

or

$= (t_n - t_{rn})\, (2.5 t_n + t_e)\ 2$
$= (0.5 - 0.104)\, (2.5 \times 0.5 + 0.375)\ 2$
$= 1.287$ 1.287 sq in.

$A_4 = 2 \times 0.5\ (0.3125^2 + 0.375^2)$
$= 0.238$ 0.238 sq in.

Area provided by $A_1 + A_2 + A_4 =$ 4.121 sq in.

$A_5 = (D_p - d - 2t_n)\, t_e$
$= (18.75 - 11.75 - 1.0)\ 0.375 \times \dfrac{13{,}250}{14{,}350}$
$= 2.078$ 2.078 sq in.

Total area available 6.199 sq in.

This is less than area required; therefore the opening is not adequately reinforced.

The size of the reinforcing element must be increased.

$A_1 + A_2 + A_4 =$ 4.121 sq in.

$A_5 = (19.00 - 11.75 - 1.0)\ 0.375 \times \dfrac{13{,}250}{14{,}350}$

$A_5 = 2.164$ 2.164 sq in.

Total area available by increasing reinforcing element OD ¼ in. 6.285 sq in.

Load to be carried by welds (UG-41(b)(2))

$W = (A - A_1)\, S$
$(6{,}216 - 2{,}596)\ 14{,}350$ 51,947 lb

Unit stresses (UW-15(b))

Outer fillet-weld shear
$= 0.49 \times 13{,}250 = 6{,}493$ psi

Inner fillet-weld shear
$= 0.49 \times 13{,}250 = 6{,}493$ psi

Groove-weld tension
$= 0.74 \times 14{,}350 = 10{,}619$ psi

Nozzle-wall shear
$= 0.70 \times 14{,}350 = 10{,}045$ psi

Strength of connection elements

(A) Inner fillet-weld shear
$= \pi/2 \times$ nozzle OD $\times$ weld leg $\times\ 6{,}493$
$= 1.57 \times 12.75 \times 0.375 \times 6{,}493$
$= 48{,}742$ lb

(B) Nozzle-wall shear
$= \pi/2 \times$ mean nozzle diam $\times\, t_n \times 10{,}045$
$= 1.57 \times 12.25 \times 0.5 \times 10{,}045$
$= 96{,}595$ lb

(C) Groove-weld tension
$= \pi/2 \times$ nozzle OD $\times\, t \times 10{,}619$
$= 1.57 \times 12.75 \times 0.75 \times 10{,}619$
$= 159{,}424$ lb

(D) Outer fillet-weld shear
$= \pi/2 \times$ reinforcing element OD $\times$ weld leg $\times\ 6{,}493$
$= 1.57 \times 19.00 \times 0.312 \times 6{,}493$
$= 60{,}430$ lb

Possible paths of failure

(1) Through (B) and (D)
$96{,}595 + 60{,}430 = 157{,}025$ lb
(2) Through (A) and (C)
$48{,}742 + 159{,}424 = 208{,}166$ lb
(3) Through (C) and (D)
$159{,}424 + 60{,}430 = 219{,}854$ lb

All paths are stronger than the required strength of 51,947 lb.

The design strength of the outer fillet weld attaching the reinforcing element to the shell is 60,430 lb or greater than the reinforcing element strength of $2.164 \times 13{,}250 = 28{,}673$ lb.

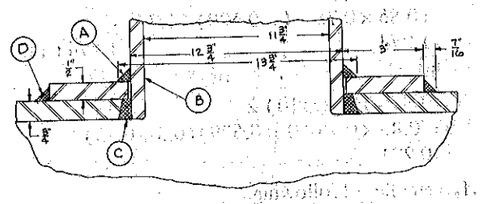


FIG. UA-280.3 EXAMPLE OF REINFORCED OPENING

Example 3:

An 11¾-in. ID, ½-in. wall, nozzle conforming to Specification SA-105, Grade I, is attached by welding to a vessel that has an inside diameter of 60 in. The nozzle passes through the longitudinal joint of the vessel. Spot examination requirements of UW-52 are to be met. The ¾-in. thick shell plate and ½-in. thick reinforcing element to conform to Specification SA-201, Grade B. The vessel is to operate at 250 psi and 700 F. There is to be no allowance for corrosion. Check the adequacy of the reinforcing element and the attachment welds shown in Fig. UA-280.3.

Wall thicknesses required (from Example 2)

$t_r = 0.529$ in. $\quad t_{rn} = 0.104$ in.

Size of welds required (UW-16(e), Fig. UW-16.1 (m))

Inner (reinforcing element) fillet weld

$t_w = 0.7\ t_{min}$
$= 0.7 \times 0.5$
$= 0.35$ in. (minimum throat required)
$t_w = 0.7 \times$ weld size
$= \dfrac{0.7\ (13.75 - 12.75)}{2}$
$= 0.35$ in. (exist)

Outer (reinforcing element) fillet weld

Throat $= \frac{1}{2}\ t_{min}$
$= 0.5 \times 0.5$
$= 0.25$ in. (minimum throat required)
Throat $= 0.7 \times$ weld size
$= 0.7 \times 0.4375$
$= 0.306$ in. (exist)

The weld sizes used are satisfactory.

Area of reinforcement required

$A = d \times t_r \times F$
$= 11.75 \times 0.529 \times 1$
$= 6.216$ — 6.216 sq in.

Area of reinforcement available

A_1 = larger of following
$= (E_1 t - F t_r)\ d$
$= (0.85 \times 0.75 - 1 \times 0.529)\ 11.75$
$= 1.274$ — 1.274 sq in.

or

$= 3E_1 t - F t_r)\ (t_n + t)\ 2$
$= (0.85 \times 0.75 - 1 \times 0.529)\ (0.5 + 0.75)\ 2$
$= 0.271$

A_2 = smaller of following
$= (t_n - t_{rn})\ 5t$
$= (0.5 - 0.104)\ (5)\ (0.75)$
$= 1.485$

or

$= (t_n - t_{rn})\ (2.5 t_n + t_e)\ 2$
$= (0.5 - 0.104)\ (2.5 \times 0.5 + 0.5)\ 2$
$= 1.386$ — 1.386 sq in.

$A_4 = 2 \times 0.5\ (0.4375^2 + 0.5^2)$
$= 0.441$ — 0.441 sq in.

Area provided by $A_1 + A_2 + A_4 =$ — 3.101 sq in.

$A_5 = (D_p - d - 2t_n)\ t_e$
$= (18.75 - 11.75 - 1)\ 0.5$
$= 3.0$ — 3.0 sq in.

Total area available — 6.101 sq in.

Opening is not adequately reinforced.

Size of reinforcing element must be increased

$A_1 + A_2 + A_4 =$ — 3.101 sq in.
$A_5 = (19.00 - 11.75 - 1)\ 0.5$ — 3.125 sq in.

Total area available by increasing OD of reinforcing element ¼ in. = — 6.226 sq in.

Load to be carried by weld (UG-41(b)(2))

$W = (A - A_1)\ S$
$= (6.216 - 1.274)\ 14{,}350 = 70{,}917$ lb

Unit stresses (UW-15(b))

Fillet-weld shear $= 0.49 \times 14{,}350$
$= 7{,}031$ psi
Groove-weld tension $= 0.74 \times 14{,}350$
$= 10{,}619$ psi
Nozzle-wall shear $= 0.70 \times 14{,}350$
$= 10{,}045$ psi

Strength of connection elements

(A) Inner (reinforcing element) fillet-weld shear
$\pi/2 \times$ nozzle OD $\times$ weld leg $\times 7{,}031$
$1.57 \times 12.75 \times 0.5 \times 7{,}031$
$= 70{,}371$ lb

(B) Nozzle wall shear
$= \pi/2 \times$ mean nozzle diam $\times\ t_n \times 10{,}045$
$= 1.57 \times 12.25 \times 0.5 \times 10{,}045$
$= 96{,}595$ lb

(C) Groove weld tension
$= \pi/2 \times$ nozzle OD $\times\ t \times 10{,}619$
$= 1.57 \times 12.75 \times 0.75 \times 10{,}619$
$= 159{,}424$ lb

(D) Outer (reinforcing element) fillet weld
$= \pi/2 \times$ reinforcing element OD $\times$ weld leg $\times 7{,}031$
$= 1.57 \times 19.0 \times 0.437 \times 7{,}031$
$= 91{,}654$ lb

Possible paths of failure

(1) Through (B) and (D)
$96{,}595 \times 91{,}654 = 188{,}249$ lb

(2) Through (A) and (C)
$70{,}371 + 159{,}424 = 229{,}795$ lb

(3) Through (C) and (D)
$159{,}424 + 91{,}654 = 251{,}078$ lb

All are stronger than the required strength of 70,917 lb.

Example 4:

A 16-in. ID weld neck, $1^{11}/_{16}$-in. wall, conforming to Specification SA-105, Grade II, is attached to a vessel that has an inside diameter of 96 in. and a shell thickness of 2 in. The shell material conforms to Specification SA-516 Grade 65. The vessel is designed to operate at 425 psi and 800 F. An allowance of $\frac{1}{16}$ in. for corrosion is included in the shell and nozzle thickness. Main seams in the vessel are to be radiographed. The opening does not pass through a main seam. Check the opening for reinforcement and check the adequacy of the attachment welds shown in Fig. UA-280.4.

Wall thicknesses required

Shell $tr = \dfrac{PR}{SE - 0.6P}$
$= \dfrac{425\ (48 + 0.0625)}{11{,}400 \times 1 - 0.6 \times 425}$
$= 1.833$ in.

Nozzle $t_{rn} = \dfrac{PR_n}{SE - 0.6P}$
$= \dfrac{425\ (8 + 0.0625)}{12{,}000 \times 1 - 0.6 \times 425}$
$= 0.292$ in.

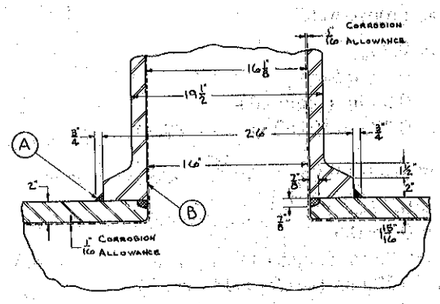


FIG. UA-280.4 EXAMPLE OF REINFORCED OPENING

Size of weld required (UW-16(f), Fig. UW-16.1 (r-1))

Inner perimeter weld

$t_w = 0.7\ t_{min}$
$= 0.7 \times 0.75$
$= 0.525$ in. (required)
$t_w = 0.875$ in. (exist) (see Fig. UA-280.4)

Outer perimeter weld

Throat $= \frac{1}{2}\ t_{min}$
$= 0.5 \times 0.75$
$= 0.375$ in. (minimum throat required)
Throat $= 0.7 \times$ weld size $= 0.7 \times 0.75$
$= 0.525$ in. (exist)

The weld sizes are satisfactory.

Area of reinforcement required

$A = d \times t_r \times F$
$= 16.125 \times 1.833 \times 1$
$= 29.557$ — 29.557 sq in.

Area of reinforcement available

A_1 = larger of following
$= (E_1 t - F t_r)\ d$
$= (1.0 \times 1.937 - 1 \times 1.833)\ 16.125$
$= 1.677$ — 1.677 sq in.

or

$= (E_1 t - F t_r)\ (t_n + t)\ 2$
$= (1.0 \times 1.937 - 1 + 1.833)\ (1.687 + 1.937)\ 2$
$= 0.753$

Check for t_e Tan $\Theta = \dfrac{(26 - 19.5)}{2} + 3.5$

Tan $\Theta = 0.928$

$\Theta = 40°$

$40° > 30°$

therefore, Fig. UG-40(d) applies and $t_e = 3.5$.

A_2 = smaller of following
$= (t_n - t_{rn})\ 5t$
$= (1.687 - 0.292)\ (5)\ (1.937)$
$= 13.510$ — 13.510 sq in.

or

$= (t_n - t_{rn})\ (2.5 t_n + t_e)\ 2$
$= (1.687 - 0.292)\ (2.5 \times 1.687 + 3.5)\ 2$
$= 21.531$

$A_4 = 2 \times 0.5 \times 0.75^2$
$= 0.562$ — 0.562 sq in.

Area provided by $A_1 + A_2 + A_4 =$ — 15.749 sq in.

$A_5 = (D_p - d - 2t_n) \times$ average thickness of reinforcement [1]

[1] Average thickness of reinforcing element
$= \dfrac{3.5 + 2}{2}$
$= 2.75$

$= (26.0 - 16.125 - 3.375)(2.75)$
$= 17.875$ 17.875 sq in.

Total area available 33.624 sq in.

This is greater than area required; therefore, the opening is adequately reinforced.

Load to be carried by welds (UG-41(b)(2))

$W = (A - A_1)\,S$
$= (29.557 - 1.677)\,11{,}400$
$= 317{,}832$ lb

Unit stresses (UW-15(b))

Fillet-weld shear $= 0.49 \times 11{,}400$
$= 5{,}586$ psi
Groove-weld shear $= 0.60 \times 11{,}400$
$= 6{,}840$ psi

Strength of connection elements

(A) Fillet-weld shear
$= \pi/2 \times$ nozzle OD $\times$ weld leg $\times$ 5,586
$= 1.57 \times 26.0 \times 0.75 \times 5{,}586$
$= 171{,}015$ lb

(B) Groove-weld shear
$= \pi/2 \times$ mean diam of weld $\times$ weld $t_w \times 6{,}840$
$= 1.57 \times 17.0 \times 0.875 \times 6{,}840$
$= 159{,}739$ lb

Connection elements (A) and (B) have a combined strength of

$171{,}015 + 159{,}739 = 330{,}754$ lb,

which exceeds the required strength of 317,832 lb.

Example 5:

A nozzle with an outside diameter of 16 in. is fabricated by welding from ¾-in. plate. It is attached by welding to a vessel that has an inside diameter of 83 in. and a shell thickness of 2 in. The vessel is designed to operate at a pressure of 500 psi at 400 F. The material in the shell and the nozzle conforms to Specification SA-285, Grade C. An allowance of ¼-in. for corrosion is included in the shell and nozzle thickness. The vessel main seams are to be radiographed. The nozzle does not pass through a main seam. Check the adequacy of the reinforcement and the attachment welds shown in Fig. UA-280.5.

Wall thickness required

Shell $t_r = \dfrac{PR}{SE - 0.6P}$
$= \dfrac{500\ (41.50 + 0.25)}{13{,}750 \times 1.0 - 0.6 \times 500}$
$= 1.553$ in.

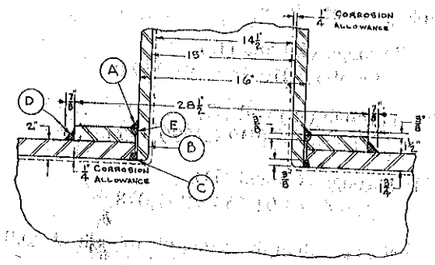


FIG. UA-280.5 EXAMPLE OF REINFORCED OPENING

Nozzle $t_{rn} = \dfrac{PR_n}{SE - 0.6P}$
$= \dfrac{500\ (7.25 + 0.25)}{13{,}750 \times 1.0 - 0.6 \times 500}$
$= 0.279$ in.

Size of weld required (UW-16(e), Fig. UW-16.1 (n))

Inner (reinforcing element) fillet weld

t_c = not less than the smaller of ¼ in. or 0.7 t_{min}
$= 0.7 \times 0.75$ or 0.7×0.5
$= 0.35$ in.; therefore throat must be at least 0.25 in.
$t_c = 0.7 \times$ weld size
$= 0.7 \times 0.375$
$= 0.263$ (exist)

Outer (reinforcing element) fillet weld

Throat $= \frac{1}{2}\, t_{min}$
$= 0.5 \times 0.75$
$= 0.375$ in. (minimum throat required)
Throat $= 0.7 \times$ weld size
$= 0.7 \times 0.875$
$= 0.612$ in. (exist)

Upper groove weld

$t_w = 0.7\, t_{min}$
$= 0.7 \times 0.5$
$= 0.35$ in. (required)
$t_w = 0.375$ in. (see Fig. UA-280.5)

Lower groove weld

$t_w = 0.7\, t_{min}$
$= 0.7 \times 0.5$
$= 0.35$ in. (required)
$t_w = 0.375$ in. (see Fig. UA-280.5)

The weld sizes used are satisfactory.

Area of reinforcement required

$A = d \times t_r \times F$
$= 15.0 \times 1.553 \times 1$
$= 23.295$ 23.295 sq in.

Area of reinforcement available

A_1 = larger of following
$= (E_1 t - F t_r)\, d$
$= 1 \times 1.75 - 1 \times 1.553)\ 15$
$= 2.955$ 2.955 sq in.

or

$= (E_1 t - F t_r)(t_n + t)\ 2$
$= (1 \times 1.75 - 1 \times 1.553)(0.5 + 1.75)\ 2$
$= 0.8865$

A_2 = smaller of following
$= (t_n - t_{rn})\ 5t$
$= (0.5 - 0.279)(5)(1.75)$
$= 1.933$

or

$= (t_n - t_{rn})(2.5t_n + t_e)\ 2$
$= 1.215$ 1.215 sq in.

$A_4 = 2 \times 0.5\ (0.875^2 + 0.375^2)$
$= 0.906$ 0.906 sq in.

Area provided by $A_1 + A_2 + A_4 =$ 5.076 sq in.

$A_5 = (D_p - d - 2t_n)\ t_i$
$= (28.5 + 15 - 1)\ 1.5$
$= 18.75$ 18.75 sq in.

Total area available 23.826 sq in.

This is greater than the required area; therefore, opening is adequately reinforced.

Load to be carried by welds (UG-41(b)(2))

$W = (A - A_1)\,S$
$= (23.295 - 2.955)\ 13{,}750$
$= 279{,}675$ lb

Load to be carried by welds (A), (C) and (E) (UG-41(b)(1))

$W = (A_2 + 2t_n t)\,S$
$= (1.215 + 2 \times 0.5 \times 1.75)\ 13{,}750$
$= 40{,}769$ lb

Unit stresses (UW-15(b))

Fillet-weld shear $= 0.49 \times 13{,}750$
$= 6{,}737$ psi
Groove-weld tension $= 0.74 \times 13{,}750$
$= 10{,}175$ psi
Groove-weld shear $= 0.60 \times 13{,}750$
$= 8{,}250$ psi
Nozzle-wall shear $= 0.70 \times 13{,}750$
$= 9{,}625$ psi

Strength of connection elements

(A) Upper groove-weld tension
$= \pi/2 \times$ nozzle OD $\times$ weld leg $\times$ 10,175
$= 1.57 \times 16.0 \times 0.375 \times 10{,}175$
$= 95{,}848$ lb

(B) Nozzle wall shear
$= \pi/2 \times$ mean nozzle diam $\times\, t_n \times 9{,}625$
$= 1.57 \times 15.5 \times 0.5 \times 9{,}625$
$= 117{,}112$ lb

(C) Lower groove-weld tension
$= \pi/2 \times$ nozzle OD $\times$ weld leg $\times$ 10,175
$= 1.57 \times 16.0 \times 0.375 \times 10{,}175$
$= 95{,}848$ lb

(D) Outer (reinforcing element) fillet weld
$= \pi/2 \times$ reinforcing element OD $\times$ weld leg $\times$ 6,737
$= 1.57 \times 28.5 \times 0.875 \times 6{,}737$
$= 263{,}766$ lb

(E) Upper fillet or cover-weld
$= \pi/2 \times$ nozzle OD $\times$ weld leg $\times$ 6,737
$= 1.57 \times 16.0 \times 0.375 \times 6{,}737$
$= 63{,}462$ lb

Possible paths of failure:

(1) Through (B) and (D)
$117{,}122 + 263{,}766 = 380{,}878$ lb

(2) Through (C) and (D)
$95{,}848 + 263{,}766 = 359{,}614$ lb

(3) Through (A), (C) and (E)
$95{,}848 + 95{,}848 + 63{,}462 = 255{,}158$ lb

Paths (1) and (2) are stronger than the total strength of 279,675 lb. Path (3) is stronger than strength of 40,769 lb. The outer fillet weld strength of 263,766 lb is greater than the reinforcing element strength of $18.75 \times 13{,}750 = 257{,}813$ lb.

LIGAMENTS

UA-290 Efficiency of Ligaments

Example 1:

Given: Pitch of tube holes in a cylindrical shell, as shown in Fig. UG-53.1, = 5¼ in.; diameter of tube = 3¼ in.; diameter of tube holes = $3\frac{9}{32}$ in.

Required: Efficiency of the ligament.

Solution: $= \dfrac{p - d}{p} = \dfrac{5.25 - 3.281}{5.25}$
$= 0.375$ or 37.5 percent.

Example 2:

Given: Spacing of tube holes in a cylindrical shell as shown in Fig. UG-53.2. Diameter of tube holes $=3\frac{9}{32}$ in.

Required: Efficiency of the ligament.

Solution: $=\frac{p-nd}{p}=\frac{12-2\times3.281}{12}$

$=0.453$ or 45.3 percent.

Example 3:

Given: Spacing of tube holes in a cylindrical shell as shown in Fig. UG-53.3. Diameter of tube holes $=3\frac{9}{32}$ in.

Required: Efficiency of the ligament.

Solution: $\frac{p-nd}{p}=\frac{29.25-5\times3.281}{29.25}$

$=0.439$ or 43.9 percent.

Example 4:

Given: Diagonal pitch of tube holes in a cylindrical shell, as shown in Fig. UG-53.4 $=6.42$ in. Diameter of holes $=4\frac{9}{32}$ in. Longitudinal pitch of tube holes $=11\frac{1}{2}$ in. $=p=p_1$.

Required: Diagonal ligament efficiency.

Solution: Longitudinal efficiency $=\frac{p-d}{p}$

$=\frac{11.5-4.031}{11.5}=0.649$ or 64.9 percent.

$\frac{p'}{p_1}=\frac{6.42}{11.5}=0.558$

From the diagram in Fig. UG-53.5, the efficiency is 33.3 percent.

Example 5:

Given: Diagonal pitch of tube holes $=6\frac{35}{64}$ in. Diameter of tube holes $=4\frac{1}{64}$ in. Longitudinal pitch of tube holes $=6\frac{1}{2}$ in. $=p=p_1$.

$\frac{p'}{p}=\frac{6.547}{6.5}=1.006$

Longitudinal efficiency $=\frac{p-d}{p}=\frac{6.5-4.0156}{6.5}$

$=0.3825$ or 38.25 percent.

From the diagram in Fig. UG-53.5, it can be seen that the vertical line representing the longitudinal efficiency intersects the p'/p_1 value of 1.006 above the curve representing equal longitudinal and diagonal efficiencies. Thus it can be seen that the longitudinal efficiency is less and is the value to be used.

APPENDIX M
INSTALLATION AND OPERATION

UA-350 Introduction

(*a*) The rules in this Appendix are for general information only, because they pertain to the installation and operation of pressure vessels, which are the prerogative and responsibility of the law enforcement authorities in those states and municipalities which have made provision for the enforcement of Section VIII of the Boiler and Pressure Vessel Code.

(*b*) It is permissible to use any departures suggested herein from provisions in the mandatory parts of this Division of Section VIII when granted by the authority having legal jurisdiction over the installation of unfired pressure vessels.

UA-351 Corrosion

(*a*) Vessels subject to external corrosion shall be so installed that there is sufficient access to all parts of the exterior to permit proper inspection of the exterior, unless adequate protection against corrosion is provided or unless the vessel is of such size and is so connected that it may readily be removed from its permanent location for inspection.

(*b*) Vessels having manholes, handholes, or cover plates to permit inspection of the interior shall be so installed that these openings are accessible.

(*c*) In vertical cylindrical vessels subject to corrosion, to insure complete drainage, the bottom head, if dished, should preferably be concave to pressure.

UA-352 Marking on the Vessel

The marking required by this Division shall be so located that it will be accessible after installation and when installed shall not be covered with insulation or other material that is not readily removable (see UG-116(i)).

UA-353 Pressure-Relieving Safety Devices

The general provisions for the installation of pressure relieving devices are fully covered in UG-134. The following paragraphs contain details in arrangement of stop valves for shutoff control of safety pressure relief devices which are sometimes necessary to the continuous operation of processing equipment of such a complex nature that the shutdown of any part of it is not feasible. There are also rules in regard to the design of discharge piping from safety and relief valves, which can only be general in nature because the design engineer must fit the arrangement and proportions of such a system to the particular requirements in the operation of the equipment involved.

UA-354 Stop Valves Between Pressure Relieving Device and Vessel

(*a*) A vessel, in which pressure can be generated because of service conditions, may have a full-area stop valve between it and its pressure relieving device for inspection and repair purposes only. When such a stop valve is provided, it shall be so arranged that it can be locked or sealed open, and it shall not be closed except by an authorized person who shall remain stationed there during that period of the vessel's operation within which the valve remains closed, and who shall again lock or seal the stop valve in the open position before leaving the station.

(*b*) A vessel or system (see UG-132(c)) for which the pressure orginates from an outside source exclusively may have individual pressure relieving devices on each vessel, or connected to any point on the connecting piping, or on any one of the vessels to be protected. Under such an arrangement, there may be a stop valve between any vessel and the pressure relieving devices, and this stop valve need not be locked open, provided it also closes off that vessel from the source of pressure.

UA-355 Stop Valves on the Discharge Side of a Pressure Relieving Device (See UG-134(e).)

A full-area stop valve may be placed on the discharge side of a pressure relieving device when its discharge is connected to a common header with other discharge lines from other pressure relieving devices on nearby vessels that are in operation, so that this stop valve when closed will prevent a discharge from any connected operating vessels from backing up beyond the valve so closed. Such a stop valve shall be so arranged that it can be locked or sealed in either the open or closed position, and it shall be locked or sealed in either position only by an authorized person. When it is to be closed while

the vessel is in operation, an authorized person shall be present, and he shall remain stationed there; he shall again lock or seal the stop valve in the open position before leaving the station. Under no condition should this valve be closed while the vessel is in operation except when a stop valve on the inlet side of the safety relieving device is installed and is first closed.

UA-356 Discharge Lines From Safety Devices

(*a*) Where it is feasible, the use of a short discharge pipe or vertical riser, connected through long-radius elbows from each individual device, blowing directly to the atmosphere, is recommended. Such discharge pipes shall be at least of the same size as the valve outlet. Where the nature of the discharge permits, telescopic (sometimes called "broken") discharge lines, whereby condensed vapor in the discharge line, or rain, is collected in a drip pan and piped to a drain, are recommended.[1]

(*b*) When discharge lines are long, or where outlets of two or more valves having set pressures within a comparable range are connected into a common line, the effect of the back pressure that may be developed therein when certain valves operate must be considered (see UG-134(g)). The sizing of any section of a common-discharge header downstream from each of the two or more pressure relieving devices that may reasonably be expected to discharge simultaneously shall be based on the total of their outlet areas, with due allowance for the pressure drop in all downstream sections. Use of specially designed valves suitable for use on high or variable back pressure service should be considered.

(*c*) All discharge lines shall be run as direct as is practicable to the point of final release for disposal. For the longer lines, due consideration shall be given to the advantage of long-radius elbows, avoidance of closeup fittings, and the minimizing of excessive line strains by expansion joints and well-known means of support to minimize line-sway and vibration under operating conditons.

NOTE: It is recognized that no simple rule can be applied generally to fit the many installation requirements, which vary from simple short lines that discharge directly to the atmosphere to the extensive manifold discharge piping systems where the quantity and rate of the product to be disposed of requires piping to a distant safe place.

UA-357 General Advisory Infomation on the Characteristics of Safety Relief Valves Discharging Into a Common Header

Because of the wide variety of types and kinds of safety relief valves, it is not considered advisable to attempt a description in this Appendix of the effects produced by discharging them into a common header. Several different types of valves may conceivably be connected into the same discharge header and the effect of back pressure on each type may be radically different. Data compiled by the manufacturers of each type of valve used, should be consulted for information relative to its performance under the conditions anticipated.

[1]This construction has the further advantage of not transmitting discharge-pipe strains to the valve. In these types of installation, the back pressure effect will be negligible, and no undue influence upon normal valve operation can result.

APPENDIX P

BASIS FOR ESTABLISHING STRESS VALUES

BASIS FOR ESTABLISHING STRESS VALUES

UA-500

In the determination of allowable stress values for pressure parts the Committee is guided by successful experience in service, insofar as evidence of satisfactory performance is available. Such evidence is considered equivalent to test data where operating conditions are known with reasonable certainty. In the evaluation of new materials, it is sometimes necessary to be guided to a certain extent by the comparison of test information with available data on successful applications of similar materials.

The mechanical properties considered, and the factors applied to establish the maximum allowable stresses are as given below:

At temperatures below the creep range, the maximum allowable stress value for ferrous materials (Table UCS-23, UCS-27, UHA-23, and UHT-23) and for nonferrous materials (Table UNF-23), is the lowest of these:

(*1*) 1/4 of the specified minimum tensile strength at room temperature,

(*2*) 1/4 of the tensile strength at temperature,

(*3*)(a) For ferrous materials:

5/8 of specified minimum yield strength at room temperature,

(b) For nonferrous materials:

2/3 of specified minimum yield strength at room temperature,

(*4*)(a) For ferrous materials:

5/8 of yield strength at temperature,

(b) For nonferrous materials:

2/3 of yield strength at temperature.

In Table UNF-23 for specific nonferrous alloys and in Table UHA-23 for austenitic materials, two sets of allowable stress values are provided. The higher values should be used only where slightly greater deformation is not in itself objectionable. The higher alternative allowable stresses are identified by a footnote. These stresses exceed two-thirds for nonferrous alloys and 62 1/2 percent for austenitic materials but do not exceed 90 percent of the minimum yield at temperature. These higher stresses are not recommended for the design of flanges and other strain sensitive applications.

At temperatures in the creep range the maximum allowable stress value for all materials shall not exceed the lowest of the following:

(*1*) 100 percent of the average stress for a creep rate of 0.01 percent per 1000 hours,

(*2*) 67 percent of the average stress for rupture at the end of 100,000 hours,

(*3*) 80 percent of the minimum stress for rupture at the end of 100,000 hours.

For *ferrous bolting* materials, the basis for setting stresses is the same as for all other materials with the added requirement that the stresses for heat treated materials at temperature below the creep range will not exceed the lower of 20 percent of the room temperature specified minimum tensile strength, or 25 percent of the room temperature specified minimum yield strength.

For *nonferrous bolting* materials, at temperatures below the creep range, the maximum allowable stress values are the lowest of:

(*1*) 1/5 of the specified minimum tensile strength at room temperature,

(*2*) 1/5 of the tensile strength at temperature,

(*3*) 1/4 of the specified minimum yield strength at room temperature,

(*4*) 1/4 of the yield strength at temperature.

APPENDIX Q
BASIS FOR ESTABLISHING STRESS VALUES FOR NONFERROUS MATERIALS

UA-600

The mechanical properties considered, and factors applied to provide the maximum allowable stresses are as given below:

At any temperature listed below the creep range, the maximum allowable stress value for nonferrous materials, Table UNF-23, except for bolting is the lowest of these:

(*1*) 1/4 of the specified minimum tensile strength at room temperature,

(*2*) 1/4 of the tensile strength at temperature,

(*3*) 2/3 of the specified minimum yield strength at room temperature,

(*4*) 2/3 of the yield strength at temperature.

At any temperature listed below the creep range, the maximum allowable stress value for nonferrous bolting materials is the lowest of:

(*1*) 1/5 of the specified minimum tensile strength at room temperature,

(*2*) 1/5 of the tensile strength at temperature,

(*3*) 1/4 of the specified minimum yield strength at room temperature,

(*4*) 1/4 of the yield strength at temperature.

At temperatures in the creep range, the maximum allowable stress values for nonferrous materials are the lower of the stress producing a secondary creep rate of 0.01 percent per 1000 hours; or, the stress producing rupture in 100,000 hours.

APPENDIX R
PREHEATING

Introduction

Preheating may be employed during welding to assist in completion of the welded joint. The need for and temperature of preheat are dependent on a number of factors, such as the chemical analysis, degree of restraint of the parts being joined, elevated physical properties, and heavy thicknesses. Mandatory rules for preheating are, therefore, not given in this Division of Section VIII except as required in the footnotes that provide for exemptions to postweld heat treatment in Tables UCS-56 and UHA-32. Some practices used for preheating are given below as a general guide for the materials listed by P-numbers in Section IX of the Code. It is cautioned that the preheating temperatures listed below do not necessarily insure satisfactory completion of the welded joint and requirements for individual materials within the P-number listing may have preheating more or less restrictive than this general guide. The procedure specification for the material being welded specifies the minimum preheating requirements under Section IX of the Code weld procedure qualification requirements.

The heat of welding may assist in maintaining preheat temperatures after the start of welding and for inspection purposes, temperature checks can be made near the weld. The method or extent of application of preheat is not therefore, specifically given. Normally when materials of two different P-number groups are joined by welding, the preheat used will be that of the material with the higher preheat specified on the procedure specified on the procedure specification.

UA-800 P-1 Group

(*a*) 175 F for material which has both a specified maximum carbon content in excess of 0.30 percent and a thickness at the joint in excess of 1 in.

(*b*) 50 F for all other materials in this group.

UA-801 P-2 Group

Preheat is not used for material in this group.

UA-802 P-3 Group

(*a*) 175 F for material which has either a specified minimum tensile strength in excess of 70,000 psi or a thickness at the joint in excess of 5/8 in.

(*b*) 50 F for all other materials in this group.

UA-803 P-4 Group

(*a*) 250 F for material which has either a specified minimum tensile strength in excess of 60,000 psi or a thickness at the joint in excess of 1/2 in.

(*b*) 50 F for all other materials in this group.

UA-804 P-5 Group

(*a*) 400 F for material which has either a specified minimum tensile strength in excess of 60,000 psi, or has both a specified minimum chromium content above 6.0 percent and a thickness at the joint in excess of 1/2 in.

(*b*) 300 F for all other materials in this group.

UA-805 P-6 Group

400 F

UA-806 P-7 Group

None

UA-807 P-8 Group

None

UA-808 P-9 Group

250 F for P-9A materials

300 F for P-9B and P-9C materials

UA-809 P-10 Group

175 F for P-10A materials

250 F for P-10B materials

For P-10C materials, preheat is neither required nor prohibited, and consideration shall be given to the limitation of interpass temperature for various thicknesses to avoid detrimental effects on the mechanical properties of heat treated material.

For P-10D and P-10E materials, 300 F with interpass temperature maintained between 350 F and 450 F.

UA-810 P-11 Group

(*a*) *P-11A Group*

Subgroup 1—None (Note 1)

Subgroup 2—Same as for P-5 Group (Note 1)

Subgroup 3—Same as for P-5 Group (Note 1)

(b) P-11B Group

Subgroup 1—Same as for P-3 Group (Note 1)

Subgroup 2—Same as for P-3 Group (Note 1)

Subgroup 3—Same as for P-3 Group (Note 1)

Subgroup 4—Same as for P-3 Group (Note 1)

Subgroup 5—Same as for P-3 Group (Note 1)

Subgroup 6—Same as for P-5 Group (Note 1)

Subgroup 7—Same as for P-5 Group (Note 1)

UA-811 P-12 Group

(*a*) *P-12A Group*

Subgroup 1—Same as for P-1 Group

(*b*) *P-12B Group*

Subgroup 1—Same as for P-3 Group

Subgroup 2—Same as for P-1 Group

Subgroup 3—Same as for P-4 Group

Subgroup 4—Same as for P-5 Group

(*c*) *P-12C Group*

Subgroup 1—Same as for P-3 Group

NOTE (1): Consideration shall be given to the limitation of interpass temperature for various thicknesses to avoid detrimental effects on the mechanical properties of heat treated materials.

APPENDIX S

DESIGN CONSIDERATIONS FOR BOLTED FLANGE CONNECTIONS

The primary purpose of the rules for bolted flange connections in Appendix II is to insure safety, but there are certain practical matters to be taken into consideration in order to obtain a serviceable design. One of the most important of these is the proportioning of the bolting, i.e., determining the number and size of the bolts.

In the great majority of designs the practice that has been used in the past should be adequate, viz., to follow the design rules in Appendix II and tighten the bolts sufficiently to withstand the test pressure without leakage. The considerations presented in the following discussion will be important only when some unusual feature exists, such as a very large diameter, a high design pressure, a high temperature, severe temperature gradients, an unusual gasket arrangement, and so on.

The maximum allowable stress values for bolting given in the various tables of Subsection C are design values to be used in determining the minimum amount of bolting required under the rules. However, a distinction must be kept carefully in mind between the design value and the bolt stress that might actually exist or that might be needed for conditions other than the design pressure. The initial tightening of the bolts is a prestressing operation, and the amount of bolt stress developed must be within proper limits, to insure, on the one hand, that it is adequate to provide against all conditions that tend to produce a leaking joint, and on the other hand, that it is not so excessive that yielding of the bolts and/or flanges can produce relaxation that also can result in leakage.

The first important consideration is the need for the joint to be tight in the hydrostatic test. An initial bolt stress of some magnitude greater than the design value therefore must be provided. If it is not, further bolt strain develops during the test, which tends to part the joint and thereby to decompress the gasket enough to allow leakage. The test pressure is usually 1 1/2 times the design pressure, and on this basis it may be thought that 50 percent extra bolt stress above the design value will be sufficient. However, this is an oversimplification because, on the one hand, the safety factor against leakage under test conditions in general need not be as great as under operating conditions. On the other hand, if a stress-strain analysis of the joint is made, it may indicate that an initial bolt stress still higher than 1 1/2 times the design value is needed. Such an analysis is one that considers the changes in bolt elongation, flange deflection, and gasket load that take place with the application of internal pressure, starting from the prestressed condition. In any event, it is evident that an initial bolt stress higher than the design value may and, in some cases, must be developed in the tightening operation, and it is the intent of this Division of Section VIII that such a practice is permissible, provided it includes necessary and appropriate provision to insure against excessive flange distortion and gross crushing of the gasket.

It is possible for the bolt stress to decrease after initial tightening, because of slow creep or relaxation of the gasket, particularly in the case of the "softer" gasket materials. This may be the cause of leakage in the hydrostatic test, in which case it may suffice merely to retighten the bolts. A decrease in bolt stress can also occur in service at elevated temperatures, as a result of creep in the bolt and/or flange or gasket material, with consequent relaxation. When this results in leakage under service conditions, it is common practice to retighten the bolts, and sometimes a single such operation, or perhaps several repeated at long intervals, is sufficient to correct the condition. To avoid chronic difficulties of this nature, however, it is advisable when designing a joint for high-temperature service to given attention to the relaxation properties of the materials involved, especially for temperatures where creep is the controlling factor in design.

In the other direction, excessive initial bolt stress can present a problem in the form of yielding in the bolting itself, and may occur in the tightening operation to the extent of damage or even breakage. This is especially likely with bolts of small diameter and with bolt materials having a relatively low yield strength. The yield strength of mild carbon steel, annealed austenitic stainless steel, and certain of the nonferrous bolting materials can easily be exceeded with ordinary wrench effort in the smaller bolt sizes. Even if no damage is evident, any additional load generated when internal pressure is applied can produce further yielding with possible leakage. Such

yielding can also occur when there is very little margin between initial bolt stress and yield strength.

An increase in bolt stress, above any that may be due to internal pressure, might occur in service during startup or other transient conditions, or perhaps even under normal operation. This can happen when there is an appreciable differential in temperature between the flanges and the bolts, or when the bolt material has a different coefficient of thermal expansion than the flange material. Any increase in bolt load due to this thermal effect, superposed on the load already existing, can cause yielding of the bolt material, whereas any pronounced decrease due to such effects can result in such a loss of bolt load as to be a direct cause of leakage. In either case, retightening of the bolts may be necessary, but it must not be forgotten that the effects of repeated retightening can be cumulative and may ultimately make the joint unserviceable.

In addition to the difficulties created by yielding of the bolts as described above, the possibility of similar difficulties arising from yielding of the flange or gasket material, under like circumstances or from other causes, should also be considered.

Excessive bolt stress, whatever the reason, may cause the flange to yield, even though the bolts may not yield. Any resulting excessive deflection of the flange, accompanied by permanent set, can produce a leaking joint when other effects are superposed. It can also damage the flange by making it more difficult to effect a tight joint thereafter. For example, irregular permanent distortion of the flange due to uneven bolt load around the circumference of the joint can warp the flange face and its gasket contact surface out of a true plane.

The gasket, too, can be overloaded, even without excessive bolt stress. The full initial bolt load is imposed entirely on the gasket, unless the gasket has a stop ring or the flange face detail is arranged to provide the equivalent. Without such means of controlling the compression of the gasket, consideration must be given to the selection of gasket type, size and material that will prevent gross crushing of the gasket.

From the foregoing, it is apparent that the bolt stress can vary over a considerable range above the design stress value. The design stress values for bolting in Subsection C have been set at a conservative value to provide a factor against yielding. At elevated temperatures, the design stress values are governed by the creep rate and stress-rupture strength. Any higher bolt stress existing before creep occurs in operation will have already served its purpose of seating the gasket and holding the hydrostatic test pressure, all at atmospheric temperature, and is not needed at the design pressure and temperature.

Theoretically, the margin against flange yielding is not as great. The design values for flange materials may be as high as five-eighths or two-thirds of the yield strength. However, the highest stress in a flange is usually the bending stress in the hub or shell, and is more or less localized. It is too conservative to assume that local yielding is followed immediately by overall yielding of the entire flange. Even if a "plastic hinge" should develop, the ring portion of the flange takes up the portion of the load the hub and shell refuse to carry. Yielding is far more significant if it occurs first in the ring, but the limitation in the rules on the combined hub and ring stresses provides a safeguard. In this connection, it should be noted that a dual set of stresses is given for some of the materials in Table UHA-23, and that the lower values should be used in order to avoid yielding in the flanges.

Another very important item in bolting design is the question whether the necessary bolt stress is actually realized, and what special means of tightening, if any, must be employed. Most joints are tightened manually by ordinary wrenching, and it is advantageous to have designs that require no more than this. Some pitfalls must be avoided, however. The probable bolt stress developed manually, when using standard wrenches, is:

$$S = \frac{45{,}000}{\sqrt{d}}$$

where S is the bolt stress and d is the nominal diameter of the bolt. It can be seen that smaller bolts will have excessive stress unless judgment is exercised in pulling up on them. On the other hand, it will be impossible to develop the desired stress in very large bolts by ordinary hand wrenching. Impact wrenches may prove serviceable, but if not, resort may be had to such methods as preheating the bolt, or using hydraulically powered bolt tensioners. With some of these methods, control of the bolt stress is possible by means inherent in the procedure, especially if effective thread lubricants are employed, but in all cases the bolt stress can be regulated within reasonable tolerances by measuring the bolt elongation with suitable extensometer equipment. Ordinarily, simple wrenching without verification of the actual bolt stress meets all practical needs, and measured control of the stress is employed only when there is some special or important reason for doing so.

APPENDIX T
TEMPERATURE PROTECTION

(*a*) Any pressure vessel in a service where it can be damaged by overheating should be provided with means by which the metal temperature can be controlled within safe limits or a safe shut-down can be effected.

(*b*) It is recognized that it is impracticable to specify detailed requirements to cover the multiplicity of means to prevent the operation of pressure vessels at overtemperature. Any means which in principle will provide compliance with (*a*) will meet the intent of this Division of Section III.

APPENDIX U
ULTRASONIC EXAMINATION OF WELDS (UT)

UA-901 Scope

This Appendix describes procedures which shall be followed when ultrasonic examination of welds is specified in this Division of Section VIII. The pulse-echo method shall be used to satisfy the requirements of this Appendix.

UA-902 Application

The principal objective of procedures given herein is the detection, location, and evaluation of defects within the weld and heat affected zone. The welds shall be examined by the angle beam where possible. In the examination of weldments where geometry does not allow angle beam examination from both sides of the weld from a single surface or a combination of surfaces, both angle beam and straight beam methods shall be used.

UA-903 Basic Calibration Reflectors

Drilled holes shall be used as basic calibration reflectors to establish a primary reference response of the equipment and to construct a distance-amplitude correction curve. These holes shall be located either in the production material or in a basic calibration block of similar metallurgical structure and the same or an equivalent P-number grouping as the production material. For the purposes of this examination, P-numbers 1, 3, 4 and 5 materials are considered to be equivalent.

(*a*) *Basic Calibration Block.* If a basic calibration block is used, it shall have a thickness relative to the production material thickness as shown by Fig. UA-903. Where two or more thicknesses are involved, the calibration thickness shall be determined by the thickness of the production material to which the search unit is applied. If the contact surface of the production material has a radius of curvature of 10 in. or less, the curvature of the basic calibration block shall correspond to the radius of the production material within ± 10 percent.

(*b*) *Basic Calibration Hole.* The basic calibration hole as shown in Fig. UA-903 shall be drilled parallel to the contact surface of the basic calibration block or the production material. The location, depth, and diameter of this hole shall be as given in the table in Figure UA-903.

(*c*) *Other Calibration Reflectors.* In lieu of the above, other calibration reflectors are permitted, provided equivalent response is demonstrated.

UA-904 Surface Preparation

(*a*) *Contact Surfaces.* The finished contact surfaces shall be free from weld spatter and any roughness that would interfere with free movement of the search unit or impair the transmission of ultrasonic vibrations.

(*b*) *Weld Surfaces.* The finished weld surfaces shall be finished so that they cannot mask or be confused with reflections from defects. The weld surface shall

merge smoothly into the surfaces of the adjacent base materials.

(*c*) *Basic Material.* The area of the base material through which the sound will travel in angle beam examination shall be completely scanned with a straight beam search unit to detect reflectors which might affect the interpretation of angle beam results. This is not a basis for rejection of the base material.

UA-905 Angle Beam Method

(*a*) *Calibration of Equipment*

(*1*) *Frequency.* The nominal frequency shall be 2.25 MHz unless variables, such as production material grain structure, necessitate the use of other frequencies in order to assure adequate penetration.

(*2*) *Beam Angle.* The beam angle in the production material shall be in the range of 40 deg to 75 deg, inclusive, with respect to the perpendicular to the contact surface.

(*3*) *Distance-Amplitude Correction.* Compensation for the distance traversed by the ultrasonic beam as it passes through the material shall be provided by the use of curves, as shown by Figure UA-905.1, or electronically.

(a) Determination of Curves. Distance-amplitude correction curves shall be constructed by utilizing the responses from the basic calibration hole described in UA-903(b). The first point on the curve is obtained by placing the search unit as near as possible but not less than 3/8 node or 2 in., whichever is less, from the calibration hole and positioning for maximum response. The gain control then is set so that this response is 75 percent of full CRT screen. *This is the primary reference response.* Without changing the gain, the search unit shall be placed similarly at other nodal positions covering the contemplated examination distance range and the corresponding responses marked on the CRT screen. These points shall be joined by a smooth line and its length shall be such as to cover the examination range. See Fig. UA-905.1.

(b) Electronic Distance-Amplitude Correction. If the instrument is equipped with an electronic distance-amplitude correction device, the primary reference responses shall be equalized at 75 percent of full CRT screen height over the distance range to be employed in the examination.

(*4*) *Transfer Mechanisms.* Transfer mechanisms shall be used to correlate the responses from the basic calibration block and from the production material. Transfer shall be accomplished by noting the difference between responses received from the same reference reflector in the basic calibration block and the production material and correcting for this difference.

These reference reflectors may be "V" notches, an angle beam search unit acting as a reflector, or any other reflector which will aid in accomplishing the transfer.

The transfer mechanisms shall be used once per 10 feet of weld per plate and, in addition, it shall be performed at least twice for each type of welded joint.

(*b*) *Examination Procedure*

(*1*) *Coverage.* Where possible, butt welds shall be examined from both sides of the weld (usually from one surface only).

(*2*) *Sensitivity Level.* The reference level sensitivity for monitoring discontinuities is the primary reference response corrected for distance by the distance-amplitude curve or electronically, modified by the transfer mechanism if used.

When possible, scanning shall be performed at a minimum gain setting of 2 times the reference level sensitivity.

(*3*) *Reference Level.* The reference level for monitoring discontinuities is the primary reference response corrected for distance by the distance-amplitude curve or electronically, modified by the transfer mechanism.

(*4*) *Detection of Defects Parallel to the Weld*

(a) Scanning Motion. The search unit shall be placed on the contact surface with the beam aimed about 90 deg to the weld and manipulated laterally and longitudinally so that the ultrasonic beam passes through all of the weld metal in two different approaches of the beam on the reflector.

(b) Two Search Unit Technique. Techniques employing two search units as shown by Fig. UA-905.2 may be used to detect lack of penetration in double-welded butt joints.

(*5*) *Detection of Defects Transverse to the Weld.* Two search units shall be placed on the contact surfaces adjacent to the weld, one on each side, making an angle of 45 deg or less with the axis of the weld as shown by Fig. UA-905.3. Alternatively, if the weld surface has been made smooth, one search unit may be placed on the centerline of the weld with the beam directed along the weld—directed to scan the entire depth and width of the weld.

UA-906 Straight Beam Method

(*a*) *Calibration of Equipment*

(*1*) *Frequency.* The nominal frequency shall be 2.25MHz unless variables, such as production

APPENDIX T
TEMPERATURE PROTECTION

(*a*) Any pressure vessel in a service where it can be damaged by overheating should be provided with means by which the metal temperature can be controlled within safe limits or a safe shut-down can be effected.

(*b*) It is recognized that it is impracticable to specify detailed requirements to cover the multiplicity of means to prevent the operation of pressure vessels at overtemperature. Any means which in principle will provide compliance with (*a*) will meet the intent of this Division of Section III.

APPENDIX U
ULTRASONIC EXAMINATION OF WELDS (UT)

UA-901 Scope

This Appendix describes procedures which shall be followed when ultrasonic examination of welds is specified in this Division of Section VIII. The pulse-echo method shall be used to satisfy the requirements of this Appendix.

UA-902 Application

The principal objective of procedures given herein is the detection, location, and evaluation of defects within the weld and heat affected zone. The welds shall be examined by the angle beam where possible. In the examination of weldments where geometry does not allow angle beam examination from both sides of the weld from a single surface or a combination of surfaces, both angle beam and straight beam methods shall be used.

UA-903 Basic Calibration Reflectors

Drilled holes shall be used as basic calibration reflectors to establish a primary reference response of the equipment and to construct a distance-amplitude correction curve. These holes shall be located either in the production material or in a basic calibration block of similar metallurgical structure and the same or an equivalent P-number grouping as the production material. For the purposes of this examination, P-numbers 1, 3, 4 and 5 materials are considered to be equivalent.

(*a*) *Basic Calibration Block.* If a basic calibration block is used, it shall have a thickness relative to the production material thickness as shown by Fig. UA-903. Where two or more thicknesses are involved, the calibration thickness shall be determined by the thickness of the production material to which the search unit is applied. If the contact surface of the production material has a radius of curvature of 10 in. or less, the curvature of the basic calibration block shall correspond to the radius of the production material within ± 10 percent.

(*b*) *Basic Calibration Hole.* The basic calibration hole as shown in Fig. UA-903 shall be drilled parallel to the contact surface of the basic calibration block or the production material. The location, depth, and diameter of this hole shall be as given in the table in Figure UA-903.

(*c*) *Other Calibration Reflectors.* In lieu of the above, other calibration reflectors are permitted, provided equivalent response is demonstrated.

UA-904 Surface Preparation

(*a*) *Contact Surfaces.* The finished contact surfaces shall be free from weld spatter and any roughness that would interfere with free movement of the search unit or impair the transmission of ultrasonic vibrations.

(*b*) *Weld Surfaces.* The finished weld surfaces shall be finished so that they cannot mask or be confused with reflections from defects. The weld surface shall

merge smoothly into the surfaces of the adjacent base materials.

(*c*) *Basic Material.* The area of the base material through which the sound will travel in angle beam examination shall be completely scanned with a straight beam search unit to detect reflectors which might affect the interpretation of angle beam results. This is not a basis for rejection of the base material.

UA-905 Angle Beam Method

(*a*) *Callbration of Equipment*

(*1*) *Frequency.* The nominal frequency shall be 2.25 MHz unless variables, such as production material grain structure, necessitate the use of other frequencies in order to assure adequate penetration.

(*2*) *Beam Angle.* The beam angle in the production material shall be in the range of 40 deg to 75 deg, inclusive, with respect to the perpendicular to the contact surface.

(*3*) *Distance-Amplitude Correction.* Compensation for the distance traversed by the ultrasonic beam as it passes through the material shall be provided by the use of curves, as shown by Figure UA-905.1, or electronically.

(a) Determination of Curves. Distance-amplitude correction curves shall be constructed by utilizing the responses from the basic calibration hole described in UA-903(b). The first point on the curve is obtained by placing the search unit as near as possible but not less than $^3/_8$ node or 2 in., whichever is less, from the calibration hole and positioning for maximum response. The gain control then is set so that this response is 75 percent of full CRT screen. *This is the primary reference response.* Without changing the gain, the search unit shall be placed similarly at other nodal positions covering the contemplated examination distance range and the corresponding responses marked on the CRT screen. These points shall be joined by a smooth line and its length shall be such as to cover the examination range. See Fig. UA-905.1.

(b) Electronic Distance-Amplitude Correction. If the instrument is equipped with an electronic distance-amplitude correction device, the primary reference responses shall be equalized at 75 percent of full CRT screen height over the distance range to be employed in the examination.

(*4*) *Transfer Mechanisms.* Transfer mechanisms shall be used to correlate the responses from the basic calibration block and from the production material. Transfer shall be accomplished by noting the difference between responses received from the same reference reflector in the basic calibration block and the production material and correcting for this difference.

These reference reflectors may be "V" notches, an angle beam search unit acting as a reflector, or any other reflector which will aid in accomplishing the transfer.

The transfer mechanisms shall be used once per 10 feet of weld per plate and, in addition, it shall be performed at least twice for each type of welded joint.

(*b*) *Examination Procedure*

(*1*) *Coverage.* Where possible, butt welds shall be examined from both sides of the weld (usually from one surface only).

(*2*) *Sensitivity Level.* The reference level sensitivity for monitoring discontinuities is the primary reference response corrected for distance by the distance-amplitude curve or electronically, modified by the transfer mechanism if used.

When possible, scanning shall be performed at a minimum gain setting of 2 times the reference level sensitivity.

(*3*) *Reference Level.* The reference level for monitoring discontinuities is the primary reference response corrected for distance by the distance-amplitude curve or electronically, modified by the transfer mechanism.

(*4*) *Detection of Defects Parallel to the Weld*

(a) Scanning Motion. The search unit shall be placed on the contact surface with the beam aimed about 90 deg to the weld and manipulated laterally and longitudinally so that the ultrasonic beam passes through all of the weld metal in two different approaches of the beam on the reflector.

(b) Two Search Unit Technique. Techniques employing two search units as shown by Fig. UA-905.2 may be used to detect lack of penetration in double-welded butt joints.

(*5*) *Detection of Defects Transverse to the Weld.* Two search units shall be placed on the contact surfaces adjacent to the weld, one on each side, making an angle of 45 deg or less with the axis of the weld as shown by Fig. UA-905.3. Alternatively, if the weld surface has been made smooth, one search unit may be placed on the centerline of the weld with the beam directed along the weld—directed to scan the entire depth and width of the weld.

UA-906 Straight Beam Method

(*a*) *Calibration of Equipment*

(*1*) *Frequency.* The nominal frequency shall be 2.25MHz unless variables, such as production

material grain structure, necessitate the use of other frequencies in order to assure adequate penetration.

(2) *Distance-Amplitude Correction.* A distance amplitude correction curve need not be constructed when the thickness of material is less than 2 in. For greater thicknesses, using the proper basic calibration block (see Fig. UA-903, position the search unit for maximum response from the basic calibration hole at $^1/_4$ T (see Fig. UA-906.1). Adjust the signal amplitude to 50 percent of full CRT screen. *This is the primary reference response.* Without changing the gain control, position the search unit for maximum response from the basic calibration hole at $^3/_4$ T and mark its amplitude on the CRT screen. Join the two points with a straight line and extend its length to cover the test range (see Fig. UA-906.2).

(3) *Electronic Distance-Amplitude Correction Device.* The primary reference response shall be equalized over the distance range to be employed in the examination.

(4) *Reference Level.* The reference level for monitoring discontinuities is the primary reference response corrected for distance-amplitude curve or electronically. (See UA-906(a)(2) or (3)).

(b) *Examination Procedure*

(1) *Scanning Motion.* The weld shall be examined by moving the search unit progressively along and across a sufficient contact area so as to scan the entire weld.

(2) *Sensitivity Level.* When possible, scanning shall be performed at a minimum gain setting of 2 times the primary reference level. Evaluation of discontinuities shall be carried out with the gain control set at the reference level.

(3) *Monitoring of Procedures.* Penetration shall be verified (1) by obtaining a reflection from an opposite parallel surface, or (2) by obtaining the back reflection on similar material while using approximately the same length of sound travel.

UA-907 Evaluation of Indications

All indications which produce a response greater than 20 percent of the reference level shall be investigated to the extent that the operator can determine the shape, identity and location of all such reflectors and evaluate them in terms of the acceptance-rejection standards of UA-908.

UA-908 Acceptance-Rejection Standards

Linear type discontinuities are unacceptable if the amplitude exceeds the reference level and discontinuities have lengths which exceed the following:

$^1/_4$″ for t up to $^3/_4$″
$^1/_3\,t$ for t from $^3/_4$″ to $2^1/_4$″
$^3/_4$″ for t over $2^1/_4$″

where t is the thickness of the weld being examined. If the weld joints two members having different thicknesses at the weld, t is the thinner of these two thicknesses. Where discontinuities are interpreted to be cracks, lack of fusion, and incomplete penetration, they are unacceptable regardless of length.

UA-909 Repairs

Repairs shall be reexamined by the same procedures used for detection of the defect(s). Acceptability of repairs shall be determined by the same acceptance-rejection standards.

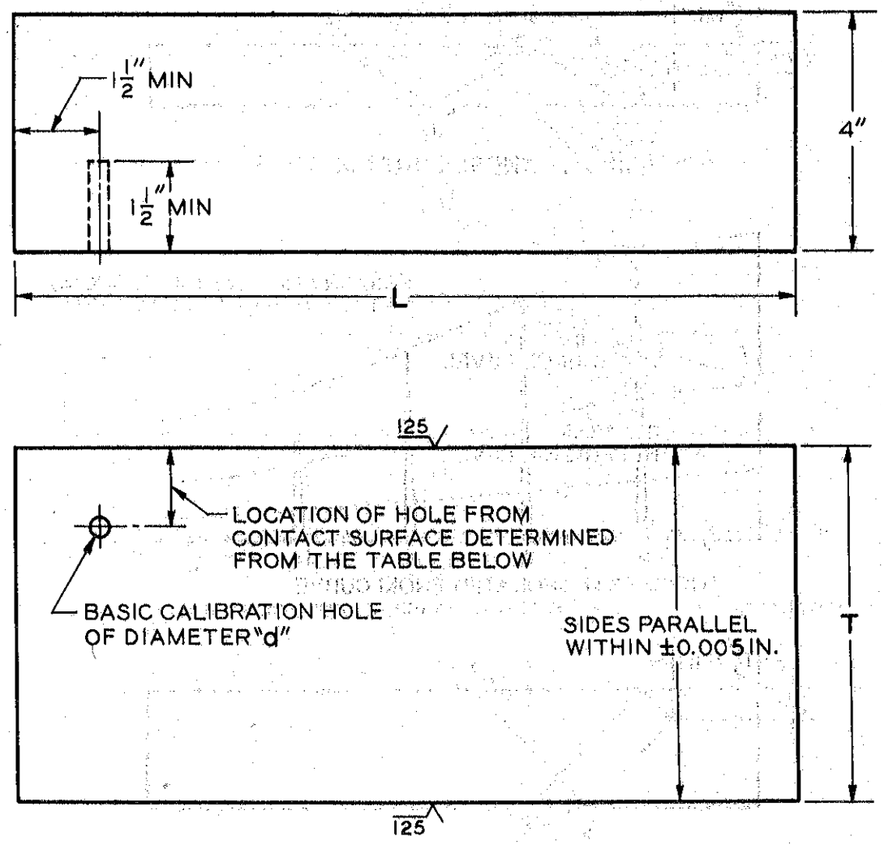
UA-910 Report of Examination

The manufacturer shall prepare a report of the ultrasonic examination and a copy of this report shall be retained until the data report is signed. The report shall contain the following:

(a) All procedures and equipment shall be identified sufficiently to permit duplication of the examination(s) at a later date. This shall include initial calibration data for the equipment and any significant changes in subsequent rechecks.

(b) A marked-up drawing or sketch indicating the weld(s) examined, the item or piece number, and identification of the operator who carried out each inspection or part thereof.

(c) A record of repaired areas shall be noted as well as the results of the reexamination of the repaired areas. The manufacturer shall maintain also a record of all reflections from uncorrected areas having responses that exceed 50 percent of the reference level. This record shall locate each area, the response level, the dimensions, the depth below the surface, and the classification.

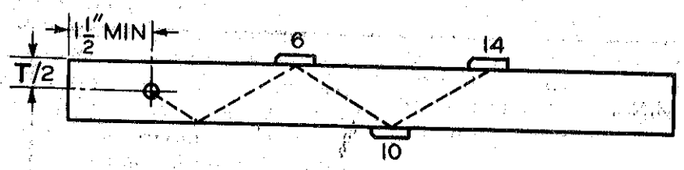


L = Length of block determined by the angle of search unit and the node used for examination of production materials.
T = Thickness of basic calibration block (see Table below).
D = Depth of basic calibration hole (see Figure).
d = Diameter of basic calibration hole (see Table below).
t = Nominal production material thickness.

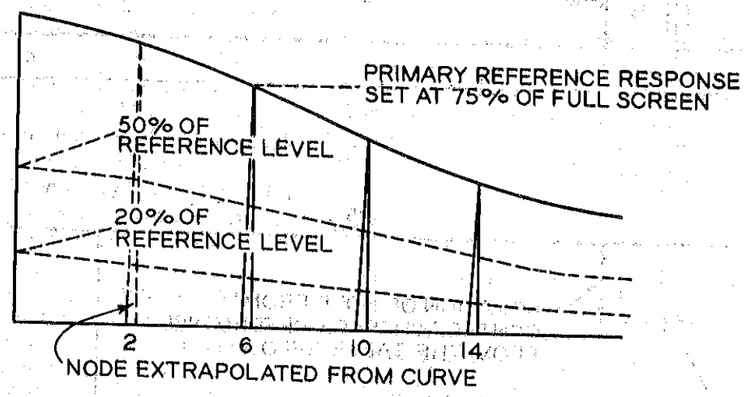
Material Production Material Thickness (t), in.	Basic Calibration Basic Thickness (T)	Hole Location	Hole Diameter (d), in.
Up to 1 incl.	$^3/_4$ in. or t	$^1/_2$ T	$^3/_{32}$
Over 1 thru 2	$1^1/_2$ in. or t	$^1/_4$ T	$^1/_8$
Over 2 thru 4	3 in. or t	$^1/_4$ T	$^3/_{16}$
Over 4 thru 6	5 in. or t	$^1/_4$ T	$^1/_4$
Over 6 thru 8	7 in. or t	$^1/_4$ T	$^5/_{16}$
Over 8 thru 10	9 in or t	$^1/_4$ T	$^3/_8$
Over 10	t	$^1/_4$ T	See Note 1

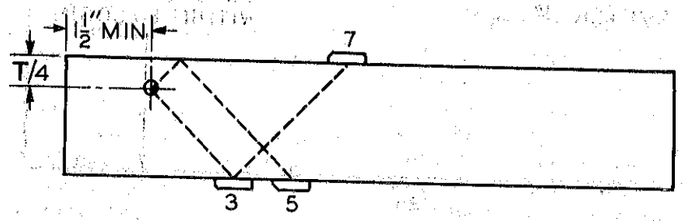
[1] For each increase in thickness of 2 in. or fraction thereof the hole diameter shall increase $^1/_{16}$ in.

FIG. UA-903 BASIC CALIBRATION BLOCK



FOR THICKNESS 1 INCH OR LESS





FOR THICKNESS OVER 1 INCH

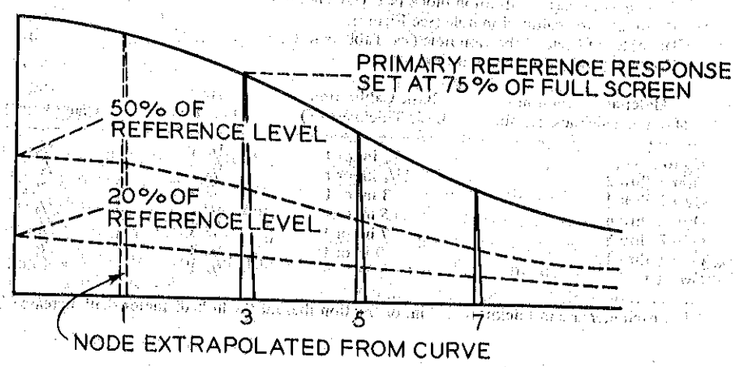
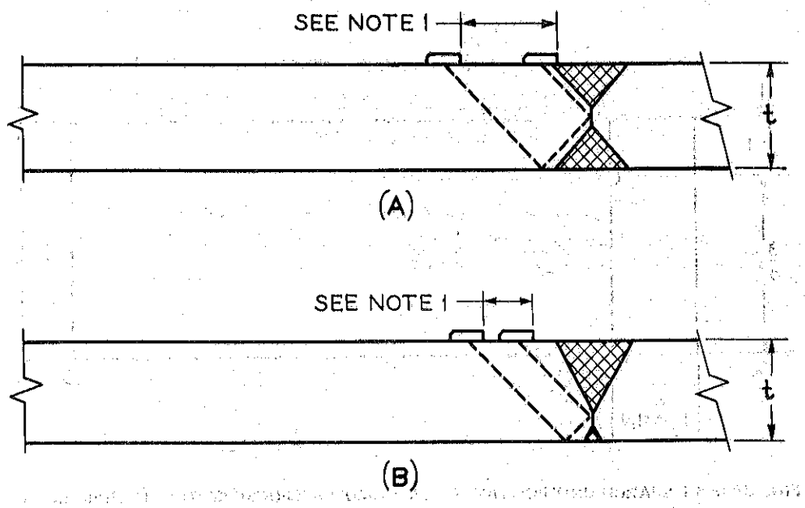


FIG. UA-905.1 TYPICAL DISTANCE AMPLITUDE CORRECTION CURVE (Angle Beam Method)
(Distance in eighths of a node. For example, 14 is 14/8 node)



[1] The Search Units position will vary because the Search Units must be located in relationship to the sound beam travel.

FIG. UA-905.2 TYPICAL DOUBLE SEARCH UNIT TECHNIQUE FOR DETECTING LACK OF PENETRATION IN DOUBLE-WELDED JOINTS

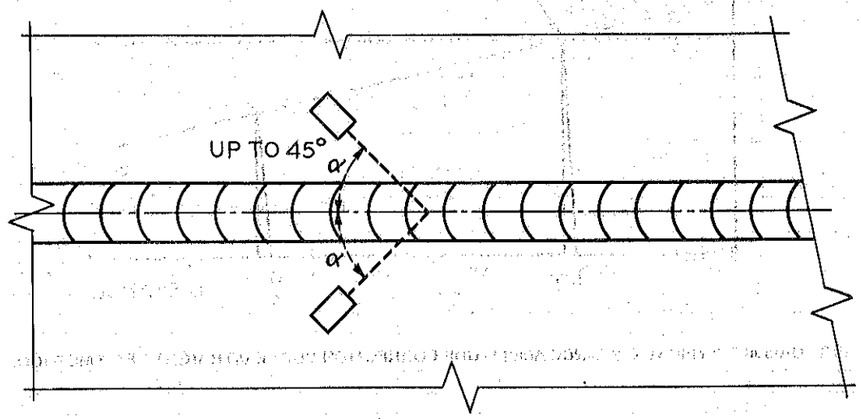


FIG. UA-905.3 TYPICAL TWO SEARCH UNIT TECHNIQUE FOR DETECTING TRANSVERSE DISCONTINUITIES

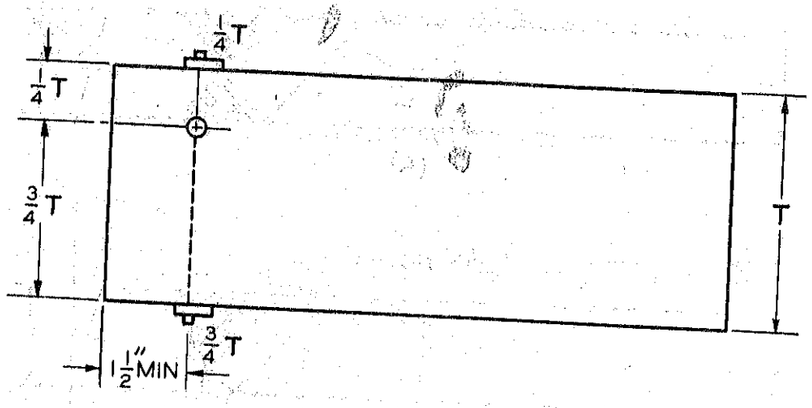


FIG. UA-906.1 SEARCH UNIT POSITION FOR MAXIMUM RESPONSE (STRAIGHT BEAM METHOD)

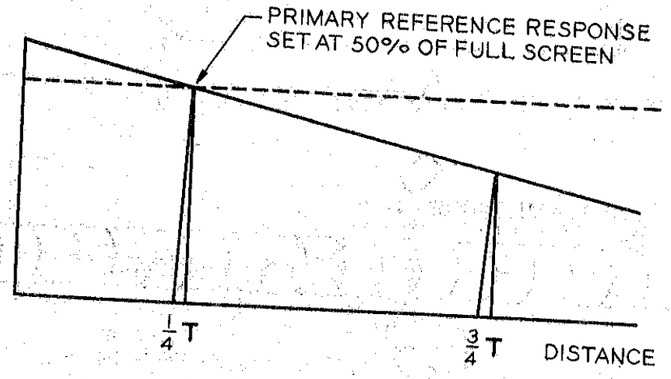


FIG. UA-906.2 TYPICAL DISTANCE AMPLITUDE CORRECTION CURVE (STRAIGHT BEAM METHOD)

FORM U-1 MANUFACTURERS' DATA REPORT FOR PRESSURE VESSELS

As required by the Provisions of the ASME Code Rules, Section VIII, Division 1

1. Manufactured by _____ (Name and address of Manufacturer)

2. Manufactured for _____ (Name and address of Purchaser)

3. Type _____ (Horiz. or Vert.) Kind _____ (Tank, Jacketed, Heat Exch.) Vessel No. _____ (Mfrs. Serial) (_____) (State & State No.) Natl. Bd. No. _____ Yr. Built _____

Items 4–9 incl. to be completed for single wall vessels (such as air tanks), jackets of jacketed vessels, or shells of heat exchanges.

4. SHELL: Material _____ (Kind and Spec. No.) T.S. _____ (Fig. or F.B. & Spec. Min. T.S.) Nominal Thickness ___ In. Corrosion Allowance ___ In. Diam. ___ Ft. ___ In. Length ___ Ft. ___ In.

5. SEAMS: Long _____ (Welded, Dbl., Single, Lap, Butt) H.T. _____ (Yes or No)[1] R.T. _____ (Spot or Complete) Sectioned _____ (Yes or No) Efficiency ___ %

Girth _____ H.T. _____ R.T. _____ Sectioned _____ No. of Courses ___

If riveted describe seams fully on reverse side of form.

6. HEADS (a) Material _____ T.S. _____ (b) Material _____ T.S. _____

Location (Top, bottom, ends)	Thickness	Crown Radius	Knuckle Radius	Elliptical Ratio	Conical Apex Angle	Hemispherical Radius	Flat Diameter	Side to Pressure (Convex or Concave)
(a)								
(b)								

If removable, bolts used _____ (Material, Spec. No., T.S., Size, Number) Other fastening _____ (Describe or Attach Sketch)

7. STAYBOLTS: _____ (Material) If hollow _____ (Size of Hole) Attachment _____ (Threaded, Welded) Pitch _____ (Horiz.) X _____ (Vert.) Diam. _____ (Nominal)

8. JACKET CLOSURE: _____ (Describe as ogee & weld, bar, etc. If bar, give dimensions, if bolted, describe or sketch)

9. Constructed for max. allowable working press[2] _____ psi at max. temp. _____ °F. Min. Temp. (when less than −20°) _____ °F. Hydrostatic / Pneumatic or / Combination } Test Press _____ psi.

Items 10 and 11 to be completed for tube sections.

10. TUBE SHEETS: Stationary, Material _____ (Kind & Spec. No.) Diam. _____ (Subject to Pressure) In. Thickness ___ In. Attachment _____ (Welded, Bolted)

Floating. Material _____ (Kind & Spec. No.) Diam. _____ In. Thickness ___ In. Attachment _____

11. TUBES: Material _____ (Kind & Spec. No.) O.D. _____ In. Thickness _____ Inches or Gage Number _____ Type _____ (Straight or U)

Items 12–15 incl. to be completed for inner chambers of jacketed vessels, or channels of heat exchangers.

12. SHELL Material _____ (Kind and Spec. No.) T.S. _____ (Fig. or F.B. & Spec. Min. T.S.) Nominal Thickness ___ In. Corrosion Allowance ___ In. Diam. ___ Ft. ___ In. Length ___ Ft. ___ In.

13. SEAMS: Long _____ (Welded, Dbl., Single, Lap, Butt) H.T. _____ (Yes or No) R.T. _____ (Spot or Complete) Sectioned _____ (Yes or No) Efficiency _____ %

Girth _____ H.T. _____ R.T. _____ Sectioned _____ No. of courses _____

If riveted describe seams fully on reverse side of form.

14. HEADS (a) Material _____ T.S. _____ (b) Material _____ T.S. _____ (c) Material _____ T.S. _____

Location	Thickness	Crown Radius	Knuckle Radius	Elliptical Ratio	Conical Apex Angle	Hemispherical Radius	Flat Diameter	Side to Pressure (Convex or Concave)
(a) Top, bottom, ends								
(b) Channel								
(c) Floating								

If removable, bolts used (a) _____ (b) _____ (c) _____ (Material, Spec. No., T.S., Size, Number) Other fastening _____ (Describe or Attach Sketch)

15. Constructed for max. allowable working press[2] _____ psi at max. temp. _____ °F. Min. temp. (when less than −20°) _____ °F. Hydrostatic / Pneumatic or / Combination } Test Press _____ psi.

Items below to be completed for all vessels where applicable.

16. SAFETY VALVE OUTLETS: Number _____ Size _____ Location _____

17. NOZZLES

Purpose (Inlet, Outlet, Drain)	Number	Diam. or Size	Type	Material	Thickness	Reinforcement Material	How Attached

[1] If postweld heat-treated. [2] List under remarks other internal or external pressure with coincident temperature when applicable.

(Over)

FORM U-1 (back)

18. INSPECTION OPENINGS: Manholes, No. ____ Size ____ Location ____; Handholes, No. ____ Size ____ Location ____; Threaded, No. ____ Size ____ Location ____

19. SUPPORTS: Skirt ____ (Yes or No) Lugs ____ (Number) Legs ____ (Number) Other ____ (Describe) Attached ____ (Where & How)

20. REMARKS: ____

(Brief description of purpose of the vessel, as Air Tank, After Cooler, Jacketed Cooker, etc. State contents of each part.)

We certify that the statements made in this report are correct and that all details of design, material, construction, and workmanship of this vessel conform to the ASME Code for Pressure Vessels, Section VIII, Division 1.

Date ____ 19 ____ Signed ____ (Manufacturer) By ____

Certificate of Authorization No. ____ Expires ____

CERTIFICATE OF SHOP INSPECTION

VESSEL MADE BY ____ at ____

I, the undersigned, holding a valid commission issued by the National Board of Boiler and Pressure Vessel Inspectors and/or the State or Province ____ and employed by ____ of ____ have inspected the pressure vessel described in this manufacturer's data report on ____ 19 ___, and state that to the best of my knowledge and belief, the manufacturer has constructed this pressure vessel in accordance with the applicable sections of the ASME Boiler and Pressure Vessel Code.

By signing this certificate neither the Inspector nor his employer makes any warranty, expressed or implied, concerning the pressure vessel described in this manufacturer's data report. Furthermore, neither the Inspector nor his employer shall be liable in any manner for any personal injury or property damage or a loss of any kind arising from or connected with this inspection.

Date ____ 19 ____

Inspectors Signature ____ Commissions ____ Nat'l Board, State, Province and No.

CERTIFICATE OF FIELD ASSEMBLY INSPECTION

I, the undersigned, holding a valid commission issued by the National Board of Boiler and Pressure Vessel Inspectors and/or the State or Province ____ and employed by ____ of ____ have compared the statements in this manufacturer's data report with the described pressure vessel and state that parts referred to as data items ____ not included in the certificate of shop inspection have been inspected by me and that to the best of my knowledge and belief the manufacturer has constructed and assembled this pressure vessel in accordance with the applicable sections of the ASME Boiler and Pressure Vessel Code. The described vessel was inspected and subjected to a hydrostatic test of ____ psi.

By signing this certificate neither the Inspector nor his employer makes any warranty, expressed or implied, concerning the pressure vessel described in this manufacturer's data report. Furthermore, neither the Inspector nor his employer shall be liable in any manner for any personal injury or property damage or a loss of any kind arising from or connected with this inspection.

Date ____ 19 ____

Inspector's Signature ____ Commissions ____ Nat'l Board, State, Province and No.

This Form is obtainable from the ASME Order Dept., 345 E. 47th St., New York, N.Y. 10017

FORM U-1A MANUFACTURERS' DATA REPORT FOR PRESSURE VESSELS
Alternate Form for Single Chamber Completely Shop-Fabricated Vessels Only
As Required by the Provisions of the ASME Code Rules, Section VIII, Division 1

1. Manufactured by ____ (Name and address of Manufacturer)

2. Manufactured for ____ (Name and address of Purchaser)

3. Type ____ (Horiz. or Vert.) Vessel No. ____ (Mfrs. Serial) (____) (State & State No.) Natl. Bd. No. ____ Yr. Built ____

4. SHELL: Matl. ____ (Kind and Spec. No.) T.S. ____ (Plg. or P.B. & Spec. Min. T.S.) Nom. Thk. ____ In. Corr. Allow ____ In. Diam. ____ Ft. ____ In. Length ____ Ft. ____ In.

5. SEAMS: Long ____ (Welded, Dbl., Single, Lap, Butt) H.T. ____ (Yes or No)[1] R.T. ____ (Spot or Complete) Sectioned ____ (Yes or No) Efficiency ____ %

Girth ____ H.T. ____ R.T. ____ Sectioned ____ No. of Courses ____

If riveted or brazed describe seams fully under remarks.

6. HEADS: (a) Material ____ T.S. ____ (b) Material ____ T.S. ____

Location (Top, bottom, ends)	Thickness	Crown Radius	Knuckle Radius	Elliptical Ratio	Conical Apex Angle	Hemispherical Radius	Flat Diameter	Side to Pressure (Convex or Concave)
(a)								
(b)								

If removable, bolts used ____ (Material, Spec. No., T.S., Size, Number) Other fastening ____ (Describe or Attach Sketch)

7. Constructed for max. allowable working press.[2] ____ psi at max. temp. ____ °F. Min. temp. (when less than –20°) ____ °F. Hydrostatic / Pneumatic or / Combination } Test Press ____ psi.

8. SAFETY OR RELIEF VALVE OUTLETS: Number ____ Size ____ Location ____

9. NOZZLES:

Purpose (Inlet, Outlet, Drain)	Number	Diam. or Size	Type	Material	Thickness	Reinforcement Material	How Attached

10. INSPECTION OPENINGS: Manholes, No. ____ Size ____ Location ____; Handholes, No. ____ Size ____ Location ____; Threaded, No. ____ Size ____ Location ____

11. SUPPORTS: Skirt ____ (Yes or No) Lugs ____ (Number) Legs ____ (Number) Other ____ (Describe) Attached ____ (Where & How)

12. REMARKS: ____

(Brief description of purpose of the vessel as Air Tank, Water Tank, L.P.G., Etc.—State Contents.
[1] If postweld heat-treated.
[2] List other internal or external pressures with coincident temperature when applicable.

We certify that the statements made in this report are correct and that all details of design, material, construction, and workmanship of this vessel conform to the ASME Code for Pressure Vessels, Section VIII, Division 1.

Date ____ 19 ____ Signed ____ (Manufacturer) By ____

Certificate of Authorization No. ____ Expires ____

CERTIFICATE OF SHOP INSPECTION

VESSEL MADE BY ____ at ____

I, the undersigned, holding a valid commission issued by the National Board of Boiler and Pressure Vessel Inspectors and/or the State or Province ____ and employed by ____ of ____ have inspected the pressure vessel described in this manufacturer's data report on ____ 19 ___, and state that to the best of my knowledge and belief, the manufacturer has constructed this pressure vessel in accordance with the applicable sections of the ASME Boiler and Pressure Vessel Code.

By signing this certificate neither the Inspector nor his employer makes any warranty, expressed or implied, concerning the pressure vessel described in this manufacturer's data report. Furthermore, neither the Inspector nor his employer shall be liable in any manner for any personal injury or property damage or a loss of any kind arising from or connected with this inspection.

Date ____ 19 ____

Inspector's Signature ____ Commissions ____ Nat'l Board, State, Province and No.

This Form is obtainable from the ASME Order Dept., 345 E. 47th St., New York, N.Y. 10017

FORM U-2 MANUFACTURERS' PARTIAL DATA REPORT
A Part of a Pressure Vessel Fabricated by One Manufacturer for Another Manufacturer
As Required by the Provisions of the ASME Code Rules, Section VIII, Division 1

1. (a) Manufactured by _____ (Name and address of manufacturer of part)

(b) Manufactured for _____ (Name and address of manufacturer of boiler or vessel)

2. Identification—Manufacturer's Serial No. of Part _____

(a) Constructed According to Blueprint No. _____ B.P. Prepared by _____

(b) Description of Part Inspected _____

3. Remarks _____

We certify that the statements made in this report are correct and that all details of design, material, construction, and workmanship of this vessel conform to the ASME Code for Pressure Vessels, Section VIII, Division 1.

Date _____ 19____ Signed _____ (Manufacturer) By _____ (Representative)

Certificate of Authorization No. _____ Expires _____ 19____

CERTIFICATE OF SHOP INSPECTION

I, the undersigned, holding a valid commission issued by the National Board of Boiler and Pressure Vessel Inspectors and/or the State or Province of _____ and employed by _____ of _____ have inspected the part of a pressure vessel described in this manufacturer's partial data report on _____ 19____, and state that to the best of my knowledge and belief, the manufacturer has constructed this part in accordance with the applicable sections of the ASME Boiler and Pressure Vessel Code.

By signing this certificate, neither the Inspector nor his employer makes any warranty, expressed or implied, concerning the part described in this manufacturer's partial data report. Furthermore, neither the Inspector nor his employer shall be liable in any manner for any personal injury or property damage or a loss of any kind arising from or connected with this inspection.

Date _____ 19____

_____ Inspector's Signature Commissions _____ Nat'l Board, State, Province, and No.

FORM U-2 (back)

Items 4–9 incl. to be completed for single wall vessels (such as air tanks), jackets of jacketed vessels, or shells of heat exchangers.

4. SHELL: Material _____ (Kind and Spec. No.) T.S. _____ (Fig. or F.B. & Spec. Min. T.S.) Nominal Thickness ____ In. Corrosion Allowance ____ In. Diam. ____ Ft. ____ In. Length ____ Ft. ____ In.

5. SEAMS: Long _____ (Welded, Dbl., Single, Lap, Butt) H.T. _____ (Yes or No)[1] R.T. _____ (Spot or Complete) Sectioned _____ (Yes or No) Efficiency _____ %

Girth _____ H.T. _____ R.T. _____ Sectioned _____ No. of Courses _____

If riveted describe seams fully on reverse side of form.

6. HEADS: (a) Material _____ T.S. _____ (b) Material _____ T.S. _____

Location (Top, bottom, ends)	Thickness	Crown Radius	Knuckle Radius	Elliptical Ratio	Conical Apex angle	Hemispherical Radius	Flat Diameter	Side to Pressure (Convex or Concave)
(a)								
(b)								

If removable, bolts used _____ (Material, Spec. No. T.S., Size, Number) Other fastening _____ (Describe or Attach Sketch)

7. STAYBOLTS: _____ (Material) If hollow _____ (Size of Hole) Attachment _____ (Threaded, Welded) Pitch _____ (Horiz.) X _____ (Vert.) Diam. _____ (Nominal)

8. JACKET CLOSURE: _____ (Describe as ogee & weld, bar, etc. If bar, give dimensions, If bolted, describe or sketch)

9. Constructed for max. allowable working press,[2] _____ psi at max. temp. _____ °F. Min. temp. (when less than −20°) _____ °F.

Items 10 and 11 to be completed for tube sections.

10. TUBE SHEETS: Stationary. Material _____ (Kind & Spec. No.) Diam. _____ (Subject to Pressure) In. Thickness ____ In. Attachment _____ (Welded, Bolted)

Floating. Material _____ (Kind & Spec. No.) Diam. _____ In. Thickness ____ In. Attachment _____

11. TUBES: Material _____ (Kind & Spec. No.) O.D. _____ In. Thickness _____ Inches or Gage Number _____ Type _____ (Straight or U)

Items 12–15 incl. to be completed for inner chambers of jacketed vessels, or channels of heat exchangers.

12. SHELL: Material _____ (Kind and Spec. No.) T.S. _____ (Fig. or F.B. & Spec. Min. T.S.) Nominal Thickness ____ In. Corrosion Allowance ____ In. Diam. ____ Ft. ____ In. Length ____ Ft. ____ In.

13. SEAMS: Long _____ (Welded, Dbl., Single, Lap, Butt) H.T. _____ (Yes or No)[1] R.T. _____ (Spot or Complete) Sectioned _____ (Yes or No) Efficiency _____ %

Girth _____ H.T. _____ R.T. _____ Sectioned _____ No. of courses _____

If riveted describe seams fully on reverse side of form.

14. HEADS: (a) Material _____ T.S. _____ (b) Material _____ T.S. _____ (c) Material _____ T.S. _____

Location	Thickness	Crown Radius	Knuckle Radius	Elliptical Ratio	Conical Apex angle	Hemispherical Radius	Flat Diameter	Side to Pressure (Convex or Concave)
(a) Top, bottom, ends								
(b) Channel								
(c) Floating								

If removable, bolts used (a) _____ (Material, Spec. No., T.S., Size, Number) (b) _____ (c) _____ Other fastening _____ (Describe, or Attach Sketch)

15. Constructed for max. allowable working press [2] _____ psi at max. temp. _____ °F. Min. temp. (when less than −20°) _____ °F.

Items below to be completed for all vessels where applicable.

16. SAFETY VALVE OUTLETS: Number _____ Size _____ Location _____

17. NOZZLES:

Purpose (Inlet, Outlet, Drain)	Number	Diam. or Size	Type	Material	Thickness	Reinforcement Material	How Attached

18. INSPECTION OPENINGS: Manholes, No. _____ Size _____ Location _____
Handholes, No. _____ Size _____ Location _____
Threaded, No. _____ Size _____ Location _____

19. SUPPORTS: Skirt _____ (Yes or No) Lugs _____ (Number) Legs _____ (Number) Other _____ (Describe) Attached _____ (Where & How)

[1] If postweld heat-treated.
[2] List under item 3 other internal or external pressures with coincident temperature when applicable.

This Form is obtainable from the ASME Order Dept., 345 E. 47th St., New York, N.Y. 10017

FORM U-3 MANUFACTURERS' CERTIFICATE OF COMPLIANCE COVERING PRESSURE VESSELS TO BE STAMPED WITH THE UM SYMBOL

[See Par. U-1(h)]

1. Manufactured by _____ (Name and address of Manufacturer)

2. Manufactured for _____ (Name and address of Purchaser)

3. Type _____ (Horizontal or Vertical) Pressure Vessel No. _____ (Mfrs. Serial No.) (State and State No.) Year built _____

4. Do the chemical and mechanical properties of all materials meet the requirements of the Code? _____

5. Shell or Drums: No. ____ Diameter ____ Ft. _____ (Or Width) In. Length over-all _____ Ft. _____ In. Height _____ Ft. _____ In.

6. Markings on shell plates _____ (Fig. or F.B. & Spec. Min. T.S.) Rivets, stays, and braces _____ (Iron or Steel)

7. Shell Plates: (Outer) _____ (Thickness) In. Butt straps _____ (thickness) In. Styles of seams: Longitudinal _____ (Riveted, Forge Welded, Brazed, or Welded—Type of Joint) Girth _____

8. Diameter of rivet holes _____ In. Pitch of rivets ____ × ____ × ____ Efficiency of joint _____ %

9. Girth Joints _____ (Single or Double Riveted) Diameter of rivet holes ____ In. Pitch of rivets ____ In. No. of courses _____

10. Inner Shell _____ (Thickness) In. Style of seams: Longitudinal _____ (Riveted, Forge Welded, Brazed, or Welded—Type of Joint) Girth _____ Length of section of course ____ Ft. ____ In.

11. Heads: Flat or dished _____ (Thickness) In. Radius of dish _____ In. Side to pressure _____ (Concave or Convex)

If removable, bolts used _____ (Number and Size) or method of fastening _____ (Describe or Sketch)

12. Staybolts _____ (Iron or Steel) If hollow _____ (Size of Hole) 13. Maximum pitch _____ (Horizontal) × _____ (Vertical) Diameter _____ (Over the Threads) In.

14. Safety Valve Outlets: No. _____ Size _____

15. Have the welders and the welding procedure been qualified in accordance with Code requirements? _____

16. Drain Connection _____ (Size) In. Hand Holes or Sight Holes _____ (Number, Size, and Location)

17. Constructed for maximum allowable working pressure _____ psi at _____ °F.

Hydrostatic test _____ psi.

Remarks: _____ (Vessel to be used for air, gas, ammonia, etc.)

We certify the above data to be correct and except for the omission of shop inspection that all details of material and construction and workmanship of this unfired pressure vessel conform to the ASME Pressure Vessel Code, Section VIII, Division 1.

Date _____ 19 ____ Signed _____ (Manufacturer) by _____

This Form is obtainable from the ASME Order Dept., 345 E. 47th St., New York, N.Y. 10017

Certificate No._____

.....
(Date)

The American Society of Mechanical Engineers
Boiler and Pressure Vessel Committee
United Engineering Center
345 East 47th Street, New York, N.Y. 10017

Gentlemen:

We fabricate .....
(power boilers or parts thereof, water walls, superheaters, steel economizers, locomotive boilers, pressure piping, steel plate heating boilers, miniature boilers, pressure vessels Div. 1, pressure vessels Div. 2, safety relief valves, or fiberglass reinforced plastic pressure vessels).

in our shops, located.....
and make application for an official stamp of The American Society of Mechanical Engineers, and also a certificate of authorization permitting its use for a specified period.

In consideration of the receipt of the official.....
("S", "L", "QP", "H", "M", "U", "U2", "V", "UV" or "RP")
stamp of The American Society of Mechanical Engineers, we hereby agree with said The American Society of Mechanical Engineers that it shall be used only by us and only in the manner prescribed in the Boiler and Pressure Vessel Code formulated by the Boiler and Pressure Vessel Committee. We further agree to surrender the stamp, or stamps subsequently issued, immediately to the Society at any time the Society may so request, or immediately at the time this company discontinues the manufacture of the above-mentioned articles, or immediately at the time this company does not have in its possession a certificate of authorization containing a currently effective date for the type of symbol issued hereunder.

Under no circumstances shall the Code symbol be used without the approval of the authorized inspector.

.....
(Corporate Name)

Corporate Seal

By .....

Official Capacity.....

STATE OF .....
} ss.
COUNTY OF .....

On the..... day of ..... 19....., before me

personally came .....to me known, who being by me duly sworn, did

depose and say that he resides in..... that he is the.....of

....., the corporation described in and which executed the foregoing instrument, that he knows the seal of said corporation; that the seal affixed to said instrument is such corporate seal; that it was so affixed by order of the Board of Directors of said corporation; that he signed his name thereto by like order; and that the facts stated in the said instrument are true.

.....
(Notary Public)

IMPORTANT

The agency performing our Code Inspection is_____

This application is available from the Boiler and Pressure Vessel Committee, ASME, 345 E. 47th St., New York, N. Y. 10017

PLEASE ATTACH THIS CODE DOCUMENT STATEMENT TO YOUR APPLICATION

The American Society of Mechanical Engineers
Boiler and Pressure Vessel Committee
United Engineering Center
345 East 47th Street, New York, New York 10017

Gentlemen:

We have the latest Sections of the 1971 ASME Boiler and Pressure Vessel Code and Addenda as checked below that are required for the stamp or stamps applied for:

"U2" Pressure Vessel, Div. 2

- Section II, MATERIAL SPECIFICATIONS.. ☐
- Section VIII, Div. 1, PRESSURE VESSELS... ☐
- Section VIII, Div. 2, PRESSURE VESSELS... ☐
- Section IX, WELDING QUALIFICATIONS... ☐
- Addenda Subscription to Section II ..... ☐
- Addenda Subscription to Section VIII Div. 1 .. ☐
- Addenda Subscription to Section VIII Div. 2 .. ☐
- Addenda Subscription to Section IX..... ☐

"UV" Pressure Vessel Safety Valve

- Section II, MATERIAL SPECIFICATIONS.. ☐
- Section VIII, Div. 2, PRESSURE VESSELS... ☐
- Addenda Subscription to Section II ..... ☐
- Addenda Subscription to Section VIII Div. 1 .. ☐

Yours truly,

_____ _____
Date (Name of Company)

By _____

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS

Certificate of Authorization

Number _____

THIS IS TO CERTIFY that

_____

is hereby authorized to use the U PRESSURE VESSEL _____ ***symbol of The American Society of Mechanical Engineers in accordance with the applicable rules of the Boiler and Pressure Vessel Code of The American Society of Mechanical Engineers. The use of the Code symbol and the authority granted by this certificate of authorization are subject to the provisions of the agreement set forth in the application. Any construction stamped with this symbol shall have been built strictly in accordance with the provisions of the Boiler and Pressure Vessel Code of The American Society of Mechanical Engineers.***

THIS AUTHORIZATION *expires on*

Authorized on _____ ***for***

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS
by the **BOILER AND PRESSURE VESSEL COMMITTEE**

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS

Chairman

Secretary

Certificate No. _____

.....
(Date)

The American Society of Mechanical Engineers
Boiler and Pressure Vessel Committee
United Engineering Center
345 East 47th Street, New York, N.Y. 10017

Gentlemen:

We fabricate unfired pressure vessels under Par. U-1 (h) of the 1971 Code in our shops located at .....

and make application for an official stamp of The American Society of Mechanical Engineers, and also for a certificate of authorization permitting its use for a specified period.

In consideration of the receipt of the official — UM — stamp of The American Society of Mechanical Engineers, we hereby agree with said The American Society of Mechanical Engineers that it shall be used only by us and only in the manner prescribed in the ASME Boiler and Pressure Vessel Code as formulated by the Boiler and Pressure Vessel Committee. We further agree to surrender the stamp, or stamps subsequently issued, immediately to the Society at any time the Society may so request, or immediately at the time this Company discontinues the manufacture of the above mentioned articles, or immediately at the time this Company does not have in its possession a certificate of authorization containing a currently effective date for the type of symbol issued hereunder.

.....
(Corporate Name)

Corporate Seal

By .....

Official Capacity .....

STATE OF .....
} ss.
COUNTY OF .....

On the .....day of .....19....., before me

personally came .....to me known, who being by me duly sworn, did

depose and say that he resides in.....,that he is the .....of

.....,the corporation described in and which executed the foregoing instrument, that he knows the seal of said corporation; that the seal affixed to said instrument is such corporate seal; that it was so affixed by order of the Board of Directors of said corporation; that he signed his name thereto by like order; and that the facts stated in the said instrument are true.

.....
(Notary Public)

IMPORTANT

The agency that reviews our procedure is _____

This application is available from the Boiler and Pressure Vessel Committee, ASME, 345 E. 47th St., New York, N. Y. 10017

PLEASE ATTACH THIS CODE DOCUMENT STATEMENT TO YOUR APPLICATION

The American Society of Mechanical Engineers
Boiler and Pressure Vessel Committee
United Engineering Center
345 East 47th Street, New York, New York 10017

Gentlemen:

We have the latest Sections of the 1971 ASME Boiler and Pressure Vessel Code and Addenda as checked below that are required for the stamp or stamps applied for:

"U2" Pressure Vessel, Div. 2

- ☐ Section II, MATERIAL SPECIFICATIONS..
- ☐ Section VIII, Div. 1, PRESSURE VESSELS...
- ☐ Section VIII, Div. 2, PRESSURE VESSELS...
- ☐ Section IX, WELDING QUALIFICATIONS...
- ☐ Addenda Subscription to Section II .....
- ☐ Addenda Subscription to Section VIII Div. 1 ..
- ☐ Addenda Subscription to Section VIII Div. 2 ..
- ☐ Addenda Subscription to Section IX.....

"UV" Pressure Vessel Safety Valve

- ☐ Section II, MATERIAL SPECIFICATIONS..
- ☐ Section VIII, Div. 2, PRESSURE VESSELS...
- ☐ Addenda Subscription to Section II .....
- ☐ Addenda Subscription to Section VIII Div. 1 ..

Yours truly,

Date _____ (Name of Company) _____

By _____

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS

Certificate of Authorization

Number _____

THIS IS TO CERTIFY that

_____

is hereby authorized to use the UM UNFIRED MINIATURE PRESSURE VESSEL ***symbol of The American Society of Mechanical Engineers in accordance with the applicable rules of the Boiler and Pressure Vessel Code of The American Society of Mechanical Engineers. The use of the Code symbol and the authority granted by this certificate of authorization are subject to the provisions of the agreement set forth in the application. Any construction stamped with this symbol shall have been built strictly in accordance with the provisions of the Boiler and Pressure Vessel Code of The American Society of Mechanical Engineers.***

THIS AUTHORIZATION *expires on*

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THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS
by the **BOILER AND PRESSURE VESSEL COMMITTEE**

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Index

Abrasion, allowance for, UG-25 . . . 10
Accessibility, pressure vessels, UA-351 . . . 325
Access openings, UG-46 . . . 32
Allowance for corrosion, erosion, or abrasion, UG-25, UR-13, UB-13, UCS-25, UCL-25 . . . 10, 88, 100, 107, 184
Applicability of Code, U-1 . . . 1
Applied linings, tightness, UCL-51 . . . 187
Approval of new materials, UG-5, UA-110 . . . 4, 301
Attachments, fitting, UG-82 . . . 40
  lugs for platforms, UG-55 . . . 37
  nonpressure parts, UW-16, UHT-85 . . . 73, 200
  of stiffening rings to shell, UG-30, UHT-30 . . . 15, 197
  pipe and nozzle necks to vessel walls, UG-43, UHT-18 . . . 31, 193
  structural, UHT-28 . . . 197

Backing strip, UW-16, UW-35 . . . 73, 80
Bending stress, welded joints, UW-9 . . . 65
Bend test, UHA-52 . . . 177
Blind flanges, UG-34 . . . 20
Bolted flange connections, UG-44 . . . 32
  bolt loads, UA-49 . . . 214
  bolt stresses, UA-49, Appendix S . . . 214, 330
  bolt studs, UA-46 . . . 210
  design of, UA-45 to UA-59, Appendix S . . . 210—225, 230
  flange stresses, UA-51, Appendix S . . . 220, 330
  materials, UG-5 to UG-13, UCD-12, UA-46 . . . 4—7, 188, 210
  tightness of, Appendix S . . . 330
  types of attachment, UA-48 . . . 213
Bolted joints, UR-19 . . . 89
Bolt heads, seal welding, UR-40 . . . 92
Bolt holes, UR-35 . . . 91
Bolts, UG-12, UR-6, UCS-10, UNF-12, UCI-12, UA-46, Appendix S . . . 7, 87, 106, 129, 179, 210, 330
Braced surfaces, UG-47 . . . 33
Brazed connections for nozzles, UB-17 to UB-19 . . . 101
Brazed joints, efficiency of, UB-14 . . . 100
  maximum service temperature, UB-12 . . . 99
  strength of, UB-10 . . . 99
Brazing, cleaning of brazed surfaces, UB-34 . . . 102
  fabrication by, UB-1, UB-30 to UB-37 . . . 98, 101, 102
  filler metal, UB-6, UB-15 . . . 99, 100
  fluxes, UB-7 . . . 99
  heads into shells, UB-16 . . . 100
  operating temperature, UB-2 . . . 99
Buttstraps, curvature, UR-31, UR-52, UB-33 . . . 90, 92, 102
  forming ends of, UG-79 . . . 39
  thickness and corrosion allowance, UR-14, UB-13 . . . 88, 100
  welding ends of, UR-31, UB-33 . . . 90, 102

Calking, riveted joints, UR-21, UR-40 . . . 89, 92
Carbon in material for welding, UF-5, UCS-5 . . . 93, 105
Cast ductile iron vessels, design, UCD-16 . . . 188
  pressure-temperature limitations, UCD-3 . . . 188
  service restrictions, UCD-2 . . . 188
Castings, defects, UG-24 . . . 9
  impact test, UG-84, UHT-6 . . . 41, 192
  inspection, UG-24 . . . 9
  quality factor, UG-24 . . . 9
  specifications, UG-8, UCS-8, UNF-8, UCD-5 . . . 5, 106, 129, 188
Cast iron circular dished heads, UCI-35 . . . 180
Cast iron parts, small, UG-11 . . . 6
Cast iron pipe fittings, UCI-3 . . . 179
Cast iron vessels, corners and fillets, UCI-37 . . . 180
  head design, UCI-32, UCI-33 . . . 180
  hydrostatic test, UCI-99 . . . 181
  nozzles and fittings, UCI-36 . . . 180
  pressure-temperature limitations, UCI-3 . . . 179
Certificate of authorization for stamp, UG-116 . . . 53
Chip marks on integrally forged vessels, UF-32 . . . 96
Circumferential joints, alignment tolerance, UHT-20 . . . 196
  assembling, UW-9, UB-16 . . . 65, 100
  back pitch of rivets in, UR-20 . . . 89
  brazing, UB-16 . . . 100
  tapering, riveted lap joints, UR-38 . . . 91
  vessels subjected to external pressure, UG-28 . . . 12
Clad material, inserted strips, UCL-33 . . . 184
Clad plate, UCL-11 . . . 183
Cleaning, of brazed surfaces, UB-34 . . . 102
  of welded surfaces, UW-32 . . . 80
Clearance between surfaces to be brazed, UB-35 . . . 102
Code, scope of, U-1 . . . 1
Combination, of different materials, UB-5 . . . 99
  of methods of fabrication, U-2, UG-17 . . . 2, 8
Computed working pressure from hydrostatic tests, UG-101, UCI-101 . . . 49, 181
Conical heads, UG-32, UA-5, UHT-33 . . . 16, 197, 205
Conical sections, UHT-19 . . . 196
Connections, bolted flange (*see* Bolted flange connections)
  brazed, UB-19 to UB-21 . . . 101
  expanded, UG-43 . . . 31
  from vessels to safety valves, UG-134 . . . 62
  postweld heat treatment of, UW-10, UHT-56 . . . 65, 198

riveted, UR-23 to UR-25 ..... 89, 90
studded, UG-43 31
threaded, UG-43 31
welded, UW-15, UW-16, UHT-17, UHT-18 ... 73, 193
Cooling, after postweld heat treating, UW-40, UHT-56, Table UHT-56 ..... 81, 197, 201
Corrosion allowance, UG-25, UR-13, UB-13, UCS-25, UCL-25, UHT-25 .. 10, 88, 100, 107, 184, 197
Corrosion resistant linings, UG-26 11
Corrugated shells, UCS-28 107
Cover plates, UG-34 20
on manholes and handholes, UG-46 32
spherically dished, UG-35, UA-6 ..... 24, 207
Cracking, stress corrosion, UHA-103 177
Crushing strength of plate, UR-12 88
Cutting plates, UG-76, UW-31, UHT-83 .. 37, 79, 220
Cylindrical shells, supplementary loading, UG-22, UA-274 ..... 8, 312
thickness, UG-27, UHT-27 ..... 11, 197
transition in, UG-36 25

Data report, manufacturer's, Forms U-1, U-1A .. 339, 341
partial Form U-2 343
Defects in welded vessels, repair, UW-38, UHT-85 ..... 81, 300
Definitions, UA-60 238
Design, brazed vessels, UB-9 99
carbon and low-alloy steel vessels, UCS-16 107
cast ductile iron vessels, UCD-16 188
cast iron vessels, UCI-16 179
clad vessels, UCL-20 183
ferritic steel vessels with properties enhanced by heat treatment, UHT-16 193
forged vessels, UF-12 94
high-alloy steel vessels, UHA-20 174
loadings, UG-22 8
multichamber vessels, UG-19 8
nonferrous vessels, UNF-16 129
pressure, UG-21 8
riveted vessels, UR-10 87
welded vessels, UW-8, UHT-1, UHT-16 .. 64, 192, 193
Diameter exemption, U-1 1
Dimensions, checking of, UG-96 47
Discharge of safety valves, UG-133, UG-134 .. 61, 62
Dished heads (*see* Formed heads)
Disks, rupture, UG-127 57
Dissimilar weld metal, UG-18, UHA-107, UCL-31 .. 8, 178, 184
Distortion, of welded vessels, UG-80 39
supports to prevent, UG-27, UG-28 ..... 11, 12
Drainage, discharge from safety and relief valves, UG-134 62
of vessels subject to corrosion, UG-25, UA-351 .. 10, 325
Drop weight tests, UHT-6 193

Eccentricity of shells, UG-80 39
Edges of plates, calking of, UR-21, UR-40 .... 89, 92
metal removal from, UHT-83 200
tapered, UW-9 65
Efficiency, around openings for welded attachments, UW-15 73
joints, riveted, UR-15 88
welded, UW-12 66
Elasticity, modulus of, UF-27 94
Electric resistance welding, UW-12 66
Ellipsoidal heads, UG-32, UG-33, UA-4, UHT-32, UHT-33 ..... 16, 19, 203, 197
Erosion, allowance for, UG-25 10
Etching, of sectioned specimens, UA-250 309
solutions for examination of materials, UA-250 309
Examination, of sectioned specimens, UW-52 ... 86
of welded joints, UW-51, UW-52, UHT-57, UHT-83 ..... 83, 86, 198, 200
Exemptions, diameter and volume, U-1 1
Expanded connections, UG-43 31
External pressure, tube and pipe, UG-31 16
External pressure vessels, UG-28 to UG-30, UG-33, UG-80, UCD-28, UHT-27, UHT-29, UHT-30, UHT-33 .. 12—15, 19, 39, 189, 197
allowable working pressure for UG-28 13
design of heads for, UG-33, UCS-33, UNF-33, UHA-31, UCI-33, UHT-33, UA-276 .... 19, 107, 130, 174, 197, 313
joints in shells of, UG-28, UHT-17 ..... 12, 193
reinforcement for openings, UG-37, UHT-17 ... 26, 193
supports for, UG-29, UA-185 ..... 13, 305
thickness of shell, UG-28, UCS-28, UNF-28, UHA-28, UCI-28, UHT-27, UCL-26 .. 12, 107, 130, 174, 180, 197, 184

Fabrication, brazed vessels, UB-30 101
carbon and low-alloy steel vessels, UCS-75 127
cast ductile iron vessels, UCD-75 190
cast iron vessels, UCI-75 181
clad vessels, UCL-30 184
ferritic steel vessels with tensile properties enhanced by heat treatment, UHT-75 198
forged vessels, UF-26 94
high-alloy steel vessels, UHA-40 176
nonferrous vessels, UNF-75 137
riveted vessels, UR-30 90
welded vessels, UW-26, UHT-1, UHT-75 .. 78, 192, 198
Ferritic steel vessels with tensile properties enhanced by heat treatment, design, UHT-16 193
fabrication, UHT-75 198
head design, UHT-33 197
heat treatment, UHT-80 199
heat treatment verification tests, UHT-81 199
marking, UHT-86 200
materials, UHT-1, UHT-5, UHT-40 ..... 192, 198
stamping, UHT-115 200
welded joints, UHT-17 193
welding, UHT-82 200
Filler plugs for trepanned holes, UA-251 310
Fillet welds, UW-18, UW-36, UCL-46 .. 77, 80, 187
Fitting attachments, UG-82, UHT-18 ..... 40, 193
Flange contact facings, UA-47 211

Flanges, bolted design, UA-45 to UA-55, Appendix S ..... 210—221, 330
of formed heads for welding, UW-13 68
type of attachment, UA-48 213
Flat heads, UG-34 20
reinforcement of openings, UG-39 28
Flat spots on formed heads, UG-32 16
Flued openings, UG-38 28
Forged parts, small, UG-11 6
Forged vessels, heat treatment, UF-31 95
localized thin areas, UF-30 95
welding, UF-32 96
Forgings, UG-7, UF-6, UCS-7, UNF-7 .. 5, 93, 106, 129
identification of, UF-47 97
Form, manufacturer's data report, Forms U-1, U-1A 339, 341
partial report, Form U-2 343
Formed heads, UG-32, UG-33, UHT-32, UHT-33 ..... 16, 19, 197
flued openings in, UG-38 28
insertion of, welded vessels, UW-13 68
joint efficiency, UG-32 16
knuckle radius, UG-32, UHT-19 ..... 18, 196
length of skirt, UG-32, UG-33, UW-13, UHT-19 ..... 16, 19, 68, 196
on welded vessels, UW-13 68
reinforcement for openings, UG-37 27
Forming, ends of shell plates and buttstraps, UG-79 39
forged heads, UF-28 95
shell sections and heads, UG-79, UCS-79, UNF-77, UHT-79 ..... 37, 127, 137, 198
Furnaces, temperatures for postweld heat treatment, UW-40 81
Furnaces for heat treating, UHT-80 199
temperature control of, UHT-80 199

Galvanized vessels, UG-99 47
Gasket materials, UA-47 211
Girth joints (*see* Circumferential joints)

Handhole and manhole openings, UG-46 32
Head flange (skirt) length, UG-32, UG-33, UW-13 ..... 16, 19, 68
Head joints, brazing, UB-16 100
welded, UW-13 68
(*see also* Heads and shells; Joints)
Head openings, entirely in spherical portion, UG-37 26
Heads, concave and convex, UG-32, UG-33, UCI-32, UCI-33, UCD-32, UCD-33, UHT-32, UHT-33 .... 16, 19, 180, 189, 197
flat (*see* Flat heads)
forged, UF-13 to UF-28 ..... 94, 95
formed (*see* Formed heads)
forming, UG-79, UCS-79, UNF-77, UHT-79 ... 39, 127, 137, 198
thickness, after forming, UG-32, UG-33, UHT-79 ..... 16, 19, 198
Heads, design, conical, UG-32, UHT-33, UA-5 .. 16, 197, 205
ellipsoidal, UG-32, UG-33, UHT-32, UHT-33, UA-4 ..... 16, 19, 197, 203
hemispherical, UG-32, UG-33, UHT-32, UHT-33, UA-4 ..... 16, 19, 197, 203
spherically dished, UG-32, UG-33, UCD-35, UA-6 ..... 16, 19, 189, 207
toriconical, UG-32, UF-13, UA-5 .. 16, 94, 205
torispherical, UG-32, UG-33, UA-4 .. 16, 19, 203
torispherical, knuckle radius, UG-32 16
Heads and shells, external pressure, out-of-roundness, UG-80, UG-81 ..... 39, 40
openings through or near welded joints, UW-14 72
roundness tolerance, UG-80, UG-81 ..... 39, 40
Heat treatment, by fabricator, UG-85, UCS-85 .... 42, 127
carbon and low-alloy steel vessels, UCS-85 127
ferritic steel vessels with tensile properties enhanced by heat treatment, UHT-80 199
forged vessels, UF-31 95
furnaces, UHT-80 199
high-alloy vessels, UHA-105 178
of test specimens, UG-85, UCS-85 ..... 42, 127
verification tests of, UHT-81 199
Hemispherical heads, UG-32, UA-4 ..... 16, 203
Holes, for screw stays, UG-83, UR-32 (*see also* Rivet holes) 41, 90
for trepanning plug sections, refilling, UA-251 .. 310
telltale, UG-25, UCL-25 ..... 11, 184
unreinforced, in welded joints, UW-14 72
Hubs, on flanges, UA-46 210
Hydrostatic proof test, UG-101, UCI-101, UCD-101 ..... 49, 181, 191
destructive, UG-101, UCI-101 ..... 49, 181
prior pressure application, UG-101 49
Hydrostatic test, cast iron vessels, UCI-99 181
combined with pneumatic, UG-100 48
enameled vessels, UG-99 47
external pressure vessels, UG-99 47
galvanized vessels, UG-99 47
standard, UG-99, UCL-52, UCD-99 .. 47, 187, 191
welded vessels, UG-99, UW-50 ..... 47, 82

Identification, of forgings, UF-47 97
of plates, UG-77, UG-85, UG-94, UHT-86 .... 37, 44, 46, 200
of welds, UW-37 80
Identification markers, radiographs, UW-51 83
Impact test, certification, UG-84 41
properties, UG-84, UHT-6 ..... 41, 192
specimens, UG-84, UHT-5, UHT-6, UHT-81, UHT-82 ..... 41, 192, 199
temperature, UHT-5 192
Inspection, before assembling, UG-90 to UG-102 ..... 44—53
brazed vessels, UB-40, UB-44 104
carbon and low-alloy steel, UCS-90 127
cast ductile iron vessels, UCD-90 191
cast iron vessels, UCI-90 181
clad vessels, UCL-50 187
during fabrication, UG-95, UG-97 47
ferritic steel vessels with tensile properties enhanced by heat treatment, UHT-90 200
fitting up, UG-96 47
forged vessels, UF-45 to UF-54 ..... 97, 98

heat treatment, forgings, UF-52 98
high-alloy steel vessels, UHA-50 176
magnetic particle, UW-50, UHT-57, UHT-83 .. 82, 198, 200
material, UG-93, UG-94 46
nonferrous vessels, UNF-90 137
plate, UG-93 to UG-95 ..... 46, 47
postweld heat treatment, UW-49, UF-52 .. 82, 98
pressure vessels, accessibility, UA-351 325
riveted vessels, UR-50 92
rivet heads, UR-53 93
rivet holes, UR-54 93
rivets and bolts, UR-53 93
sectioning of welded joints, UW-41 82
spot examination, UW-52 86
steel castings, UG-24, UA-80 ..... 9, 287
surfaces exposed and component parts, UG-95, UF-46 ..... 47, 97
test specimens, UF-53 98
vessels, UG-90, UG-97, UW-46, UR-51, UHT-90 ..... 44, 47, 82, 92, 200
vessels exempted from, U-1 1
welded vessels, UW-46 to UW-52 ..... 82—86
Inspection openings, UG-46 32
Inspectors, access to plant, UG-92 46
control of stamping, UG-116 53
facilities, UG-92 46
qualification, UG-91 46
reports, UG-120 56
Installation, pressure-relieving devices, UG-134, UHT-125, UA-353 to UA-357 .. 62, 201, 325, 326
pressure vessel, UA-350 325
Integral cast iron dished heads, UCI-35 180
Internal structures, UA-140 to UA-142 303

Jacketed vessels, UG-28, UA-100 to UA-109 .. 12, 293
Joints, bolted, UR-19 89
brazed, UB-16 100
calking of, UR-21, UR-40 ..... 89, 92
circumferential (*see* Circumferential joints)
efficiency, brazed, UB-14 100
riveted, UR-15 88
welded, UW-12 66
electric resistance, butt welding, UW-12 66
in cladding and applied linings, UCL-31 184
in vessels subjected to external pressure, UG-28 12
lap (*see* Lap joints)
longitudinal (*see* Longitudinal joints)
riveted (*see* Riveted joints)
tightness, UR-40 92

Knuckles, radius, UG-32, UHT-19 ..... 16, 196
transition section, UG-36, UHT-19 ..... 25, 196

Lap joints, amount of overlap, UW-9, UB-16 .. 65, 100
brazed, UB-16 100
longitudinal under external pressure, UG-28 12
riveted, UR-18, UCS-18, UNF-18 .. 89, 107, 129
limits of shell, UR-18 89
welded, UW-9 65
Lethal gases or liquids, UW-2, UCI-2 ..... 63, 179
Ligaments, efficiency of, UA-290 323
Limitation on welded vessels, UW-2 63
Limit of out-of-roundness of shells, UG-80 39
Linings, UG-26, UCL-12 ..... 11, 183
corrosion resistant, UA-170 to UA-172 304
Liquid penetrant examination, UHT-57, UHT-83, Appendix VIII 198, 200, 290
Loadings, UG-22 8
Local postweld heat treatment, UW-40 81
Longitudinal joints, alignment tolerance, UHT-20 .. 196
brazing, UB-16 100
lap riveted, UR-18 89
location of rivet holes on, UR-22 89
riveted, UR-16, UR-18 ..... 88, 89
vessels subjected to external pressure, UG-28 .. 12
Low-temperature operation, UCS-65 126
Low-temperature vessels, brazed, UB-22 101
for gases and liquids, UCS-65 to 67, UNF-65, UCL-27 ..... 126, 137, 184
impact test requirements, UG-84, UHA-51 .. 41, 176
impact tests, when not required, UCS-66 126
marking, UG-116 53
materials, UG-84 41
testing of materials, UG-84 41
Lugs for ladders, platforms, and other attachments, UG-55 37

Magnetic particle inspection, UHT-57, UHT-83 UA-70 to UA-72 ..... 198, 200, 284
Manholes, and handholes, UG-46 32
cover plates for, UG-34 20
minimum vessel diameter requiring, UG-46 32
Manufacturer, responsibility of, UG-90, UW-26 .. 44, 78
Manufacturer's data report, Forms U-1, U-1A .. 339, 341
partial, Form U-2 343
Manufacturer's stamps, UG-77, UG-94 ..... 37, 46
Marking, castings, UG-24 9
materials, UG-94, UHT-86 ..... 46, 200
plates, UG-10, UG-77, UG-85, UG-94, UHA-41, UHT-86 ..... 5, 37, 44, 46, 176, 200
standard pressure parts, UG-11 6
valves and fittings, UG-11 6
with Code symbol, UG-116, UHT-115 .. 53, 200
Markings, transfer after cutting plates, UG-77, UG-94 ..... 37, 46
Materials, approval of new, UG-5, UA-110 .. 4, 301
approval of repairs, UG-78, UCI-78 ..... 39, 181
brazed vessels, UB-5 99
carbon and low-alloy steel vessels, UCS-5 105
cast ductile iron, UCD-5 188
castings, UG-8 5
cast iron vessels, UCI-5 179
clad vessels, UCL-10 182
combination of, UG-18, UHT-40 ..... 8, 198
ferritic steel vessels with tensile properties enhanced by heat treatment, UHT-5 192
forged vessels, UF-5 93
forgings, UG-7 5
for nonpressure parts, UG-6 4
heat treatment of, UG-85, UCS-85, UHT-80 .. 44, 127
high-alloy steel vessels, UHA-11 157
inspection of, UG-93, UG-95 ..... 46, 47

nonferrous vessels, UNF-5 128
pipe and tubes, UG-9 5
plate, UG-6 5
riveted vessels, UR-5 87
rods and bars, UCS-12 106
specifications for UG-5, UG-23, UCS-23, UNF-23, UHA-23, UCI-23, UCD-5, UHT-5, UHT-23 .. 4, 9, 107, 130, 174, 179, 188, 192, 196
standard pressure, parts, UG-11 5
unidentified, UG-10 5
use of, over thickness listed in Section II, UG-6 .. 4
welded vessels, UW-5 64
Measurement of out-of-roundness of shells, UG-80 39
Metal temperature, determination, UA-130 302
control of, Appendix T 332
Mill undertolerance, UG-16 7
Minimum thickness of plate, UG-16, UR-10, UCS-16, UNF-16, UHA-20, UCL-20, UHT-16 .. 7, 87, 107, 129, 174, 183, 193
Miscellaneous pressure parts, UG-11 6
Multichamber vessels, design, UG-19 8
Multiple safety valves, UG-134 62

Nameplates, UG-117, UG-118, UHT-115 .. 55, 200
New materials, UG-5, UA-110 ..... 4, 301
Nonpressure parts, attachment of, UG-55, UHT-85 ..... 37, 200
Notch ductility test, UHT-5 192
Nozzle openings, reinforced, UG-36, UHT-18 .. 25, 193
unreinforced, UG-36 25
vessels subjected to external pressure, UG-37 .. 26
Nozzles, attachment of, to shell, UG-43, UHT-18 .. 31, 193
minimum thickness of neck, UG-45, UHT-18 .. 32, 193
(*see also* Connections)
Nuts and washers, UG-13, UCS-11, UNF-13 .. 7, 106, 129

Offset of edges of plates at joints, UW-33, UHT-20 ..... 80, 196
Openings, adjacent to welds, UW-14 72
closure of, UA-251 310
for connections to brazed vessels, UB-19 101
for drainage, UG-25 11
head (*see* Openings, head and shell)
in flat heads, UG-39 28
inspection, UG-46 32
manhole (*see* Manholes)
nozzle (*see* Nozzle openings)
shell (*see* Openings, head and shell)
through welded joints, UW-14 72
Openings, head and shell, computation of, UA-280 315
not requiring additional reinforcement, UG-36 25
reinforced, size, UG-36, UHT-18 ..... 25, 193
reinforcement for adjacent openings, UG-42 .. 30
reinforcement of, UG-37, UHT-18 ..... 26, 193
requiring additional reinforcement, UG-36 .. 25
shapes permissible, UG-36 25
unreinforced, size, UG-36 25
Outlets, discharge, pressure relieving devices, UG-134 62
Out-of-roundness, UG-80, UG-81, UF-27 .. 39, 40, 94
Overpressure limit for vessels, UG-125 56

Partial data report, manufacturer's, UG-120 56
Parts, miscellaneous, UG-11 6
Peening, UW-39 81
Penetrameters, UW-51 83
Pipe connections, openings for, UG-43 31
Pipe fittings, vessels built of, UCS-9 106
Pipes and tubes, UG-9, UG-31, UCS-9, UNF-9 .. 5, 16, 106, 129
Pipe used for shells, UCS-27 107
Piping external to vessel, U-1 1
Plate, curvature, UR-52, UB-33 ..... 92, 102
measurement, dimensional check, UG-96 47
Plate edges, calking, UR-40 92
cutting, UG-76, UG-93, UW-31, UHT-83 .. 37, 46, 79, 200
exposed left unwelded, UG-76 37
inspection of, UG-95 47
Plates, alignment, UW-31, UHT-20 ..... 79, 196
cover, UG-34 20
crushing strength, UR-12 82
cutting, UG-76, UG-93, UW-31, UHT-83 .. 37, 46, 79, 200
forming, UG-79, UCS-79, UNF-77, UHT-79 .. 39, 127, 137, 198
heat treatment, UG-85 44
identification, UG-77, UG-94, UHT-86 .. 37, 46, 200
impact test, UG-84, UHT-5, UHT-6, UHT-81 .. 41, 192, 199
inspection, UG-93 to UG-95 ..... 46, 47
laying out, UG-77 37
less than ¼ in. thickness, UG-77 37
markings, transfer after cutting, UG-77, UG-94 ..... 37, 46
minimum thickness, UG-16, UR-10, UCS-16, UNF-16, UHA-20, UCL-20, UHT-5, UHT-79 .. 7, 87, 107, 129, 174, 183, 192, 198
planing edges, UR-21 89
repair of defects, UG-78, UCI-78 ..... 39, 181
specifications, UG-6, UCS-6, UNF-6, UHT-5 .. 4, 105, 128, 192
Plug welds, UW-17 77
Pneumatic test, pressure, UG-100 48
yielding, UG-100 48
Porosity, welded joints, UW-51, Appendix IV .. 83, 242
Porosity charts, UA-65 242
Postheat treatment, UHT-79, UHT-82 ..... 198, 200
Postweld heat treatment, connections for nozzles and attachments, UR-23, UHT-56 .. 89, 198
cooling, after, UW-40, UHT-56 ..... 81, 198
furnace temperature, UW-40 81
inspection, UW-49 82
local, UW-40 81
requirements, UCS-56, UHT-56 ..... 124, 198
riveted vessels, UR-36 91
temperature range, UHT-56 198

welded vessels, UW-10, UW-40, UHA-32, UCL-34, UHT-56 . . . . 65, 81, 174, 185, 198
Preheating, Appendix R 328
Preparation of plates for welding, UW-31, UW-32 . . 79, 80
Pressure, design, UG-21 8
limits, U-1 1
(*see also* Working pressure, allowable)
Pressure parts, miscellaneous, UG-11 6
Pressure relieving devices, discharge, UG-134 62
installation and operation, UG-134, UA-353 to UA-357 . . . . 62, 325, 326
rupture disks, UG-127 57
setting, UG-133 61
(*see also* Safety and relief valves)
Pressure vessels, exempted from inspection U-1 . . 1
Proof test, hydrostatic (*see* Hydrostatic proof test)

Qualification, of brazers, UB-43 104
of welders, UW-29, UCL-45 . . . . 78, 187
of welding procedure, UW-28, UCL-40 to UCL-44 . . . . 78, 185, 186
Quenching and tempering, UHT-80 to UHT-82 . . 199, 200
Quick-actuating closures, UG-35 24

Radiograph factor, UW-12 66
Radiographing, examination by, UW-11, UHT-57 . . 65, 198
joint efficiency, UW-12 66
requirements, UCS-57, UHA-33, UCL-35, UHT-57 . . . . 126, 175, 185, 198
spot examination, UW-52 86
retests, UW-11, UW-52 . . . . 65, 86
technique, UW-51 83
thickness, mandatory minimum, UW-11, UCS-57 . . . . 65, 126
Radiographs, acceptance by inspector, UW-51, UW-52 . . . . 83, 86
gamma rays, radium capsule, UW-51 83
interpretation by standard procedure, UW-51, UW-52 . . . . 83, 86
Reaming holes for screw stays, UG-83, UR-32 . . . . 41, 91
Reducer sections, rules for, UA-5 205
Reinforcement, defined limits, UG-40 28
head and shell openings, UG-37, UG-39 . . . . 26, 28
large openings, UG-36, UA-7 . . . . 25, 209
multiple openings, UG-42 30
nozzle openings, UG-37 to UG-42, UHT-18 . . . . 26—30, 193
of openings in shells, computation of, UA-280 315
openings subject to rapid pressure fluctuation, UG-36 25
strength, UG-41 30
Relief devices, UG-125 to UG-134 (*see also* Pressure relieving devices; Safety and relief valves) . . . . 56—62
Relief valves (*see* Safety and relief valves)
Relieving capacity of safety valves, UG-132 61
Repairs, approval of defects in material, UG-78, UF-32, UF-46, UCD-78 . . . . 39, 96, 97, 190
defective brazing, UB-37 102
defects in forgings, UF-37 96
defects in welds, UW-38, UF-38, UHT-57 . . . . 81, 97, 198
Responsibility of manufacturer, UG-90, UW-26 . . . . 44, 78
Retests, forgings, UF-54 98
impact specimens, UG-84, UHT-6 . . . . 41, 192
joints, welded, UW-52 86
Riveted connections for nozzles, UR-23 to UR-25 . . 89, 90
Riveted joints, assembling, UR-37 91
back pitch, UR-20 89
buttstraps, UR-14, UR-31, UB-33 . . . . 88, 90, 102
calking, UR-21, UR-40 . . . . 89, 92
circumferential, UR-17 88
edge distance, UR-22 89
efficiency, UR-15 88
longitudinal, UR-16, UR-18 . . . . 88, 89
replacement of rivets, UR-55 93
seal welding, UR-40 92
spacing of rivet holes, UR-22 89
strength around openings, UR-25 90
Rivet heads, eccentricity limits, UR-39 91
forms, UR-39 91
inspection, UR-53 93
seal welding, UR-40 92
Rivet holes, burrs removal, or chamfering, UR-34 . . 91
countersunk (and swell neck) UR-32 90
drilled, UR-32 90
edge distance, UR-22 89
inspection of, UR-51, UR-54 . . . . 92, 93
subdrilling or subpunching, and reaming, UR-32 90
tolerance for, UR-33 91
Rivets, allowable shearing strength, UR-11 87
cold driven, UR-33 91
design stress values, UR-11 87
driving, UR-39 91
hot driven, UR-33 91
inspection, UR-53 93
length and heads, UR-39 91
material, UR-6, UCD-12 . . . . 87, 188
pitch of, in riveted joints, UR-20 89
replacement, UR-55 93
strength, around openings, UR-25 90
swell neck, UR-13 88
testing for tightness, UR-55 93
Rods, bars, and shapes, UG-14, UCS-12, UNF-14 . . . . 7, 106, 129
Rolled parts, small, UG-11, UHT-6 . . . . 6, 192
Rupture disks, UG-125, UG-127, UG-129, UG-133, UG-134 . . . . 56—58, 61, 62

Safety and relief valves, capacity, certification, UG-131 59
capacity, conversion, UA-230 307
connection to vessels, UG-134 62
construction, UG-126 57
discharge capacity of multiple, UG-134 62
discharge pipe, UG-134 62
drain, UG-126 57
installation on vessels in service, UG-134 62

liquid relief, UG-129 58
marking, UG-129 58
pressure setting, UG-133 61
spring loaded, UG-126 57
springs, adjustment, UG-133 61
stamping, UG-131 59
stop valves adjacent to, UG-134 62
test, UG-131 59
Safety devices, UG-125 to UG-134 . . . . 56—62
for unfired steam boiler, UG-125 56
Scope of Section VIII of the Code, U-1 1
Seal welding, of bolt heads, UR-40 92
of calking edges, UR-40 92
Sectioning, closing holes left by, UA-251 310
etching plugs taken, UA-250 309
examination by, UW-41 82
Service restrictions, UW-2 63
Shapes, special, UG-19 8
Shearing strength of rivets, UR-11 87
Shell plates, forming ends of, UG-79 39
Shells, allowable working pressure, UG-27 11
computation of openings in, UA-280 315
forming, UG-79, UCS-79, UNF-77, UHT-79 . . . . 39, 127, 137, 198
made from pipe, UCS-27 107
stiffening rings, UG-29, UG-30, UCS-29, UHT-29 to UHT-30 . . . . 13, 15, 107, 197
thickness, UG-27, UG-28, UCD-28, UHT-27, UHT-79 . . . . 11, 12, 189, 197, 198
transition section, UG-36, UHT-19 . . . . 25, 196
Sigma-phase formation, UHA-104 177
Skirts, length on heads, UG-32, UG-33, UW-13, UHT-19 . . . . 16, 19, 68, 196
support of vessels, UA-189 305
Slag inclusions in welds, UW-51, UW-52 . . . . 83, 86
Special constructions, UG-19 8
Specifications for materials, UG-5, UG-23, UCS-23, UNF-23, UHA-23, UCI-23, UCD-5, UHT-5, UHT-23 . . . . 4, 9, 107, 130, 174, 179, 188, 192, 196
Spherical sections of vessels, UG-32, UG-33 . . . . 16, 19
Spherical shells, thickness, UG-27, UHT-27 . . . . 11, 197
Spot examination of welded joints, UW-52 86
Springs for safety valves, UG-126, UG-133 . . . . 57, 61
Stamping, location of, UG-116 53
multipressure vessels, UG-19, UG-116 . . . . 8, 53
omission of, UHT-86 200
safety valves, UG-131 59
with Code symbol, UG-116, UHT-115 . . . . 53, 200
Stamps, certificate of authorization, UG-116 53
low stress, UHT-86 200
not to be covered, UA-352 325
to be visible on plates, UG-77, UHT-86 . . . . 37, 200
Static head, in setting safety valves, effect of, on limiting stresses, UG-98 47
Stayed surfaces, UG-47 33
Staying formed heads, UG-32 16
Stays and staybolts, adjacent to edges of staybolted surface, UG-49 34
allowable stress, UG-50 34
area supported, UG-47, UG-50 . . . . 33, 34
dimensions, UG-50 34
ends, UG-48, UW-19 . . . . 34, 77
holes, UR-32 90
location, UG-49 34
pitch, UG-47 34
screw, holes for, UG-83 41
upset for threading, UG-48 34
welded, UW-19 77
Steam generating vessels, unfired, U-1 1
Steel, carbon content, UCS-5 105
Stenciling plates for identification, UG-77 37
Stiffening rings, attachment to shell, UG-30, UF-5, UHT-30 . . . . 15, 93, 197
for vessels under external pressure, UG-29, UG-30, UCS-29, UHT-28, UHT-29 . . . . 13, 15, 107, 197
Stiffness, support of large vessels for, UG-27, UG-28 . . . . 11, 12
Stop valves, adjacent to safety and relief valves, UG-134, UA-354, UA-355 . . . . 62, 325
Strength, of brazed joints, UB-10 99
of circumferential joints, UR-17 88
of rivets, allowable shearing, UR-11 87
Stress corrosion cracking, UHA-103 177
Stress values, attachment welds, UW-15 73
basis for establishing, UA-500, UA-600 . . . . 327, 328
carbon and low-alloy steel, Table UCS-23 108
cast ductile iron, Table UCD-23 189
cast iron, Table UCI-23 180
ferritic steels with tensile properties enhanced by heat treatment, Table UHT-23 196
high-alloy steel, Table UHA-23 158
nonferrous metals, Table UNF-23.1 131
Stud bolt threads, UG-12 7
Studded connections, UG-43 31
Supplementary design formulas, UA-1 to UA-7 . . . . 202—209
Supports, design, UG-54, UA-185 . . . . 37, 305
pressure vessels, UG-54, UG-82, UR-26 . . . . 37, 40, 90
temperature, free movement under, UA-186 305
types of steel permissible for, UG-6 4
vessels subjected to external pressure, UG-29, UHT-29, UA-185 . . . . 13, 197, 305

Tables, effective gasket width *b*, Table UA-49.2 216
gasket materials and contact facings, Table UA-49.1 215
maximum allowable efficiencies for arc and gas welded joints, Table UW-12 67
minimum number of pipe threads for connections, Table UG-43 31
minimum thickness of buttstraps, Table UR-14 88
minimum thickness of independent riveted reinforcing rings or flanges, Table UR-25 90
molecular weights of gases and vapors, Table UA-230 309
of stress values, carbon and low-alloy steel, Table UCS-23 108
cast iron, Table UCI-23 180
cast nodular iron, Table UCD-23 189
ferritic steels with tensile properties enhanced by heat treatment, Table UHT-23 196
high-alloy steel, Table UHA-23 158
nonferrous metals, Table UNF-23.1 131
welded carbon low-alloy pipe and tubes, Table UCS-27 122
of values, factor *K*, Table UA-4.1 205

factor *M*, Table UA-4.2 205
factor Δ, Table UA-5.1, UA-5.2 206
postweld heat treatment requirements, Table UCS-56, Table UHT-56 ..... 124, 197
recommended temperature ranges for heat treatment, Table UHA-105 178
spherical radius factor K_1, Table UG-37 27
Telltale holes, UG-25, UCL-25 ..... 10, 184
in opening reinforcement, UW-15 73
Temperature, definitions, UA-60 238
design, UG-20 8
determination, UA-130 302
free movement of vessel on supports, UA-186 .. 305
heat treatment, Table UCS-56, Table UHT-56 .. 124, 198
limitations, of brazed vessels, UB-2 99
of cast ductile iron, UCD-3 188
of postweld heat treating, UW-40, UCS-56, UHA-32, UHT-56 ..... 81, 124, 174, 198
metal, control of, Appendix T 332
operating or working, definitions, UA-60 238
zones of different, UG-20 8
Test coupons, UHT-81 199
Test gages, requirements, UG-102 53
Test plates, heat treatment, UG-84 43
impact tests, UG-84, UHA-51 ..... 41, 176
production, UNF-95 137
Tests, hydrostatic proof, UG-101, UCI-101, UCD-101 ..... 49, 181, 191
pneumatic (*see* Pneumatic test)
vessels whose strength cannot be calculated, U-2, UG-101, UCI-101 ..... 2, 49, 181
Thermal buffers, UHT-81 199
Thermocouples, attachment, UA-130 302
Thickness gages, details, UW-51 83
Thick shells, cylindrical, UA-2 202
spherical, UA-3 202
Thin plates, marking, UG-77, UHT-86 ..... 37, 200
Threaded connections, UG-43 31
Threaded inspection openings, UG-46 32
Threads, stud bolts, UG-12 7
Tolerances, forged shells and heads, UF-27, UF-29 ..... 94, 95
heads and shells, UG-80, UG-81 ..... 39, 40
rivet holes, UR-33 91
Toriconical heads, UG-32, UG-33 ..... 16, 19
Torispherical heads, UG-32, UG-33, UA-4 .. 16, 19, 203
Transferring markings on plates, UG-77 37
Transition in cylindrical shells, UG-36 25
Trays and baffles, acting as partial shell stiffeners, UG-29 13
Tubes and pipe, UG-9, UG-31, UCS-9, UNF-9 .. 5, 16, 108, 129

Ultrasonic examination of welds, Appendix U 332
Unfired steam boiler, U-1 1
Unidentified materials, UG-10 5

Valves, safety and relief (*see* Safety and relief valves)
Valves and fittings, marking, UG-11 6
Verification tests, heat treatment, UHT-81 199
Volume exemption, U-1 1

Weld deposits, cleaning, UW-32 80
peening, UW-39 81
Welded joints, category, UW-3, UHT-17 ..... 64, 193
description of types, UA-60 238
efficiency, UW-12 66
impact test, across, UCS-66, UHT-81 ..... 126, 199
porosity, UW-51 83
postweld heat treating, UW-10, UW-40, UCS-56, UNF-56, UHA-32, UCL-34, UHT-56 .. 65, 81, 124, 130, 174, 185, 198
radiographic examination, complete, UW-51, UHT-57 ..... 83, 198
radiographing requirements, UW-11, UCS-57, UHA-33, UCL-35, UHT-57 ..... 65, 126, 175, 185, 198
sectioning, etch tests, UA-250 309
spot examination, UW-52 86
staggered, longitudinal, UW-9 65
taper, plates of unequal thicknesses, UW-9 65
types, around openings, UW-15, UW-16, UHT-18 ..... 73, 193
ultrasonic examination of, Appendix U 332
Welded reinforcement of nozzle openings, UW-15, UW-16 73
Welded stayed construction, UW-19 77
Welded vessels, holes in joints of, UW-14 72
inspection, UW-46 to UW-52 ..... 82—86
limitations on, UW-2 63
tests of, UG-99, UW-50 ..... 47, 82
Welders and welding operators, identifying stamps, UW-29 78
records of, by manufacturers, UW-29 79
test of, qualification, UW-29, UHT-82 ..... 78, 200
Welding, cleaning of welded surfaces, UW-32 80
details, limitations, Fig. UW-13 68
forged vessels, UF-32 96
materials having different coefficients of expansion, UHT-40 198
of attachment around openings, UW-15, UW-16 73
plate, fitting up joint, UW-31 79
plate edges, matching, UW-31 79
preparation of plates, UW-31, UW-32 ..... 79, 80
procedure qualification, UW-28, UCL-40 to UCL-44, UHT-82 ..... 78, 185, 186, 200
processes, UW-27, UA-60 ..... 78, 238
test requirements, UW-46 to UW-52, UHT-82 ..... 82—86, 200
Weld metal composition, UHA-42, UCL-32, UHT-82 ..... 176, 184, 200
Welds, acceptability, when radiographed, UW-51, UW-52 ..... 83, 86
when sectioned, UW-51 83
fillet, UW-18, UW-36, UCL-46 ..... 77, 80, 187
finish, UHT-84 200
identification of, UW-37 80
plug, UW-17 77
reinforcement, butt welds, UW-35, UHT-84 ..... 80, 200
repairs of defects in, UW-38, UF-38, UF-46, UHT-85 ..... 81, 97, 200
sharp angles, avoid, at weld edges, UW-35 80

structural, UHT-85 200
tack, UW-31 79
temporary, UHT-85 200
types, description, UA-60 238
ultrasonic examination of, Appendix U 332

Working pressure, allowable,
braced and stayed surfaces, UG-47 33
by proof test, U-2, UG-101, UCI-101 .. 2, 49, 179
definition of, UG-98, UA-60 ..... 47, 238
on shells with lap-riveted joints, UR-18 89