ASME BPVC.III.1.NB-2023

SECTION III
Rules for Construction of Nuclear Facility Components

2023 ASME Boiler and Pressure Vessel Code
An International Code

Division 1 — Subsection NB
Class 1 Components

ASME
SETTING THE STANDARD

Markings such as “ASME,” “ASME Standard,” or any other marking including “ASME,” ASME logos, or the ASME Single Certification Mark shall not be used on any item that is not constructed in accordance with all of the applicable requirements of the Code or Standard. Use of the ASME Single Certification Mark requires formal ASME certification; if no certification program is available, such ASME markings may not be used. (For Certification and Accreditation Programs, see https://www.asme.org/certification-accreditation.)

Items produced by parties not formally possessing an ASME Certificate may not be described, either explicitly or implicitly, as ASME certified or approved in any code forms or other document.

AN INTERNATIONAL CODE

2023 ASME Boiler & Pressure Vessel Code

2023 Edition July 1, 2023

III

RULES FOR CONSTRUCTION OF NUCLEAR FACILITY COMPONENTS

Division 1 - Subsection NB

Class 1 Components

ASME Boiler and Pressure Vessel Committee
on Construction of Nuclear Facility Components

The American Society of Mechanical Engineers
Two Park Avenue • New York, NY • 10016 USA

Date of Issuance: July 1, 2023

This international code or standard was developed under procedures accredited as meeting the criteria for American National Standards and it is an American National Standard. The standards committee that approved the code or standard was balanced to ensure that individuals from competent and concerned interests had an opportunity to participate. The proposed code or standard was made available for public review and comment, which provided an opportunity for additional public input from industry, academia, regulatory agencies, and the public-at-large.

ASME does not "approve," "certify," "rate," or "endorse" any item, construction, proprietary device, or activity. ASME does not take any position with respect to the validity of any patent rights asserted in connection with any items mentioned in this document, and does not undertake to insure anyone utilizing a standard against liability for infringement of any applicable letters patent, nor does ASME assume any such liability. Users of a code or standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, is entirely their own responsibility.

Participation by federal agency representatives or persons affiliated with industry is not to be interpreted as government or industry endorsement of this code or standard.

ASME accepts responsibility for only those interpretations of this document issued in accordance with the established ASME procedures and policies, which precludes the issuance of interpretations by individuals.

The endnotes and preamble in this document (if any) are part of this American National Standard.

ASME Collective Membership Mark

ASME Single Certification Mark

Library of Congress Catalog Card Number: 56-3934

Adopted by the Council of The American Society of Mechanical Engineers, 1914; latest edition 2023.

The American Society of Mechanical Engineers
Two Park Avenue, New York, NY 10016-5990

TABLE OF CONTENTS

Figures

Tables

LIST OF SECTIONS

(23)

SECTIONS

I Rules for Construction of Power Boilers

II Materials
- Part A — Ferrous Material Specifications
- Part B — Nonferrous Material Specifications
- Part C — Specifications for Welding Rods, Electrodes, and Filler Metals
- Part D — Properties (Customary)
- Part D — Properties (Metric)

III Rules for Construction of Nuclear Facility Components
- Subsection NCA — General Requirements for Division 1 and Division 2
- Appendices
- Division 1
  - Subsection NB — Class 1 Components
  - Subsection NCD — Class 2 and Class 3 Components
  - Subsection NE — Class MC Components
  - Subsection NF — Supports
  - Subsection NG — Core Support Structures
- Division 2 — Code for Concrete Containments
- Division 3 — Containment Systems for Transportation and Storage of Spent Nuclear Fuel and High-Level Radioactive Material
- Division 4 — Fusion Energy Devices
- Division 5 — High Temperature Reactors

IV Rules for Construction of Heating Boilers

V Nondestructive Examination

VI Recommended Rules for the Care and Operation of Heating Boilers

VII Recommended Guidelines for the Care of Power Boilers

VIII Rules for Construction of Pressure Vessels
- Division 1
- Division 2 — Alternative Rules
- Division 3 — Alternative Rules for Construction of High Pressure Vessels

IX Welding, Brazing, and Fusing Qualifications

X Fiber-Reinforced Plastic Pressure Vessels

XI Rules for Inservice Inspection of Nuclear Reactor Facility Components
- Division 1 — Rules for Inspection and Testing of Components of Light-Water-Cooled Plants
- Division 2 — Requirements for Reliability and Integrity Management (RIM) Programs for Nuclear Reactor Facilities

XII Rules for Construction and Continued Service of Transport Tanks

XIII Rules for Overpressure Protection

FOREWORD*

In 1911, The American Society of Mechanical Engineers established the Boiler and Pressure Vessel Committee to formulate standard rules for the construction of steam boilers and other pressure vessels. In 2009, the Boiler and Pressure Vessel Committee was superseded by the following committees:

(a) Committee on Power Boilers (I)
(b) Committee on Materials (II)
(c) Committee on Construction of Nuclear Facility Components (III)
(d) Committee on Heating Boilers (IV)
(e) Committee on Nondestructive Examination (V)
(f) Committee on Pressure Vessels (VIII)
(g) Committee on Welding, Brazing, and Fusing (IX)
(h) Committee on Fiber-Reinforced Plastic Pressure Vessels (X)
(i) Committee on Nuclear Inservice Inspection (XI)
(j) Committee on Transport Tanks (XII)
(k) Committee on Overpressure Protection (XIII)
(l) Technical Oversight Management Committee (TOMC)

Where reference is made to "the Committee" in this Foreword, each of these committees is included individually and collectively.

The Committee's function is to establish rules of safety relating to pressure integrity, which govern the construction** of boilers, pressure vessels, transport tanks, and nuclear components, and the inservice inspection of nuclear components and transport tanks. For nuclear items other than pressure-retaining components, the Committee also establishes rules of safety related to structural integrity. The Committee also interprets these rules when questions arise regarding their intent. The technical consistency of the Sections of the Code and coordination of standards development activities of the Committees is supported and guided by the Technical Oversight Management Committee. This Code does not address other safety issues relating to the construction of boilers, pressure vessels, transport tanks, or nuclear components, or the inservice inspection of nuclear components or transport tanks. Users of the Code should refer to the pertinent codes, standards, laws, regulations, or other relevant documents for safety issues other than those relating to pressure integrity and, for nuclear items other than pressure-retaining components, structural integrity. Except for Sections XI and XII, and with a few other exceptions, the rules do not, of practical necessity, reflect the likelihood and consequences of deterioration in service related to specific service fluids or external operating environments. In formulating the rules, the Committee considers the needs of users, manufacturers, and inspectors of components addressed by the Code. The objective of the rules is to afford reasonably certain protection of life and property, and to provide a margin for deterioration in service to give a reasonably long, safe period of usefulness. Advancements in design and materials and evidence of experience have been recognized.

This Code contains mandatory requirements, specific prohibitions, and nonmandatory guidance for construction activities and inservice inspection and testing activities. The Code does not address all aspects of these activities and those aspects that are not specifically addressed should not be considered prohibited. The Code is not a handbook and cannot replace education, experience, and the use of engineering judgment. The phrase *engineering judgment* refers to technical judgments made by knowledgeable engineers experienced in the application of the Code. Engineering judgments must be consistent with Code philosophy, and such judgments must never be used to overrule mandatory requirements or specific prohibitions of the Code.

The Committee recognizes that tools and techniques used for design and analysis change as technology progresses and expects engineers to use good judgment in the application of these tools. The designer is responsible for complying with Code rules and demonstrating compliance with Code equations when such equations are mandatory. The Code neither requires nor prohibits the use of computers for the design or analysis of components constructed to the requirements of the Code. However, designers and engineers using computer programs for design or analysis are cautioned that they are

* The information contained in this Foreword is not part of this American National Standard (ANS) and has not been processed in accordance with ANSI's requirements for an ANS. Therefore, this Foreword may contain material that has not been subjected to public review or a consensus process. In addition, it does not contain requirements necessary for conformance to the Code.

** *Construction*, as used in this Foreword, is an all-inclusive term comprising materials, design, fabrication, examination, inspection, testing, certification, and overpressure protection.

responsible for all technical assumptions inherent in the programs they use and the application of these programs to their design.

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 Committee meets regularly to consider revisions of the rules, new rules as dictated by technological development, Code Cases, and requests for interpretations. Only the Committee has the authority to provide official interpretations of this Code. Requests for revisions, new rules, Code Cases, or interpretations shall be addressed to the Secretary in writing and shall give full particulars in order to receive consideration and action (see Submittal of Technical Inquiries to the Boiler and Pressure Vessel Standards Committees). Proposed revisions to the Code resulting from inquiries will be presented to the Committee for appropriate action. The action of the Committee becomes effective only after confirmation by ballot of the Committee and approval by ASME. Proposed revisions to the Code approved by the Committee are submitted to the American National Standards Institute (ANSI) and published at http://go.asme.org/BPVCPublicReview to invite comments from all interested persons. After public review and final approval by ASME, revisions are published at regular intervals in Editions of the Code.

The Committee does not rule on whether a component shall or shall not be constructed to the provisions of the Code. The scope of each Section has been established to identify the components and parameters considered by the Committee in formulating the Code rules.

Questions or issues regarding compliance of a specific component with the Code rules are to be directed to the ASME Certificate Holder (Manufacturer). Inquiries concerning the interpretation of the Code are to be directed to the Committee. ASME is to be notified should questions arise concerning improper use of the ASME Single Certification Mark.

When required by context in this Section, the singular shall be interpreted as the plural, and vice versa, and the feminine, masculine, or neuter gender shall be treated as such other gender as appropriate.

The words "shall," "should," and "may" are used in this Standard as follows:

– *Shall* is used to denote a requirement.
– *Should* is used to denote a recommendation.
– *May* is used to denote permission, neither a requirement nor a recommendation.

STATEMENT OF POLICY ON THE USE OF THE ASME SINGLE CERTIFICATION MARK AND CODE AUTHORIZATION IN ADVERTISING

ASME has established procedures to authorize qualified organizations to perform various activities in accordance with the requirements of the ASME Boiler and Pressure Vessel Code. It is the aim of the Society to provide recognition of organizations so authorized. An organization holding authorization to perform various activities in accordance with the requirements of the Code may state this capability in its advertising literature.

Organizations that are authorized to use the ASME Single Certification Mark for marking items or constructions that have been constructed and inspected in compliance with the ASME Boiler and Pressure Vessel Code are issued Certificates of Authorization. It is the aim of the Society to maintain the standing of the ASME Single Certification Mark for the benefit of the users, the enforcement jurisdictions, and the holders of the ASME Single Certification Mark who comply with all requirements.

Based on these objectives, the following policy has been established on the usage in advertising of facsimiles of the ASME Single Certification Mark, Certificates of Authorization, and reference to Code construction. The American Society of Mechanical Engineers does not "approve," "certify," "rate," or "endorse" any item, construction, or activity and there shall be no statements or implications that might so indicate. An organization holding the ASME Single Certification Mark and/or a Certificate of Authorization may state in advertising literature that items, constructions, or activities "are built (produced or performed) or activities conducted 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." An ASME corporate logo shall not be used by any organization other than ASME.

The ASME Single Certification Mark 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 the ASME Single Certification Mark who may also use the facsimile in advertising to show that clearly specified items will carry the ASME Single Certification Mark.

STATEMENT OF POLICY ON THE USE OF ASME MARKING TO IDENTIFY MANUFACTURED ITEMS

The ASME Boiler and Pressure Vessel Code provides rules for the construction of boilers, pressure vessels, and nuclear components. This includes requirements for materials, design, fabrication, examination, inspection, and stamping. Items constructed in accordance with all of the applicable rules of the Code are identified with the ASME Single Certification Mark described in the governing Section of the Code.

Markings such as "ASME," "ASME Standard," or any other marking including "ASME" or the ASME Single Certification Mark shall not be used on any item that is not constructed in accordance with all of the applicable requirements of the Code.

Items shall not be described on ASME Data Report Forms nor on similar forms referring to ASME that tend to imply that all Code requirements have been met when, in fact, they have not been. Data Report Forms covering items not fully complying with ASME requirements should not refer to ASME or they should clearly identify all exceptions to the ASME requirements.

PERSONNEL
ASME Boiler and Pressure Vessel Standards Committees, Subgroups, and Working Groups

(23)

January 1, 2023

TECHNICAL OVERSIGHT MANAGEMENT COMMITTEE (TOMC)

R. E. McLaughlin, *Chair*
N. A. Finney, *Vice Chair*
S. J. Rossi, *Staff Secretary*
G. Aurioles, Sr.
R. W. Barnes
T. L. Bedeaux
C. Brown
D. B. DeMichael
R. P. Deubler
J. G. Feldstein
G. W. Galanes
J. A. Hall
T. E. Hansen
G. W. Hembree
R. B. Keating
B. Linnemann
W. M. Lundy
D. I. Morris
T. P. Pastor
M. D. Rana
S. C. Roberts
F. J. Schaaf, Jr.
G. Scribner
W. J. Sperko
D. Srnic
R. W. Swayne
J. Vattappilly
M. Wadkinson
B. K. Nutter, *Ex-Officio Member*
M. J. Pischke, *Ex-Officio Member*
J. F. Henry, *Honorary Member*

Subgroup on Research and Development (TOMC)

S. C. Roberts, *Chair*
S. J. Rossi, *Staff Secretary*
R. W. Barnes
N. A. Finney
W. Hoffelner
R. B. Keating
R. E. McLaughlin
T. P. Pastor
D. Andrei, *Contributing Member*

Subgroup on Strategic Initiatives (TOMC)

N. A. Finney, *Chair*
S. J. Rossi, *Staff Secretary*
R. W. Barnes
T. L. Bedeaux
G. W. Hembree
M. H. Jawad
R. B. Keating
R. E. McLaughlin
T. P. Pastor
S. C. Roberts

Task Group on Remote Inspection and Examination (SI-TOMC)

S. C. Roberts, *Chair*
P. J. Coco
N. A. Finney
S. A. Marks
R. Rockwood
C. Stevens
M. Tannenbaum
J. Cameron, *Alternate*
A. Byk, *Contributing Member*
J. Pang, *Contributing Member*
S. J. Rossi, *Contributing Member*
C. A. Sanna, *Contributing Member*

Special Working Group on High Temperature Technology (TOMC)

D. Dewees, *Chair*
F. W. Brust
T. D. Burchell
P. R. Donavin
B. F. Hantz
R. I. Jetter
P. Smith

ADMINISTRATIVE COMMITTEE

R. E. McLaughlin, *Chair*
N. A. Finney, *Vice Chair*
S. J. Rossi, *Staff Secretary*
J. Cameron
R. B. Keating
B. Linnemann
B. K. Nutter
M. J. Pischke
M. D. Rana
S. C. Roberts
R. R. Stevenson
R. W. Swayne
M. Wadkinson

MARINE CONFERENCE GROUP

J. Oh, *Staff Secretary*
J. G. Hungerbuhler, Jr.
G. Nair
H. N. Patel
N. Prokopuk
J. D. Reynolds

CONFERENCE COMMITTEE

R. D. Troutt — Texas, *Chair*
J. T. Amato — Ohio, *Secretary*
W. Anderson — Mississippi
R. Becker — Colorado
T. D. Boggs — Missouri
R. A. Boillard — Indiana
D. P. Brockerville — Newfoundland and Labrador, Canada
R. J. Bunte — Iowa
J. H. Burpee — Maine
M. Carlson — Washington
T. G. Clark — Oregon
B. J. Crawford — Georgia
E. L. Creaser — New Brunswick, Canada
J. J. Dacanay — Hawaii
R. DeLury — Manitoba, Canada
A. Denham — Michigan
C. Dinic — Ontario, Canada
D. A. Ehler — Nova Scotia, Canada
S. D. Frazier — Washington
T. J. Granneman II — Oklahoma
S. Harder — Arizona
M. L. Jordan — Kentucky
R. Kamboj — British Columbia, Canada
E. Kawa — Massachusetts
A. Khssassi — Quebec, Canada
D. Kinney — North Carolina
K. S. Lane — Alaska
J. LeSage, Jr. — Louisiana
A. M. Lorimor — South Dakota
M. Mailman — Northwest Territories, Canada
W. McGivney — City of New York, New York
S. F. Noonan — Maryland
C. L. O'Guin — Tennessee
B. S. Oliver — New Hampshire
J. L. Oliver — Nevada
P. B. Polick — Illinois
J. F. Porcella — West Virginia
B. Ricks — Montana
W. J. Ross — Pennsylvania
M. H. Sansone — New York
T. S. Seime — North Dakota
C. S. Selinger — Saskatchewan, Canada
J. E. Sharier — Ohio
R. Spiker — North Carolina
D. Srnic — Alberta, Canada
D. J. Stenrose — Michigan
R. J. Stimson II — Kansas
R. K. Sturm — Utah
D. K. Sullivan — Arkansas
J. Taveras — Rhode Island
G. Teel — California
D. M. Warburton — Florida
M. Washington — New Jersey
E. Wiggins — Alabama

INTERNATIONAL INTEREST REVIEW GROUP

V. Felix
Y.-G. Kim
S. H. Leong
W. Lin
O. F. Manafa
C. Minu
Y.-W. Park
A. R. Reynaga Nogales
P. Williamson

COMMITTEE ON POWER BOILERS (BPV I)

R. E. McLaughlin, *Chair*
E. M. Ortman, *Vice Chair*
U. D'Urso, *Staff Secretary*
D. I. Anderson
J. L. Arnold
K. K. Coleman
J. G. Feldstein
S. Fincher
G. W. Galanes
T. E. Hansen
J. S. Hunter
M. Ishikawa
M. Lemmons
L. Moedinger
Y. Oishi
M. Ortolani
A. Spangenberg
D. E. Tompkins
D. E. Tuttle
J. Vattappilly
M. Wadkinson
R. V. Wielgoszinski
F. Zeller
H. Michael, *Delegate*
D. L. Berger, *Honorary Member*
P. D. Edwards, *Honorary Member*
D. N. French, *Honorary Member*
J. Hainsworth, *Honorary Member*
J. F. Henry, *Honorary Member*
W. L. Lowry, *Honorary Member*
J. R. MacKay, *Honorary Member*
P. A. Molvie, *Honorary Member*
J. T. Pillow, *Honorary Member*
B. W. Roberts, *Honorary Member*
R. D. Schueler, Jr., *Honorary Member*
J. M. Tanzosh, *Honorary Member*
R. L. Williams, *Honorary Member*
L. W. Yoder, *Honorary Member*

Executive Committee (BPV I)

E. M. Ortman, *Chair*
R. E. McLaughlin, *Vice Chair*
D. I. Anderson
J. L. Arnold
J. R. Braun
K. K. Coleman
H. Dalal
T. Dhanraj
U. D'Urso
P. F. Gilston
K. Hayes
P. Jennings
A. Spangenberg
D. E. Tompkins
M. Wadkinson

Subgroup on Design (BPV I)

D. I. Anderson, *Chair*
L. S. Tsai, *Secretary*
P. Becker
L. Krupp
C. T. McDaris
N. S. Ranck
J. Vattappilly
M. Wadkinson
D. Dewees, *Contributing Member*
J. P. Glaspie, *Contributing Member*

Subgroup on Fabrication and Examination (BPV I)

J. L. Arnold, *Chair*
P. F. Gilston, *Vice Chair*
P. Becker, *Secretary*
K. K. Coleman
S. Fincher
G. W. Galanes
T. E. Hansen
P. Jennings
M. Lewis
C. T. McDaris
R. E. McLaughlin
R. J. Newell
Y. Oishi
R. V. Wielgoszinski

Subgroup on General Requirements and Piping (BPV I)

D. E. Tompkins, *Chair*
M. Wadkinson, *Vice Chair*
M. Lemmons, *Secretary*
R. Antoniuk
T. E. Hansen
M. Ishikawa
R. E. McLaughlin
L. Moedinger
B. J. Mollitor
Y. Oishi
E. M. Ortman
D. E. Tuttle
J. Vattappilly
R. V. Wielgoszinski
W. L. Lowry, *Contributing Member*

Subgroup on Locomotive Boilers (BPV I)

J. R. Braun, *Chair*
S. M. Butler, *Secretary*
G. W. Galanes
D. W. Griner
M. A. Janssen
S. A. Lee
L. Moedinger
G. M. Ray
M. W. Westland

Subgroup on Materials (BPV I)

K. K. Coleman, *Chair*
K. Hayes, *Vice Chair*
M. Lewis, *Secretary*
S. H. Bowes
G. W. Galanes
P. F. Gilston
J. S. Hunter
E. Liebl
F. Masuyama
L. S. Nicol
M. Ortolani
D. W. Rahoi
F. Zeller
B. W. Roberts, *Contributing Member*
J. M. Tanzosh, *Contributing Member*

Subgroup on Solar Boilers (BPV I)

P. Jennings, *Chair*
R. E. Hearne, *Secretary*
S. Fincher
J. S. Hunter
P. Swarnkar

Task Group on Modernization (BPV I)

D. I. Anderson, *Chair*
U. D'Urso, *Staff Secretary*
J. L. Arnold
D. Dewees
G. W. Galanes
J. P. Glaspie
T. E. Hansen
R. E. McLaughlin
E. M. Ortman
D. E. Tuttle
J. Vattappilly

Germany International Working Group (BPV I)

A. Spangenberg, *Chair*
P. Chavdarov, *Secretary*
B. Daume
J. Fleischfresser
C. Jaekel
R. Kauer
D. Koelbl
S. Krebs
T. Ludwig
R. A. Meyers
H. Michael
F. Miunske
M. Sykora
R. Helmholdt, *Contributing Member*
J. Henrichsmeyer, *Contributing Member*
B. Müller, *Contributing Member*

India International Working Group (BPV I)

H. Dalal, *Chair*
T. Dhanraj, *Vice Chair*
K. Thanupillai, *Secretary*
P. Brahma
S. Chakrabarti
A. Hantodkar
A. J. Patil
S. Purkait
M. G. Rao
G. U. Shanker
D. K. Shrivastava
K. Singha
R. Sundararaj
S. Venkataramana

COMMITTEE ON MATERIALS (BPV II)

J. Cameron, *Chair*
G. W. Galanes, *Vice Chair*
C. E. Rodrigues, *Staff Secretary*
A. Appleton
P. Chavdarov
K. K. Coleman
D. W. Gandy
J. F. Grubb
J. A. Hall
D. O. Henry
K. M. Hottle
M. Ishikawa
K. Kimura
M. Kowalczyk
D. L. Kurle
F. Masuyama
S. Neilsen
L. S. Nicol
M. Ortolani
D. W. Rahoi
W. Ren
E. Shapiro
R. C. Sutherlin
F. Zeller
O. Oldani, *Delegate*
A. Chaudouet, *Contributing Member*
J. D. Fritz, *Contributing Member*
W. Hoffelner, *Contributing Member*
K. E. Orie, *Contributing Member*
D. T. Peters, *Contributing Member*
B. W. Roberts, *Contributing Member*
J. M. Tanzosh, *Contributing Member*
E. Upitis, *Contributing Member*
R. G. Young, *Contributing Member*

Executive Committee (BPV II)

J. Cameron, *Chair*
C. E. Rodrigues, *Staff Secretary*
A. Appleton
K. K. Coleman
G. W. Galanes
J. F. Grubb
S. Guzey
W. Hoffelner
M. Ishikawa
M. Ortolani
P. K. Rai
J. Robertson
E. Shapiro

Subgroup on External Pressure (BPV II)

S. Guzey, *Chair*
E. Alexis, *Vice Chair*
J. A. A. Morrow, *Secretary*
L. F. Campbell
H. Chen
D. S. Griffin
J. F. Grubb
M. H. Jawad
S. Krishnamurthy
D. L. Kurle
R. W. Mikitka
P. K. Rai
M. Wadkinson

Subgroup on Ferrous Specifications (BPV II)

A. Appleton, *Chair*
K. M. Hottle, *Vice Chair*
C. Hyde, *Secretary*
D. Amire-Brahimi
G. Cuccio
O. Elkadim
D. Fialkowski
J. F. Grubb
D. S. Janikowski
Y.-J. Kim
S. G. Lee
W. C. Mack
J. Nickel
K. E. Orie
D. Poweleit
E. Upitis
L. Watzke
J. D. Fritz, *Contributing Member*
C. Meloy, *Contributing Member*

Subgroup on International Material Specifications (BPV II)

M. Ishikawa, *Chair*
P. Chavdarov, *Vice Chair*
A. Chaudouet
H. Chen
A. F. Garbolevsky
D. O. Henry
W. M. Lundy
F. Zeller
C. Zhou
O. Oldani, *Delegate*
H. Lorenz, *Contributing Member*
T. F. Miskell, *Contributing Member*
E. Upitis, *Contributing Member*

Subgroup on Nonferrous Alloys (BPV II)

E. Shapiro, *Chair*
W. MacDonald, *Vice Chair*
J. Robertson, *Secretary*
R. M. Beldyk
J. M. Downs
J. F. Grubb
J. A. Hall
D. Maitra
J. A. McMaster
D. W. Rahoi
W. Ren
R. C. Sutherlin
R. Wright
S. Yem
D. B. Denis, *Contributing Member*
D. T. Peters, *Contributing Member*

Subgroup on Physical Properties (BPV II)

P. K. Rai, *Chair*
S. Neilsen, *Vice Chair*
G. Aurioles, Sr.
D. Chandiramani
P. Chavdarov
H. Eshraghi
J. F. Grubb
B. F. Hantz
R. D. Jones
P. K. Lam
D. W. Rahoi
E. Shapiro
D. K. Verma
S. Yem
D. B. Denis, *Contributing Member*

Subgroup on Strength, Ferrous Alloys (BPV II)

M. Ortolani, *Chair*
L. S. Nicol, *Secretary*
G. W. Galanes
J. A. Hall
M. Ishikawa
S. W. Knowles
F. Masuyama
M. Osterfoss
D. W. Rahoi
S. Rosinski
M. Ueyama
F. Zeller
F. Abe, *Contributing Member*
R. G. Young, *Contributing Member*

Subgroup on Strength of Weldments (BPV II & BPV IX)

K. K. Coleman, *Chair*
K. L. Hayes, *Vice Chair*
S. H. Bowes, *Secretary*
M. Denault
G. W. Galanes
D. W. Gandy
M. Ghahremani
W. F. Newell, Jr.
J. Penso
D. W. Rahoi
W. J. Sperko
J. P. Swezy, Jr.
M. Ueyama
P. D. Flenner, *Contributing Member*
B. W. Roberts, *Contributing Member*

Working Group on Materials Database (BPV II)

W. Hoffelner, *Chair*
C. E. Rodrigues, *Staff Secretary*
F. Abe
W. MacDonald
R. C. Sutherlin
D. Andrei, *Contributing Member*
J. L. Arnold, *Contributing Member*
J. Cameron, *Contributing Member*
J. F. Grubb, *Contributing Member*
D. T. Peters, *Contributing Member*
W. Ren, *Contributing Member*
B. W. Roberts, *Contributing Member*
E. Shapiro, *Contributing Member*

Working Group on Creep Strength Enhanced Ferritic Steels (BPV II)

M. Ortolani, *Chair*
G. W. Galanes, *Vice Chair*
P. Becker, *Secretary*
S. H. Bowes
K. K. Coleman
K. Kimura
M. Lang
S. Luke
F. Masuyama
T. Melfi
W. F. Newell, Jr.
J. J. Sanchez-Hanton
J. A. Siefert
W. J. Sperko
F. Zeller
F. Abe, *Contributing Member*
P. D. Flenner, *Contributing Member*
J. M. Tanzosh, *Contributing Member*

Working Group on Data Analysis (BPV II)

J. F. Grubb, *Chair*
W. Ren, *Vice Chair*
K. Kimura
F. Masuyama
S. Neilsen
M. Ortolani
M. J. Swindeman
F. Abe, *Contributing Member*
W. Hoffelner, *Contributing Member*
W. C. Mack, *Contributing Member*
D. T. Peters, *Contributing Member*
B. W. Roberts, *Contributing Member*

China International Working Group (BPV II)

T. Xu, *Secretary*
W. Cai
W. Fang
Q. C. Feng
S. Huo
F. Kong
H. Leng
Hli Li
Hongbin Li
J. Li
S. Liu
Z. Rongcan
S. Tan
C. Wang
Jinguang Wang
Jiongxiang Wang
Q.-J. Wang
X. Wang
H.-C. Yang
J. Yang
L. Yin
H. Zhang
X.-H. Zhang
Y. Zhang

COMMITTEE ON CONSTRUCTION OF NUCLEAR FACILITY COMPONENTS (BPV III)

R. B. Keating, *Chair*
T. M. Adams, *Vice Chair*
D. E. Matthews, *Vice Chair*
A. Maslowski, *Staff Secretary*
A. Appleton
S. Asada
R. W. Barnes
W. H. Borter
M. E. Cohen
R. P. Deubler
P. R. Donavin
A. C. Eberhardt
J. V. Gardiner
J. Grimm
S. Hunter
R. M. Jessee
R. I. Jetter
C. C. Kim
G. H. Koo
D. W. Lewis
M. A. Lockwood
K. A. Manoly
K. Matsunaga
B. McGlone
S. McKillop
J. McLean
J. C. Minichiello
M. N. Mitchell
T. Nagata
J. B. Ossmann
S. Pellet
E. L. Pleins
T.-L. Sham
W. J. Sperko
W. Windes
C. Basavaraju, *Alternate*
C. T. Smith, *Contributing Member*
W. K. Sowder, Jr., *Contributing Member*
M. Zhou, *Contributing Member*
E. B. Branch, *Honorary Member*
G. D. Cooper, *Honorary Member*
D. F. Landers, *Honorary Member*
C. Pieper, *Honorary Member*

Executive Committee (BPV III)

R. B. Keating, *Chair*
A. Maslowski, *Secretary*
T. M. Adams
P. R. Donavin
J. V. Gardiner
J. Grimm
D. W. Lewis
K. A. Manoly
D. E. Matthews
S. McKillop
J. McLean
T.-L. Sham
W. K. Sowder, Jr.
K. A. Kavanagh, *Alternate*

Argentina International Working Group (BPV III)

M. F. Liendo, *Chair*
J. Fernández, *Vice Chair*
O. Martinez, *Staff Secretary*
O. A. Verastegui, *Secretary*
E. H. Aldaz
G. O. Anteri
A. P. Antipasti
D. O. Bordato
G. Bourguigne
M. Brusa
A. Claus
R. G. Cocco
A. J. Dall'Osto
J. I. Duo
M. M. Gamizo
I. M. Guerreiro
I. A. Knorr
D. E. Matthews
A. E. Pastor
M. Rivero
M. D. Vigliano
P. Yamamoto
M. Zunino

China International Working Group (BPV III)

Y. Wang, *Chair*
H. Yu, *Secretary*
L. Feng
J. Gu
L. Guo
C. Jiang
D. Kang
Y. Li
H. Lin
S. Liu
W. Liu
J. Ma
K. Mao
D. E. Matthews
J. Ming
W. Pei
C. Peiyin
Z. Sun
G. Tang
L. Ting
F. Wu
C. Yang
P. Yang
W. Yang
H. Yin
D. Yuangang
G. Zhang
D. Zhao
Z. Zhong
Q. Zhou
H. Zhu

Germany International Working Group (BPV III)

J. Wendt, *Chair*
D. Koelbl, *Vice Chair*
R. Gersinska, *Secretary*
P. R. Donavin
R. Döring
C. G. Frantescu
A. Huber
R. E. Hueggenberg
C. Huttner
E. Iacopetta
M. H. Koeppen
C. Kuschke
H.-W. Lange
T. Ludwig
X. Pitoiset
M. Reichert
G. Roos
J. Rudolph
L. Sybertz
I. Tewes
R. Tiete
F. Wille

India International Working Group (BPV III)

R. N. Sen, *Chair*
S. B. Parkash, *Vice Chair*
A. D. Bagdare, *Secretary*
S. Aithal
S. Benhur
N. M. Borwankar
M. Brijlani
H. Dalal
S. K. Goyal
A. Johori
A. P. Kishore
D. Kulkarni
R. Kumar
S. Kumar
M. Lakshminarasimhan
T. Mukherjee
D. Narain
A. D. Paranjpe
J. R. Patel
E. L. Pleins
T. J. P. Rao
V. Sehgal
S. Singh
B. K. Sreedhar

Korea International Working Group (BPV III)

G. H. Koo, *Chair*
O.-S. Kim, *Secretary*
H. Ahn
S. Cho
G.-S. Choi
M.-J. Choi
S. Choi
J. Y. Hong
N.-S. Huh
J.-K. Hwang
S. S. Hwang
C. Jang
I. I. Jeong
S. H. Kang
J.-I. Kim
J.-S. Kim
M.-W. Kim
S.-S. Kim
Y.-B. Kim
Y.-S. Kim
D. Kwon
B. Lee
D. Lee
S. Lee
S.-G. Lee
H. Lim
I.-K. Nam
C.-K. Oh
C.-Y. Oh
E.-J. Oh
C. Park
H. Park
Y. S. Pyun
T. Shin
S. Song
W. J. Sperko
J. S. Yang
O. Yoo

Seismic Design Steering Committee (BPV III)

T. M. Adams, *Chair*
F. G. Abatt, *Secretary*
G. A. Antaki
C. Basavaraju
D. Chowdhury
R. Döring
G. H. Koo
A. Maekawa
K. Matsunaga
J. McLean
R. M. Pace
D. Watkins

Task Group on Alternate Requirements (BPV III)

J. Wen, *Chair*
R. R. Romano, *Secretary*
P. J. Coco
P. R. Donavin
J. V. Gardiner
J. Grimm
R. S. Hill III
M. Kris
M. A. Lockwood
D. E. Matthews
S. McKillop
B. P. Nolan
J. B. Ossmann
E. C. Renaud
M. A. Richter
I. H. Tseng
Y. Wang

United Kingdom International Working Group (BPV III)

C. D. Bell, *Chair*
P. M. James, *Vice Chair*
C. B. Carpenter, *Secretary*
T. M. Adams
T. Bann
M. J. Chevalier
A. J. Cole-Baker
M. Consonni
M. J. Crathorne
G. Innes
S. A. Jones
B. Pellereau
C. R. Schneider
J. W. Stairmand
J. Sulley
J. Talamantes-Silva
A. J. Holt, *Contributing Member*

Special Working Group on New Plant Construction Issues (BPV III)

J. B. Ossmann, *Chair*
A. Maslowski, *Staff Secretary*
M. C. Buckley, *Secretary*
M. Arcaro
A. Cardillo
P. J. Coco
K. Harris
J. Honcharik
M. Kris
R. E. McLaughlin
E. L. Pleins
D. W. Sandusky
M. C. Scott
R. R. Stevenson
H. Xu
J. Yan
J. C. Minichiello, *Contributing Member*

Special Working Group on Editing and Review (BPV III)

D. E. Matthews, *Chair*
R. P. Deubler
A. C. Eberhardt
J. V. Gardiner
S. Hunter
J. C. Minichiello
J. F. Strunk
C. Wilson

Special Working Group on HDPE Stakeholders (BPV III)

S. Patterson, *Secretary*
S. Choi
C. M. Faidy
M. Golliet
R. M. Jessee
J. Johnston, Jr.
M. Kuntz
M. Lashley
K. A. Manoly
D. P. Munson
T. M. Musto
J. E. O'Sullivan
V. Rohatgi
F. J. Schaaf, Jr.
R. Stakenborghs
M. Troughton
B. Lin, *Alternate*

Special Working Group on Honors and Awards (BPV III)

J. C. Minichiello, *Chair*
A. Appleton
R. W. Barnes
R. M. Jessee
D. E. Matthews

Special Working Group on International Meetings and IWG Liaisons (BPV III)

D. E. Matthews, *Chair*
A. Maslowski, *Staff Secretary*
T. M. Adams
R. W. Barnes
P. R. Donavin
E. L. Pleins
W. J. Sperko

Joint ACI-ASME Committee on Concrete Components for Nuclear Service (BPV III)

J. McLean, *Chair*
L. J. Colarusso, *Vice Chair*
J. Cassamassino, *Staff Secretary*
A. Dinizulu, *Staff Secretary*
C. J. Bang
A. C. Eberhardt
B. D. Hovis
T. C. Inman
C. Jones
T. Kang
N.-H. Lee
J. A. Munshi
T. Muraki
J. S. Saini
J. F. Strunk
G. Thomas
A. Varma
S. Wang
A. Istar, *Alternate*
A. Adediran, *Contributing Member*
S. Bae, *Contributing Member*
J.-B. Domage, *Contributing Member*
P. S. Ghosal, *Contributing Member*
B. B. Scott, *Contributing Member*
M. R. Senecal, *Contributing Member*
Z. Shang, *Contributing Member*
M. Sircar, *Contributing Member*
C. T. Smith, *Contributing Member*

Special Working Group on Modernization (BPV III-2)

S. Wang, *Chair*
J. McLean, *Vice Chair*
A. Adediran
S. Malushte
J. S. Saini
A. Varma
F. Lin, *Contributing Member*
J. A. Pires, *Contributing Member*
I. Zivanovic, *Contributing Member*

Task Group on Steel-Concrete Composite Containments (BPV III-2)

A. Varma, *Chair*
S. Malushte
J. McLean
J. A. Pires
J. S. Saini

Working Group on Design (BPV III-2)

N.-H. Lee, *Chair*
S. Wang, *Vice Chair*
M. Allam
S. Bae
L. J. Colarusso
A. C. Eberhardt
B. D. Hovis
T. C. Inman
C. Jones
J. A. Munshi
T. Muraki
J. S. Saini
G. Thomas
A. Istar, *Alternate*
P. S. Ghosal, *Contributing Member*
S.-Y. Kim, *Contributing Member*
J. Kwon, *Contributing Member*
S. E. Ohler-Schmitz, *Contributing Member*
B. B. Scott, *Contributing Member*
Z. Shang, *Contributing Member*
M. Shin, *Contributing Member*
M. Sircar, *Contributing Member*

Working Group on Materials, Fabrication, and Examination (BPV III-2)

C. Jones, *Chair*
A. Eberhardt, *Vice Chair*
C. J. Bang
B. Birch
J.-B. Domage
T. Kang
N.-H. Lee
Z. Shang
J. F. Strunk
A. A. Aboelmagd, *Contributing Member*
P. S. Ghosal, *Contributing Member*
B. B. Scott, *Contributing Member*
I. Zivanovic, *Contributing Member*

Subcommittee on Design (BPV III)

P. R. Donavin, *Chair*
S. McKillop, *Vice Chair*
R. P. Deubler
M. A. Gray
R. I. Jetter
R. B. Keating
J.-I. Kim
K. A. Manoly
D. E. Matthews
M. N. Mitchell
B. Pellereau
T.-L. Sham
W. F. Weitze
C. Basavaraju, *Alternate*
G. L. Hollinger, *Contributing Member*
M. H. Jawad, *Contributing Member*
W. J. O'Donnell, Sr., *Contributing Member*
K. Wright, *Contributing Member*

Subgroup on Component Design (SC-D) (BPV III)

D. E. Matthews, *Chair*
P. Vock, *Vice Chair*
S. Pellet, *Secretary*
T. M. Adams
D. J. Ammerman
G. A. Antaki
J. J. Arthur
S. Asada
J. F. Ball
C. Basavaraju
D. Chowdhury
N. A. Costanzo
R. P. Deubler
M. Kassar
D. Keck
T. R. Liszkai
K. A. Manoly
J. C. Minichiello
T. Mitsuhashi
D. Murphy
T. M. Musto
T. Nagata
G. Z. Tokarski
S. Willoughby-Braun
C. Wilson
A. A. Dermenjian, *Contributing Member*
P. Hirschberg, *Contributing Member*
R. B. Keating, *Contributing Member*
O.-S. Kim, *Contributing Member*
R. J. Masterson, *Contributing Member*
H. S. Mehta, *Contributing Member*
I. Saito, *Contributing Member*
J. P. Tucker, *Contributing Member*

Task Group to Improve Section III/XI Interface (SG-CD) (BPV III)

P. Vock, *Chair*
E. Henry, *Secretary*
G. A. Antaki
A. Cardillo
D. Chowdhury
J. Honcharik
J. Hurst
J. Lambin
C. A. Nove
T. Nuoffer
J. B. Ossmann
A. T. Roberts III
J. Sciulli
A. Udyawar
S. Willoughby-Braun

Working Group on Core Support Structures (SG-CD) (BPV III)

D. Keck, *Chair*
R. Z. Ziegler, *Vice Chair*
R. Martin, *Secretary*
G. W. Delport
L. C. Hartless
T. R. Liszkai
M. Nakajima
M. D. Snyder
R. Vollmer
T. M. Wiger
C. Wilson
Y. Wong
H. S. Mehta, *Contributing Member*

Working Group on Design of Division 3 Containment Systems (SG-CD) (BPV III)

D. J. Ammerman, *Chair*
S. Klein, *Secretary*
G. Bjorkman
V. Broz
D. W. Lewis
J. M. Piotter
A. Rigato
P. Sakalaukus, Jr.
D. Siromani
R. Sypulski
X. Zhai
X. Zhang
C. R. Sydnor, *Alternate*
J. C. Minichiello, *Contributing Member*

Working Group on HDPE Design of Components (SG-CD) (BPV III)

T. M. Musto, *Chair*
J. B. Ossmann, *Secretary*
M. Brandes
S. Choi
J. R. Hebeisen
P. Krishnaswamy
M. Kuntz
K. A. Manoly
D. P. Munson
F. J. Schaaf, Jr.
R. Stakenborghs
M. T. Audrain, *Alternate*
J. C. Minichiello, *Contributing Member*

Working Group on Piping (SG-CD) (BPV III)

G. A. Antaki, *Chair*
G. Z. Tokarski, *Secretary*
C. Basavaraju
J. Catalano
F. Claeys
C. M. Faidy
R. G. Gilada
N. M. Graham
M. A. Gray
R. J. Gurdal
R. W. Haupt
A. Hirano
P. Hirschberg
M. Kassar
J. Kawahata
D. Lieb
I.-K. Nam
J. O'Callaghan
K. E. Reid II
D. Vlaicu
S. Weindorf
T. M. Adams, *Contributing Member*
R. B. Keating, *Contributing Member*
T. B. Littleton, *Contributing Member*
Y. Liu, *Contributing Member*
J. F. McCabe, *Contributing Member*
J. C. Minichiello, *Contributing Member*
A. N. Nguyen, *Contributing Member*
M. S. Sills, *Contributing Member*
N. C. Sutherland, *Contributing Member*
E. A. Wais, *Contributing Member*
C.-I. Wu, *Contributing Member*

Working Group on Pressure Relief (SG-CD) (BPV III)

K. R. May, *Chair*
R. Krithivasan, *Secretary*
M. Brown
J. W. Dickson
S. Jones
R. Lack
D. Miller
T. Patel
K. Shores
I. H. Tseng
B. J. Yonsky
Y. Wong, *Alternate*
J. Yu, *Alternate*
S. T. French, *Contributing Member*
D. B. Ross, *Contributing Member*
S. Ruesenberg, *Contributing Member*

Working Group on Pumps (SG-CD) (BPV III)

D. Chowdhury, *Chair*
J. V. Gregg, Jr., *Secretary*
B. Busse
M. D. Eftychiou
R. A. Fleming
K. J. Noel
J. Sulley
K. B. Wilson
Y. Wong
I. H. Tseng, *Alternate*
X. Di, *Contributing Member*
C. Gabhart, *Contributing Member*
R. Ladefian, *Contributing Member*

Working Group on Supports (SG-CD) (BPV III)

N. A. Costanzo, *Chair*
U. S. Bandyopadhyay, *Secretary*
K. Avrithi
N. M. Bisceglia
R. P. Deubler
N. M. Graham
Y. Matsubara
S. Pellet
G. Thomas
G. Z. Tokarski
L. Vandersip
P. Wiseman
R. J. Masterson, *Contributing Member*
J. R. Stinson, *Contributing Member*

Working Group on Valves (SG-CD) (BPV III)

P. Vock, *Chair*
S. Jones, *Secretary*
M. C. Buckley
A. Cardillo
G. A. Jolly
J. Lambin
T. Lippucci
C. A. Mizer
H. O'Brien
J. O'Callaghan
M. Rain
K. E. Reid II
J. Sulley
I. H. Tseng
J. P. Tucker
Y. Wong, *Alternate*

Working Group on Vessels (SG-CD) (BPV III)

D. Murphy, *Chair*
S. Willoughby-Braun, *Secretary*
J. J. Arthur
C. Basavaraju
M. Brijlani
L. Constantinescu
J. I. Kim
O.-S. Kim
D. E. Matthews
T. Mitsuhashi
T. J. Schriefer
M. C. Scott
P. K. Shah
D. Vlaicu
C. Wilson
R. Z. Ziegler
R. J. Huang, *Alternate*
B. Basu, *Contributing Member*
R. B. Keating, *Contributing Member*
W. F. Weitze, *Contributing Member*

Subgroup on Design Methods (SC-D) (BPV III)

S. McKillop, *Chair*
P. R. Donavin, *Vice Chair*
J. Wen, *Secretary*
K. Avrithi
L. Davies
M. A. Gray
J. V. Gregg, Jr.
K. Hsu
R. Kalnas
D. Keck
J. I. Kim
B. Pellereau
W. D. Reinhardt
P. Smith
R. Vollmer
W. F. Weitze
T. M. Adams, *Contributing Member*
C. W. Bruny, *Contributing Member*
S. R. Gosselin, *Contributing Member*
H. T. Harrison III, *Contributing Member*
W. J. O'Donnell, Sr., *Contributing Member*
K. Wright, *Contributing Member*

Special Working Group on Computational Modeling for Explicit Dynamics (SG-DM) (BPV III)

G. Bjorkman, *Chair*
D. J. Ammerman, *Vice Chair*
V. Broz, *Secretary*
S. Kuehner
D. Molitoris
W. D. Reinhardt
D. Siromani
C.-F. Tso
M. C. Yaksh
U. Zencker
X. Zhang
Y. Wong, *Contributing Member*

Working Group on Design Methodology (SG-DM) (BPV III)

B. Pellereau, *Chair*
R. Vollmer, *Secretary*
K. Avrithi
C. Basavaraju
F. Berkepile
C. M. Faidy
Y. Gao
M. Kassar
J. I. Kim
T. R. Liszkai
D. Lytle
K. Matsunaga
S. McKillop
S. Ranganath
W. D. Reinhardt
P. K. Shah
S. Wang
W. F. Weitze
J. Wen
T. M. Wiger
K. Hsu, *Alternate*
G. Banyay, *Contributing Member*
D. S. Bartran, *Contributing Member*
R. D. Blevins, *Contributing Member*
M. R. Breach, *Contributing Member*
C. W. Bruny, *Contributing Member*
D. L. Caldwell, *Contributing Member*
H. T. Harrison III, *Contributing Member*
C. F. Heberling II, *Contributing Member*
P. Hirschberg, *Contributing Member*
R. B. Keating, *Contributing Member*
A. Walker, *Contributing Member*
K. Wright, *Contributing Member*

Working Group on Environmental Fatigue Evaluation Methods (SG-DM) (BPV III)

M. A. Gray, *Chair*
W. F. Weitze, *Secretary*
S. Asada
K. Avrithi
R. C. Cipolla
T. M. Damiani
C. M. Faidy
A. Hirano
P. Hirschberg
K. Hsu
J.-S. Park
B. Pellereau
D. Vlaicu
K. Wang
R. Z. Ziegler
S. Cuvilliez, *Contributing Member*
T. D. Gilman, *Contributing Member*
S. R. Gosselin, *Contributing Member*
Y. He, *Contributing Member*
H. S. Mehta, *Contributing Member*
K. Wright, *Contributing Member*

Working Group on Fatigue Strength (SG-DM) (BPV III)

P. R. Donavin, *Chair*
M. S. Shelton, *Secretary*
R. S. Bass
T. M. Damiani
D. W. DeJohn
C. M. Faidy
P. Gill
S. R. Gosselin
R. J. Gurdal
C. F. Heberling II
C. E. Hinnant
P. Hirschberg
K. Hsu
J. I. Kim
S. H. Kleinsmith
B. Pellereau
S. Ranganath
Y. Wang
W. F. Weitze
Y. Zou
S. Majumdar, *Contributing Member*
H. S. Mehta, *Contributing Member*
W. J. O'Donnell, Sr., *Contributing Member*
K. Wright, *Contributing Member*

Working Group on Probabilistic Methods in Design (SG-DM) (BPV III)

M. Golliet, *Chair*
R. Kalnas, *Vice Chair*
K. Avrithi
G. Brouette
J. Hakii
D. O. Henry
A. Hirano
K. A. Manoly
P. J. O'Regan
B. Pellereau
M. Yagodich
R. S. Hill III, *Contributing Member*

Subgroup on Containment Systems for Spent Nuclear Fuel and High-Level Radioactive Material (BPV III)

D. W. Lewis, *Chair*
D. J. Ammerman, *Vice Chair*
S. Klein, *Secretary*
G. Bjorkman
V. Broz
A. Rigato
P. Sakalaukus, Jr.
D. Siromani
D. B. Spencer
R. Sypulski
J. Wellwood
X. J. Zhai
X. Zhang
D. Dunn, *Alternate*
W. H. Borter, *Contributing Member*
E. L. Pleins, *Contributing Member*
N. M. Simpson, *Contributing Member*

Subgroup on Fusion Energy Devices (BPV III)

W. K. Sowder, Jr., *Chair*
A. Maslowski, *Staff Secretary*
M. Ellis, *Secretary*
M. Bashir
J. P. Blanchard
T. P. Davis
B. R. Doshi
L. El-Guebaly
G. Holtmeier
D. Johnson
I. Kimihiro
C. J. Lammi
S. Lawler
P. Mokaria
D. J. Roszman
F. J. Schaaf, Jr.
P. Smith
Y. Song
C. Vangaasbeek
I. J. Zatz
R. W. Barnes, *Contributing Member*

Special Working Group on Fusion Stakeholders (BPV III-4)

T. P. Davis, *Chair*
R. W. Barnes
V. Chugh
S. S. Desai
F. Deschamps
M. Hua
S. Lawler
S. C. Middleburgh
R. J. Pearson
W. K. Sowder, Jr.
D. A. Sutherland
N. Young
J. Zimmermann

Working Group on General Requirements (BPV III-4)

D. J. Roszman, *Chair*
M. Ellis
P. Mokaria
W. K. Sowder, Jr.

Working Group on In-Vessel Components (BPV III-4)

M. Bashir, *Chair*
Y. Carin
T. P. Davis
M. Kalsey
S. T. Madabusi

Working Group on Magnets (BPV III-4)

W. K. Sowder, Jr., *Chair*
D. S. Bartran

Working Group on Materials (BPV III-4)

M. Porton, *Chair*
T. P. Davis
P. Mummery

Working Group on Vacuum Vessels (BPV III-4)

I. Kimihiro, *Chair*
L. C. Cadwallader
B. R. Doshi
D. Johnson
Q. Shijun
Y. Song

Working Group on Analysis Methods (SG-HTR) (BPV III)

M. C. Messner, *Chair*
H. Mahajan, *Secretary*
R. W. Barnes
J. A. Blanco
P. Carter
W. T. Jessup
R. I. Jetter
G. H. Koo
H. Qian
T. Riordan
T.-L. Sham
X. Wei
S. X. Xu
J. Young
M. R. Breach, *Contributing Member*
T. Hassan, *Contributing Member*
S. Krishnamurthy, *Contributing Member*
M. J. Swindeman, *Contributing Member*

Working Group on Creep-Fatigue and Negligible Creep (SG-HTR) (BPV III)

Y. Wang, *Chair*
M. Ando
P. Carter
M. E. Cohen
J. I. Duo
R. I. Jetter
G. H. Koo
H. Mahajan
M. McMurtrey
M. C. Messner
T. Nguyen
J. C. Poehler
H. Qian
R. Rajasekaran
T.-L. Sham
X. Wei
J. Young
M. Yoo, *Alternate*

Working Group on High Temperature Flaw Evaluation (SG-HTR) (BPV III)

C. J. Sallaberry, *Chair*
F. W. Brust
P. Carter
S. Kalyanam
B.-L. Lyow
M. C. Messner
J. C. Poehler
H. Qian
D. A. Scarth
D. J. Shim
A. Udyawar
X. Wei
S. X. Xu
M. Yoo, *Alternate*

Working Group on Nonmetallic Design and Materials (SG-HTR) (BPV III)

W. Windes, *Chair*
W. J. Geringer, *Vice Chair*
J. Potgieter, *Secretary*
G. Beirnaert
C. Chen
A. N. Chereskin
V. Chugh
C. Contescu
N. Gallego
S. T. Gonczy
K. Harris
M. G. Jenkins
J. Lang
M. P. Metcalfe
M. N. Mitchell
J. Parks
T.-L. Sham
A. Tzelepi
G. L. Zeng
M. Yoo, *Alternate*
A. Appleton, *Contributing Member*
R. W. Barnes, *Contributing Member*
A. A. Campbell, *Contributing Member*
S.-H. Chi, *Contributing Member*
Y. Katoh, *Contributing Member*
A. Mack, *Contributing Member*
J. B. Ossmann, *Contributing Member*

Subgroup on Materials, Fabrication, and Examination (BPV III)

J. Grimm, *Chair*
S. Hunter, *Secretary*
W. H. Borter
M. Brijlani
G. R. Cannell
A. Cardillo
S. Cho
P. J. Coco
R. H. Davis
D. B. Denis
B. D. Frew
D. W. Gandy
S. E. Gingrich
M. Golliet
L. S. Harbison
R. M. Jessee
C. C. Kim
M. Kris
D. W. Mann
T. Melfi
I.-K. Nam
J. B. Ossmann
J. E. O'Sullivan
M. C. Scott
W. J. Sperko
J. R. Stinson
J. F. Strunk
W. Windes
R. Wright
S. Yee
H. Michael, *Delegate*
A. L. Hiser, Jr., *Alternate*
R. W. Barnes, *Contributing Member*

Task Group on Advanced Manufacturing (BPV III)

D. W. Mann, *Chair*
D. W. Gandy, *Secretary*
R. Bass
D. Chowdhury
P. J. Coco
B. D. Frew
J. Grimm
A. L. Hiser, Jr.
J. Lambin
T. Lippucci
K. Matsunaga
T. Melfi
E. C. Renaud
W. J. Sperko
J. F. Strunk
J. Sulley
S. Tate
S. Wolbert
H. Xu
D. W. Pratt, *Alternate*
S. Malik, *Contibuting Member*

Joint Working Group on HDPE (SG-MFE) (BPV III)

M. Brandes, *Chair*
T. M. Musto, *Chair*
J. B. Ossmannn, *Secretary*
G. Brouette
M. C. Buckley
S. Choi
M. Golliet
J. Hebeisen
J. Johnston, Jr.
P. Krishnaswamy
M. Kuntz
B. Lin
K. Manoly
D. P. Munson
J. O'Sullivan
V. Rohatgi
F. Schaaf, Jr.
S. Schuessler
R. Stakenborghs
M. Troughton
P. Vibien
J. Wright
T. Adams, *Contributing Member*

COMMITTEE ON HEATING BOILERS (BPV IV)

M. Wadkinson, *Chair*
J. L. Kleiss, *Vice Chair*
C. R. Ramcharran, *Staff Secretary*
B. Ahee
L. Badziagowski
T. L. Bedeaux
B. Calderon
J. P. Chicoine
C. Dinic
J. M. Downs
J. A. Hall
M. Mengon
D. Nelson
H. Michael, *Delegate*
D. Picart, *Delegate*
P. A. Molvie, *Contributing Member*

Executive Committee (BPV IV)

M. Wadkinson, *Chair*
C. R. Ramcharran, *Staff Secretary*
L. Badziagowski
T. L. Bedeaux
J. P. Chicoine
J. A. Hall
J. L. Kleiss

Subgroup on Cast Boilers (BPV IV)

J. P. Chicoine, *Chair*
J. M. Downs, *Vice Chair*
C. R. Ramcharran, *Staff Secretary*
T. L. Bedeaux
J. A. Hall
J. L. Kleiss
M. Mengon

Subgroup on Materials (BPV IV)

J. A. Hall, *Chair*
J. M. Downs, *Vice Chair*
C. R. Ramcharran, *Staff Secretary*
L. Badziagowski
T. L. Bedeaux
Y. Teng
M. Wadkinson

Subgroup on Water Heaters (BPV IV)

J. L. Kleiss, *Chair*
L. Badziagowski, *Vice Chair*
C. R. Ramcharran, *Staff Secretary*
B. Ahee
J. P. Chicoine
C. Dinic
B. J. Iske
M. Mengon
Y. Teng
T. E. Trant
P. A. Molvie, *Contributing Member*

Subgroup on Welded Boilers (BPV IV)

T. L. Bedeaux, *Chair*
C. R. Ramcharran, *Staff Secretary*
B. Ahee
L. Badziagowski
B. Calderon
J. P. Chicoine
C. Dinic
J. L. Kleiss
M. Mengon
M. Wadkinson
M. J. Melita, *Alternate*
D. Nelson, *Alternate*
P. A. Molvie, *Contributing Member*

Europe International Working Group (BPV IV)

L. Badziagowski, *Chair*
D. Picart, *Vice Chair*
R. Lozny
E. Van Bruggen
G. Vicchi
A. Alessandrini, *Alternate*

COMMITTEE ON NONDESTRUCTIVE EXAMINATION (BPV V)

N. A. Finney, *Chair*
C. May, *Vice Chair*
C. R. Ramcharran, *Staff Secretary*
D. Bajula
P. L. Brown
M. A. Burns
N. Carter
T. Clausing
C. Emslander
A. F. Garbolevsky
P. T. Hayes
G. W. Hembree
F. B. Kovacs
K. Krueger
B. D. Laite
P. B. Shaw
C. Vorwald
S. J. Akrin, *Contributing Member*
J. E. Batey, *Contributing Member*
A. S. Birks, *Contributing Member*
N. Y. Faransso, *Contributing Member*
J. F. Halley, *Contributing Member*
R. W. Kruzic, *Contributing Member*
L. E. Mullins, *Contributing Member*
F. J. Sattler, *Contributing Member*
H. C. Graber, *Honorary Member*
T. G. McCarty, *Honorary Member*

Executive Committee (BPV V)

C. May, *Chair*
N. A. Finney, *Vice Chair*
C. R. Ramcharran, *Staff Secretary*
N. Carter
V. F. Godinez-Azcuaga
P. T. Hayes
G. W. Hembree
F. B. Kovacs
K. Krueger
E. Peloquin
C. Vorwald

Subgroup on General Requirements/Personnel Qualifications and Inquiries (BPV V)

C. Vorwald, *Chair*
D. Bajula
N. Carter
P. Chavdarov
T. Clausing
C. Emslander
N. A. Finney
G. W. Hembree
F. B. Kovacs
K. Krueger
C. May
S. J. Akrin, *Contributing Member*
N. Y. Faransso, *Contributing Member*
J. F. Halley, *Contributing Member*
D. I. Morris, *Contributing Member*
J. P. Swezy, Jr., *Contributing Member*

Project Team on Assisted Analysis (BPV V)

K. Hayes, *Chair*
J. Aldrin
J. Chen
N. A. Finney
V. F. Godinez-Azcuaga
C. Hansen
G. W. Hembree
R. S. F. Orozco
E. Peloquin
T. Thulien

Subgroup on Volumetric Methods (BPV V)

C. May, *Chair*
P. T. Hayes, *Vice Chair*
D. Adkins
P. L. Brown
N. A. Finney
A. F. Garbolevsky
R. W. Hardy
G. W. Hembree
F. B. Kovacs
K. Krueger
E. Peloquin
C. Vorwald
S. J. Akrin, *Contributing Member*
N. Y. Faransso, *Contributing Member*
J. F. Halley, *Contributing Member*
R. W. Kruzic, *Contributing Member*
L. E. Mullins, *Contributing Member*
F. J. Sattler, *Contributing Member*

Working Group on Radiography (SG-VM) (BPV V)

C. Vorwald, *Chair*
D. M. Woodward, *Vice Chair*
J. Anderson
P. L. Brown
C. Emslander
A. F. Garbolevsky
R. W. Hardy
G. W. Hembree
F. B. Kovacs
B. D. Laite
T. R. Lerohl
C. May
R. J. Mills
J. F. Molinaro
T. Vidimos
B. White
S. J. Akrin, *Contributing Member*
T. L. Clifford, *Contributing Member*
N. Y. Faransso, *Contributing Member*
R. W. Kruzic, *Contributing Member*

Working Group on Ultrasonics (SG-VM) (BPV V)

K. Krueger, *Chair*
D. Bajula, *Vice Chair*
D. Adkins
C. Brown
C. Emslander
N. A. Finney
P. T. Hayes
G. W. Hembree
B. D. Laite
T. R. Lerohl
C. May
E. Peloquin
J. Schoneweis
D. Tompkins
D. Van Allen
J. Vinyard
C. Vorwald
C. Wassink
N. Y. Faransso, *Contributing Member*
J. F. Halley, *Contributing Member*
R. W. Kruzic, *Contributing Member*
P. Mudge, *Contributing Member*
L. E. Mullins, *Contributing Member*
M. J. Quarry, *Contributing Member*
F. J. Sattler, *Contributing Member*
J. Vanvelsor, *Contributing Member*

Working Group on Acoustic Emissions (SG-VM) (BPV V)

V. F. Godinez-Azcuaga, *Chair*
J. Catty, *Vice Chair*
S. R. Doctor
N. F. Douglas, Jr.
R. K. Miller
N. Y. Faransso, *Contributing Member*

Working Group on Full Matrix Capture (SG-VM) (BPV V)

E. Peloquin, *Chair*
C. Wassink, *Vice Chair*
D. Bajula
D. Bellistri
J. Catty
N. A. Finney
J. L. Garner
R. T. Grotenhuis
P. T. Hayes
G. W. Hembree
K. Krueger
M. Lozev
R. Nogueira
D. Richard
M. Sens
D. Tompkins
J. F. Halley, *Contributing Member*
L. E. Mullins, *Contributing Member*

Subgroup on Inservice Examination Methods and Techniques (BPV V)

P. T. Hayes, *Chair*
E. Peloquin, *Vice Chair*
M. A. Burns
M. Carlson
N. A. Finney
V. F. Godinez-Azcuaga
G. W. Hembree
K. Krueger
C. May
D. D. Raimander
C. Vorwald

Subgroup on Surface Examination Methods (BPV V)

N. Carter, *Chair*
B. D. Laite, *Vice Chair*
R. M. Beldyk
P. L. Brown
T. Clausing
C. Emslander
N. Farenbaugh
N. A. Finney
A. F. Garbolevsky
K. Hayes
G. W. Hembree
C. May
P. B. Shaw
R. Tedder
C. Vorwald
C. Wassink
D. M. Woodward
S. J. Akrin, *Contributing Member*
N. Y. Faransso, *Contributing Member*
J. F. Halley, *Contributing Member*
R. W. Kruzic, *Contributing Member*
L. E. Mullins, *Contributing Member*
F. J. Sattler, *Contributing Member*

Germany International Working Group (BPV V)

P. Chavdarov, *Chair*
C. Kringe, *Vice Chair*
H.-P. Schmitz, *Secretary*
K.-H. Gischler
D. Kaiser
S. Mann
V. Reusch

India International Working Group (BPV V)

P. Kumar, *Chair*
A. V. Bhagwat
J. Chahwala
S. Jobanputra
D. Joshi
G. R. Joshi
A. Relekar
V. J. Sonawane
D. B. Tanpure

Italy International Working Group (BPV V)

D. D. Raimander, *Chair*
O. Oldani, *Vice Chair*
C. R. Ramcharran, *Staff Secretary*
P. Campli, *Secretary*
M. Agostini
T. Aldo
F. Bresciani
N. Caputo
M. Colombo
P. L. Dinelli
F. Ferrarese
E. Ferrari
M. A. Grimoldi
G. Luoni
U. Papponetti
P. Pedersoli
A. Veroni
M. Zambon
V. Calo, *Contributing Member*
G. Gobbi, *Contributing Member*
A. Gusmaroli, *Contributing Member*
G. Pontiggia, *Contributing Member*

COMMITTEE ON PRESSURE VESSELS (BPV VIII)

S. C. Roberts, *Chair*
M. D. Lower, *Vice Chair*
S. J. Rossi, *Staff Secretary*
G. Aurioles, Sr.
S. R. Babka
R. J. Basile
P. Chavdarov
D. B. DeMichael
J. F. Grubb
B. F. Hantz
M. Kowalczyk
D. L. Kurle
R. Mahadeen
S. A. Marks
P. Matkovics
R. W. Mikitka
B. R. Morelock
T. P. Pastor
D. T. Peters
M. J. Pischke
M. D. Rana
G. B. Rawls, Jr.
F. L. Richter
C. D. Rodery
J. C. Sowinski
D. Srnic
D. B. Stewart
P. L. Sturgill
K. Subramanian
D. A. Swanson
J. P. Swezy, Jr.
S. Terada
E. Upitis
A. Viet
K. Xu
P. A. McGowan, *Delegate*
H. Michael, *Delegate*
K. Oyamada, *Delegate*
M. E. Papponetti, *Delegate*
A. Chaudouet, *Contributing Member*
J. P. Glaspie, *Contributing Member*
K. T. Lau, *Contributing Member*
U. R. Miller, *Contributing Member*
K. Mokhtarian, *Contributing Member*
G. G. Karcher, *Honorary Member*
K. K. Tam, *Honorary Member*

Executive Committee (BPV VIII)

M. D. Lower, *Chair*
S. J. Rossi, *Staff Secretary*
G. Aurioles, Sr.
C. W. Cary
J. Hoskinson
M. Kowalczyk
S. A. Marks
P. Matkovics
S. C. Roberts
J. C. Sowinski
K. Subramanian
K. Xu

Subgroup on Design (BPV VIII)

J. C. Sowinski, *Chair*
C. S. Hinson, *Vice Chair*
G. Aurioles, Sr.
S. R. Babka
O. A. Barsky
R. J. Basile
D. Chandiramani
M. D. Clark
M. Faulkner
B. F. Hantz
C. E. Hinnant
M. H. Jawad
S. Krishnamurthy
D. L. Kurle
K. Kuscu
M. D. Lower
R. W. Mikitka
B. Millet
M. D. Rana
G. B. Rawls, Jr.
S. C. Roberts
C. D. Rodery
T. G. Seipp
D. Srnic
D. A. Swanson
S. Terada
J. Vattappilly
K. Xu
K. Oyamada, *Delegate*
M. E. Papponetti, *Delegate*
P. K. Lam, *Contributing Member*
K. Mokhtarian, *Contributing Member*
T. P. Pastor, *Contributing Member*
S. C. Shah, *Contributing Member*
K. K. Tam, *Contributing Member*
E. Upitis, *Contributing Member*

Working Group on Design-by-Analysis (BPV VIII)

B. F. Hantz, *Chair*
T. W. Norton, *Secretary*
D. A. Arnett
J. Bedoya
S. Guzey
C. F. Heberling II
C. E. Hinnant
M. H. Jawad
S. Kataoka
S. Kilambi
K. D. Kirkpatrick
S. Krishnamurthy
A. Mann
C. Nadarajah
P. Prueter
T. G. Seipp
M. A. Shah
S. Terada
R. G. Brown, *Contributing Member*
D. Dewees, *Contributing Member*
K. Saboda, *Contributing Member*

Working Group on Elevated Temperature Design (BPV I and VIII)

A. Mann, *Chair*
C. Nadarajah, *Secretary*
D. Anderson
D. Dewees
B. F. Hantz
M. H. Jawad
R. I. Jetter
S. Krishnamurthy
T. Le
M. C. Messner
M. N. Mitchell
P. Prueter
M. J. Swindeman
J. P. Glaspie, *Contributing Member*
N. McMurray, *Contributing Member*
B. J. Mollitor, *Contributing Member*

Subgroup on Fabrication and Examination (BPV VIII)

S. A. Marks, *Chair*
D. I. Morris, *Vice Chair*
T. Halligan, *Secretary*
N. Carter
J. Lu
B. R. Morelock
O. Mulet
M. J. Pischke
M. J. Rice
J. Roberts
C. D. Rodery
B. F. Shelley
D. Smith
P. L. Sturgill
J. P. Swezy, Jr.
E. Upitis
C. Violand
K. Oyamada, *Delegate*
W. J. Bees, *Contributing Member*
L. F. Campbell, *Contributing Member*
R. Uebel, *Contributing Member*

Subgroup on General Requirements (BPV VIII)

J. Hoskinson, *Chair*
M. Faulkner, *Vice Chair*
N. Barkley
R. J. Basile
T. P. Beirne
D. B. DeMichael
M. D. Lower
T. P. Pastor
I. Powell
G. B. Rawls, Jr.
F. L. Richter
S. C. Roberts
J. Rust
J. C. Sowinski
P. Speranza
D. Srnic
D. B. Stewart
D. A. Swanson
J. P. Glaspie, *Contributing Member*
Y. Yang, *Contributing Member*

Task Group on Fired Heater Pressure Vessels (BPV VIII)

J. Hoskinson, *Chair*
W. Kim
S. Kirk
D. Nelson
T. P. Pastor
R. Robles
J. Rust
P. Shanks
E. Smith
D. Srnic

Task Group on Subsea Applications (BPV VIII)

M. Sarzynski, *Chair*
A. J. Grohmann, *Vice Chair*
L. P. Antalffy
R. C. Biel
J. Ellens
J. Hademenos
J. Kaculi
K. Karpanan
F. Kirkemo
C. Lan
P. Lutkiewicz
N. McKie
S. K. Parimi
R. H. Patil
M. P. Vaclavik
R. Cordes, *Contributing Member*
D. T. Peters, *Contributing Member*
J. R. Sims, *Contributing Member*

Subgroup on Heat Transfer Equipment (BPV VIII)

P. Matkovics, *Chair*
M. D. Clark, *Vice Chair*
L. Bower, *Secretary*
G. Aurioles, Sr.
S. R. Babka
J. H. Barbee
O. A. Barsky
T. Bunyarattaphantu
A. Chaudouet
D. L. Kurle
R. Mahadeen
S. Mayeux
S. Neilsen
E. Smith
A. M. Voytko
R. P. Wiberg
J. Pasek, *Contributing Member*
D. Srnic, *Contributing Member*
Z. Tong, *Contributing Member*

Working Group on Plate Heat Exchangers (BPV VIII)

D. I. Morris, *Chair*
S. R. Babka
J. F. Grubb
V. Gudge
R. Mahadeen
S. A. Marks
P. Matkovics
M. J. Pischke
P. Shanks
E. Smith
D. Srnic
S. Sullivan

Subgroup on High Pressure Vessels (BPV VIII)

K. Subramanian, *Chair*
M. Sarzynski, *Vice Chair*
A. Dinizulu, *Staff Secretary*
L. P. Antalffy
J. Barlow
R. C. Biel
P. N. Chaku
L. Fridlund
D. Fuenmayor
J. Gibson
R. T. Hallman
K. Karpanan
J. Keltjens
A. K. Khare
G. T. Nelson
D. T. Peters
E. D. Roll
J. R. Sims
E. Smith
F. W. Tatar
S. Terada
Y. Xu
A. M. Clayton, *Contributing Member*
R. Cordes, *Contributing Member*
R. D. Dixon, *Contributing Member*
Q. Dong, *Contributing Member*
T. A. Duffey, *Contributing Member*
R. M. Hoshman, *Contributing Member*
F. Kirkemo, *Contributing Member*
R. A. Leishear, *Contributing Member*
G. M. Mital, *Contributing Member*
M. Parr, *Contributing Member*
M. D. Rana, *Contributing Member*
C. Romero, *Contributing Member*
C. Tipple, *Contributing Member*
K.-J. Young, *Contributing Member*
D. J. Burns, *Honorary Member*
G. J. Mraz, *Honorary Member*

Subgroup on Materials (BPV VIII)

M. Kowalczyk, *Chair*
P. Chavdarov, *Vice Chair*
S. Kilambi, *Secretary*
J. Cameron
J. F. Grubb
D. Maitra
D. W. Rahoi
J. Robertson
R. C. Sutherlin
E. Upitis
K. Xu
S. Yem
A. Di Rienzo, *Contributing Member*
J. D. Fritz, *Contributing Member*
M. Katcher, *Contributing Member*
W. M. Lundy, *Contributing Member*
J. Penso, *Contributing Member*

Subgroup on Toughness (BPV VIII)

K. Xu, *Chair*
T. Halligan, *Vice Chair*
T. Finn
C. S. Hinson
S. Kilambi
D. L. Kurle
T. Newman
J. Qu
M. D. Rana
F. L. Richter
K. Subramanian
D. A. Swanson
J. P. Swezy, Jr.
S. Terada
E. Upitis
J. Vattappilly
K. Oyamada, *Delegate*
L. Dong, *Contributing Member*
S. Krishnamurthy, *Contributing Member*
K. Mokhtarian, *Contributing Member*

Subgroup on Graphite Pressure Equipment (BPV VIII)

C. W. Cary, *Chair*
A. Viet, *Vice Chair*
G. C. Becherer
F. L. Brown
R. J. Bulgin
J. D. Clements
H. Lee, Jr.
S. Mehrez
T. Rudy
A. A. Stupica

Argentina International Working Group (BPV VIII)

A. Dominguez, *Chair*
R. Robles, *Vice Chair*
G. Glissenti, *Secretary*
M. M. Acosta
R. A. Barey
C. Alderetes
F. A. Andres
A. Antipasti
D. A. Bardelli
L. F. Boccanera
O. S. Bretones
A. Burgueno
G. Casanas
D. H. Da Rold
D. A. Del Teglia
J. I. Duo
M. Favareto
M. D. Kuhn
F. P. Larrosa
L. M. Leccese
C. Meinl
M. A. Mendez
J. J. Monaco
C. Parente
M. A. A. Pipponzi
L. C. Rigoli
A. Rivas
D. Rizzo
J. C. Rubeo
S. Schamun
G. Telleria
M. M. C. Tocco

China International Working Group (BPV VIII)

X. Chen, *Chair*
B. Shou, *Vice Chair*
Z. Fan, *Secretary*
Y. Chen
J. Cui
R. Duan
J.-G. Gong
B. Han
J. Hu
Q. Hu
H. Hui
K. Li
D. Luo
Y. Luo
C. Miao
L. Sun
C. Wu
J. Xiaobin
F. Xu
G. Xu
F. Yang
Y. Yang
Y. Yuan
Yanfeng Zhang
Yijun Zhang
S. Zhao
J. Zheng
G. Zhu

Germany International Working Group (BPV VIII)

R. Kauer, *Chair*
M. Sykora, *Vice Chair*
A. Aloui
P. Chavdarov
A. Emrich
J. Fleischfresser
C. Jaekel
D. Koelbl
S. Krebs
T. Ludwig
R. A. Meyers
H. Michael
S. Reich
A. Spangenberg
C. Stobbe
G. Naumann, *Contributing Member*

India International Working Group (BPV VIII)

D. Chandiramani, *Chair*
D. Kulkarni, *Vice Chair*
A. D. Dalal, *Secretary*
P. Arulkumar
B. Basu
P. Gandhi
U. Ganesan
S. K. Goyal
V. Jayabalan
V. K. Joshi
A. Kakumanu
V. V. P. Kumar
T. Mukherjee
P. C. Pathak
D. Prabhu
A. Sadasivam
M. P. Shah
R. Tiru
V. T. Valavan
M. Sharma, *Contributing Member*

Italy International Working Group (BPV VIII)

A. Teli, *Chair*
M. Millefanti, *Vice Chair*
P. Campli, *Secretary*
B. G. Alborali
P. Aliprandi
A. Avogadri
A. Camanni
N. Caputo
M. Colombo
P. Conti
D. Cortassa
P. L. Dinelli
F. Finco
M. Guglielmetti
A. F. Magri
P. Mantovani
L. Moracchioli
P. Pacor
S. Sarti
V. Calo, *Contributing Member*
G. Gobbi, *Contributing Member*
A. Gusmaroli, *Contributing Member*
G. Pontiggia, *Contributing Member*
D. D. Raimander, *Contributing Member*

Special Working Group on Bolted Flanged Joints (BPV VIII)

W. Brown, *Chair*
M. Osterfoss, *Vice Chair*
G. Aurioles, Sr.
D. Bankston, Jr.
H. Bouzid
A. Chaudouet
H. Chen
D. Francis
H. Lejeune
A. Mann
W. McDaniel
R. W. Mikitka
D. Nash
M. Ruffin
R. Wacker
E. Jamalyaria, *Contributing Member*
J. R. Payne, *Contributing Member*
G. Van Zyl, *Contributing Member*
J. Veiga, *Contributing Member*

Subgroup on Interpretations (BPV VIII)

G. Aurioles, Sr., *Chair*
J. Oh, *Staff Secretary*
S. R. Babka
J. Cameron
C. W. Cary
B. F. Hantz
M. Kowalczyk
D. L. Kurle
M. D. Lower
S. A. Marks
P. Matkovics
D. I. Morris
D. T. Peters
F. L. Richter
S. C. Roberts
C. D. Rodery
T. G. Seipp
J. C. Sowinski
D. B. Stewart
K. Subramanian
D. A. Swanson
J. P. Swezy, Jr.
J. Vattappilly
A. Viet
K. Xu
R. J. Basile, *Contributing Member*
D. B. DeMichael, *Contributing Member*
R. D. Dixon, *Contributing Member*
S. Kilambi, *Contributing Member*
R. Mahadeen, *Contributing Member*
T. P. Pastor, *Contributing Member*
P. L. Sturgill, *Contributing Member*

COMMITTEE ON WELDING, BRAZING, AND FUSING (BPV IX)

M. J. Pischke, *Chair*
P. L. Sturgill, *Vice Chair*
R. Rahaman, *Staff Secretary*
M. Bernasek
M. A. Boring
D. A. Bowers
N. Carter
J. G. Feldstein
P. Gilston
S. E. Gingrich
K. L. Hayes
R. M. Jessee
J. S. Lee
W. M. Lundy
D. W. Mann
S. A. Marks
T. Melfi
W. F. Newell, Jr.
E. G. Reichelt
M. J. Rice
M. B. Sims
W. J. Sperko
J. P. Swezy, Jr.
A. D. Wilson
E. W. Woelfel
D. Pojatar, *Delegate*
A. Roza, *Delegate*
M. Consonni, *Contributing Member*
P. D. Flenner, *Contributing Member*
S. A. Jones, *Contributing Member*
D. K. Peetz, *Contributing Member*
S. Raghunathan, *Contributing Member*
M. J. Stanko, *Contributing Member*
P. L. Van Fosson, *Contributing Member*
R. K. Brown, Jr., *Honorary Member*
M. L. Carpenter, *Honorary Member*
B. R. Newmark, *Honorary Member*
S. D. Reynolds, Jr., *Honorary Member*

Subgroup on Brazing (BPV IX)

S. A. Marks, *Chair*
E. W. Beckman
A. F. Garbolevsky
N. Mohr
M. J. Pischke
P. L. Sturgill
J. P. Swezy, Jr.

Subgroup on General Requirements (BPV IX)

N. Carter, *Chair*
P. Gilston, *Vice Chair*
J. P. Bell
D. A. Bowers
M. Heinrichs
A. Howard
R. M. Jessee
S. A. Marks
H. B. Porter
P. L. Sturgill
J. P. Swezy, Jr.
E. W. Woelfel
E. W. Beckman, *Contributing Member*
A. Davis, *Contributing Member*
D. K. Peetz, *Contributing Member*
B. R. Newmark, *Honorary Member*

Subgroup on Materials (BPV IX)

M. Bernasek, *Chair*
T. Anderson
L. Constantinescu
E. Cutlip
M. Denault
S. E. Gingrich
L. S. Harbison
M. James
R. M. Jessee
T. Melfi
S. D. Nelson
M. J. Pischke
A. Roza
C. E. Sainz
P. L. Sturgill
C. Zanfir
V. G. V. Giunto, *Delegate*
D. J. Kotecki, *Contributing Member*
B. Krueger, *Contributing Member*
W. J. Sperko, *Contributing Member*
M. J. Stanko, *Contributing Member*

Subgroup on Plastic Fusing (BPV IX)

K. L. Hayes, *Chair*
R. M. Jessee
J. Johnston, Jr.
J. E. O'Sullivan
E. G. Reichelt
M. J. Rice
S. Schuessler
M. Troughton
C. Violand
E. W. Woelfel
J. Wright

Subgroup on Welding Qualifications (BPV IX)

T. Melfi, *Chair*
A. D. Wilson, *Vice Chair*
K. L. Hayes, *Secretary*
M. Bernasek
M. A. Boring
D. A. Bowers
R. Campbell
R. B. Corbit
L. S. Harbison
M. Heinrichs
J. S. Lee
W. M. Lundy
D. W. Mann
W. F. Newell, Jr.
E. G. Reichelt
M. J. Rice
M. B. Sims
W. J. Sperko
P. L. Sturgill
J. P. Swezy, Jr.
C. Violand
D. Chandiramani, *Contributing Member*
M. Consonni, *Contributing Member*
M. Dehghan, *Contributing Member*
P. D. Flenner, *Contributing Member*
T. C. Wiesner, *Contributing Member*

Argentina International Working Group (BPV IX)

A. Burgueno, *Chair*
A. R. G. Frinchaboy, *Vice Chair*
R. Rahaman, *Staff Secretary*
M. D. Kuhn, *Secretary*
B. Bardott
L. F. Boccanera
P. J. Cabot
J. Caprarulo
M. Favareto
J. A. Gandola
C. A. Garibotti
J. A. Herrera
M. A. Mendez
A. E. Pastor
G. Telleria
M. M. C. Tocco

Germany International Working Group (BPV IX)

A. Roza, *Chair*
A. Spangenberg, *Vice Chair*
R. Rahaman, *Staff Secretary*
P. Chavadarov
B. Daume
J. Fleischfresser
P. Khwaja
S. Krebs
T. Ludwig
S. Wegener
F. Wodke
J. Daldrup, *Contributing Member*
E. Floer, *Contributing Member*
R. Helmholdt, *Contributing Member*
G. Naumann, *Contributing Member*
K.-G. Toelle, *Contributing Member*

Italy International Working Group (BPV IX)

D. D. Raimander, *Chair*
F. Ferrarese, *Vice Chair*
R. Rahaman, *Staff Secretary*
M. Bernasek
A. Camanni
P. L. Dinelli
M. Mandina
A. S. Monastra
L. Moracchioli
P. Pacor
P. Siboni
V. Calo, *Contributing Member*
G. Gobbi, *Contributing Member*
A. Gusmaroli, *Contributing Member*
G. Pontiggia, *Contributing Member*

Spain International Working Group (BPV IX)

F. J. Q. Pandelo, *Chair*
F. L. Villabrille, *Vice Chair*
R. Rahaman, *Staff Secretary*
F. R. Hermida, *Secretary*
C. A. Celimendiz
M. A. F. Garcia
R. G. Garcia
F. Manas
B. B. Miguel
A. D. G. Munoz
A. B. Pascual
S. Sevil
G. Gobbi, *Contributing Member*

COMMITTEE ON FIBER-REINFORCED PLASTIC PRESSURE VESSELS (BPV X)

B. Linnemann, *Chair*
D. Eisberg, *Vice Chair*
P. D. Stumpf, *Staff Secretary*
A. L. Beckwith
F. L. Brown
J. L. Bustillos
B. R. Colley
T. W. Cowley
I. L. Dinovo
J. Eihusen
M. R. Gorman
B. Hebb
L. E. Hunt
D. H. McCauley
N. L. Newhouse
G. Ramirez
J. R. Richter
B. F. Shelley
G. A. Van Beek
S. L. Wagner
D. O. Yancey, Jr.
P. H. Ziehl
D. H. Hodgkinson, *Contributing Member*
D. L. Keeler, *Contributing Member*

COMMITTEE ON NUCLEAR INSERVICE INSPECTION (BPV XI)

R. W. Swayne, *Chair*
D. W. Lamond, *Vice Chair*
A. T. Roberts III, *Vice Chair*
D. Miro-Quesada, *Staff Secretary*
J. F. Ball
W. H. Bamford
M. L. Benson
J. M. Boughman
C. Brown
S. B. Brown
T. L. Chan
R. C. Cipolla
D. R. Cordes
H. Do
E. V. Farrell, Jr.
M. J. Ferlisi
T. J. Griesbach
J. Hakii
M. L. Hall
P. J. Hennessey
D. O. Henry
K. Hojo
S. D. Kulat
C. Latiolais
J. T. Lindberg
H. Malikowski
S. L. McCracken
S. A. Norman
T. Nuoffer
J. Nygaard
J. E. O'Sullivan
N. A. Palm
G. C. Park
D. A. Scarth
F. J. Schaaf, Jr.
S. Takaya
D. Vetter
T. V. Vo
J. G. Weicks
M. Weis
Y.-K. Chung, *Delegate*
C. Ye, *Delegate*
B. Lin, *Alternate*
R. O. McGill, *Alternate*
L. A. Melder, *Alternate*
A. Udyawar, *Alternate*
E. B. Gerlach, *Contributing Member*
C. D. Cowfer, *Honorary Member*
R. E. Gimple, *Honorary Member*
F. E. Gregor, *Honorary Member*
R. D. Kerr, *Honorary Member*
P. C. Riccardella, *Honorary Member*
R. A. West, *Honorary Member*
C. J. Wirtz, *Honorary Member*
R. A. Yonekawa, *Honorary Member*

Executive Committee (BPV XI)

D. W. Lamond, *Chair*
R. W. Swayne, *Vice Chair*
D. Miro-Quesada, *Staff Secretary*
M. L. Benson
M. J. Ferlisi
S. D. Kulat
J. T. Lindberg
S. L. McCracken
T. Nuoffer
N. A. Palm
G. C. Park
A. T. Roberts III
B. L. Lin, *Alternate*

Argentina International Working Group (BPV XI)

O. Martinez, *Staff Secretary*
A. Claus
I. M. Guerreiro
L. R. Miño
F. J. Schaaf, Jr.
F. M. Schroeter
P. Yamamoto

China International Working Group (BPV XI)

J. H. Liu, *Chair*
J. F. Cai, *Vice Chair*
C. Ye, *Vice Chair*
M. W. Zhou, *Secretary*
H. Chen
H. D. Chen
Y. Cheng
Y. B. Guo
Y. Hongqi
D. R. Horn
Y. Hou
S. X. Lin
Y. Nie
W. N. Pei
L. Shiwei
S. Shuo
Y. Sixin
Y. X. Sun
G. X. Tang
Q. Wang
Q. W. Wang
Z. S. Wang
L. Xing
F. Xu
S. X. Xu
Q. Yin
K. Zhang
Y. Zhe
Z. M. Zhong

Germany International Working Group (BPV XI)

R. Döring, *Chair*
M. Hagenbruch, *Vice Chair*
R. Piel, *Secretary*
A. Casse
C. G. Frantescu
E. Iacopetta
S. D. Kulat
H.-W. Lange
N. Legl
T. Ludwig
X. Pitoiset
M. Reichert
L. Sybertz
I. Tewes
R. Tiete
J. Wendt

India International Working Group (BPV XI)

S. B. Parkash, *Chair*
D. Narain, *Vice Chair*
K. K. Rai, *Secretary*
Z. M. Mansuri
M. R. Nadgouda
N. Palm
D. Rawal
R. Sahai
R. K. Sharma

Special Working Group on Editing and Review (BPV XI)

R. W. Swayne, *Chair*
R. C. Cipolla
D. O. Henry
M. Orihuela
D. A. Scarth

Task Group on Inspectability (BPV XI)

J. T. Lindberg, *Chair*
E. Henry, *Secretary*
A. Bushmire
A. Cardillo
K. Caver
D. R. Cordes
P. Gionta
D. O. Henry
J. Honcharik
C. Latiolais
G. A. Lofthus
S. Matsumoto
D. E. Matthews
P. J. O'Regan
J. B. Ossmann
C. Thomas

Working Group on Spent Nuclear Fuel Storage and Transportation Containment Systems (BPV XI)

K. Hunter, *Chair*
M. Orihuela, *Secretary*
D. J. Ammerman
W. H. Borter
J. Broussard
C. R. Bryan
T. Carraher
S. Corcoran
D. Dunn
N. Fales
R. C. Folley
G. Grant
B. Gutherman
M. W. Joseph
M. Keene
M. Liu
K. Mauskar
R. M. Meyer
R. M. Pace
E. L. Pleins
M. A. Richter
B. Sarno
R. Sindelar
M. Staley
J. Wellwood
K. A. Whitney
X. J. Zhai
P.-S. Lam, *Alternate*
G. White, *Alternate*
J. Wise, *Alternate*
H. Smith, *Contributing Member*

Task Group on Mitigation and Repair of Spent Nuclear Fuel Canisters (WG-SNFS & TCS) (BPV XI)

J. Tatman, *Chair*
D. J. Ammerman
J. Broussard
C. R. Bryan
G. R. Cannell
K. Dietrich
D. Dunn
N. Fales
R. C. Folley
D. Jacobs
N. Klymyshyn
M. Kris
M. Liu
K. Mauskar
S. L. McCracken
M. Orihuela
M. Richter
K. E. Ross
B. Sarno
R. Sindelar
J. Wellwood
A. Williams

Subgroup on Evaluation Standards (SG-ES) (BPV XI)

N. A. Palm, *Chair*
S. X. Xu, *Secretary*
W. H. Bamford
M. Brumovsky
H. D. Chung
R. C. Cipolla
C. M. Faidy
M. M. Farooq
B. R. Ganta
T. J. Griesbach
K. Hasegawa
K. Hojo
D. N. Hopkins
D. R. Lee
Y. S. Li
R. O. McGill
K. Miyazaki
R. M. Pace
J. C. Poehler
S. Ranganath
D. A. Scarth
D. J. Shim
A. Udyawar
T. V. Vo
G. M. Wilkowski
M. L. Benson, *Alternate*
H. S. Mehta, *Contributing Member*

Task Group on Evaluation of Beyond Design Basis Events (SG-ES) (BPV XI)

R. M. Pace, *Chair*
S. X. Xu, *Secretary*
F. G. Abatt
G. A. Antaki
P. R. Donavin
R. G. Gilada
T. J. Griesbach
M. Hayashi
K. Hojo
S. A. Kleinsmith
S. M. Moenssens
T. V. Vo
G. M. Wilkowski
H. S. Mehta, *Contributing Member*
T. Weaver, *Contributing Member*

Working Group on Flaw Evaluation (SG-ES) (BPV XI)

R. C. Cipolla, *Chair*
S. X. Xu, *Secretary*
W. H. Bamford
M. L. Benson
M. Brumovsky
H. D. Chung
N. G. Cofie
M. A. Erickson
C. M. Faidy
M. M. Farooq
B. R. Ganta
R. G. Gilada
C. Guzman-Leong
P. H. Hoang
K. Hojo
D. N. Hopkins
S. Kalyanam
Y. Kim
V. Lacroix
D. R. Lee
Y. S. Li
C. Liu
M. Liu
G. A. Miessi
K. Miyazaki
S. Noronha
R. K. Qashu
S. Ranganath
D. A. Scarth
W. L. Server
D. J. Shim
S. Smith
M. Uddin
A. Udyawar
T. V. Vo
K. Wang
B. Wasiluk
G. M. Wilkowski
H. S. Mehta, *Contributing Member*

Working Group on Flaw Evaluation Reference Curves (SG-ES) (BPV XI)

A. Udyawar, *Chair*
D. A. Scarth, *Secretary*
W. H. Bamford
M. L. Benson
F. W. Brust
R. C. Cipolla
M. M. Farooq
A. E. Freed
P. Gill
K. Hasegawa
K. Hojo
V. Lacroix
K. Miyazaki
B. Pellereau
S. Ranganath
D. J. Shim
S. Smith
M. Uddin
T. V. Vo
G. White
S. X. Xu
H. S. Mehta, *Contributing Member*

Working Group on Operating Plant Criteria (SG-ES) (BPV XI)

N. A. Palm, *Chair*
A. E. Freed, *Secretary*
W. H. Bamford
M. Brumovsky
M. A. Erickson
T. J. Griesbach
M. Hayashi
R. Janowiak
M. Kirk
S. A. Kleinsmith
H. Kobayashi
A. D. Odell
R. M. Pace
J. C. Poehler
S. Ranganath
W. L. Server
C. A. Tomes
A. Udyawar
T. V. Vo
H. Q. Xu
H. S. Mehta, *Contributing Member*

Task Group on Appendix L (WG-OPC) (BPV XI)

N. Glunt, *Chair*
R. M. Pace, *Secretary*
J. I. Duo
A. E. Freed
M. A. Gray
T. J. Griesbach
H. Nam
A. Nana
A. D. Odell
C.-S. Oh
H. Park
S. Ranganath
A. Scott
D. J. Shim
S. Smith
A. Udyawar
T. V. Vo

Working Group on Pipe Flaw Evaluation (SG-ES) (BPV XI)

D. A. Scarth, *Chair*
S. Kalyanam, *Secretary*
K. Azuma
W. H. Bamford
M. L. Benson
M. Brumovsky
F. W. Brust
H. D. Chung
R. C. Cipolla
N. G. Cofie
C. M. Faidy
M. M. Farooq
B. R. Ganta
R. G. Gilada
S. R. Gosselin
C. E. Guzman-Leong
K. Hasegawa
P. H. Hoang
K. Hojo
D. N. Hopkins
E. J. Houston
R. Janowiak
K. Kashima
Y. Kim
V. Lacroix
Y. S. Li
R. O. McGill
G. A. Miessi
K. Miyazaki
S. M. Parker
S. H. Pellet
C. J. Sallaberry
W. L. Server
D. J. Shim
S. Smith
M. F. Uddin
A. Udyawar
T. V. Vo
K. Wang
B. Wasiluk
G. M. Wilkowski
S. X. Xu
Y. Zou
K. Gresh, *Alternate*
H. S. Mehta, *Contributing Member*

Task Group on Code Case N-513 (WG-PFE) (BPV XI)

R. O. McGill, *Chair*
S. M. Parker, *Secretary*
G. A. Antaki
R. C. Cipolla
M. M. Farooq
K. Gresh
E. J. Houston
R. Janowiak
S. H. Pellet
D. Rudland
D. A. Scarth
S. X. Xu

Task Group on Evaluation Procedures for Degraded Buried Pipe (WG-PFE) (BPV XI)

R. O. McGill, *Chair*
S. X. Xu, *Secretary*
F. G. Abatt
G. A. Antaki
R. C. Cipolla
R. G. Gilada
K. Hasegawa
K. M. Hoffman
R. Janowiak
M. Kassar
M. Moenssens
D. P. Munson
R. M. Pace
S. H. Pellet
D. Rudland
D. A. Scarth

Task Group on Flaw Evaluation for HDPE Pipe (WG-PFE) (BPV XI)

S. Kalyanam, *Chair*
P. Krishnaswamy
M. Moenssens
D. P. Munson
D. A. Scarth
D. J. Shim
M. Troughton
J. Wright
S. X. Xu

Subgroup on Nondestructive Examination (SG-NDE) (BPV XI)

J. T. Lindberg, *Chair*
D. O. Henry, *Vice Chair*
T. Cinson, *Secretary*
M. Briley
C. Brown
A. Bushmire
T. L. Chan
D. R. Cordes
S. E. Cumblidge
K. J. Hacker
J. Harrison
D. A. Kull
C. Latiolais
F. J. Schaaf, Jr.
R. V. Swain
C. A. Nove, *Alternate*

Working Group on Personnel Qualification and Surface Visual and Eddy Current Examination (SG-NDE) (BPV XI)

C. Brown, *Chair*
M. Orihuela, *Secretary*
J. Bennett
T. Cinson
S. E. Cumblidge
A. Diaz
N. Farenbaugh
D. O. Henry
J. T. Lindberg
C. Shinsky
R. Tedder
T. Thulien
J. T. Timm

Working Group on Procedure Qualification and Volumetric Examination (SG-NDE) (BPV XI)

J. Harrison, *Chair*
D. A. Kull, *Secretary*
M. Briley
A. Bushmire
D. R. Cordes
K. J. Hacker
R. E. Jacob
W. A. Jensen
C. Latiolais
C. A. Nove
D. R. Slivon
R. V. Swain
D. Van Allen
J. Williams
B. Lin, *Alternate*

Subgroup on Reliability and Integrity Management Program (SG-RIM) (BPV XI)

A. T. Roberts III, *Chair*
D. Vetter, *Secretary*
T. Anselmi
M. T. Audrain
N. Broom
F. W. Brust
V. Chugh
S. R. Doctor
J. D. Fletcher
J. T. Fong
R. Grantom
K. Harris
P. J. Hennessey
S. Kalyanam
D. R. Lee
R. J. McReynolds
R. Meyer
M. Orihuela
C. J. Sallaberry
F. J. Schaaf, Jr.
H. M. Stephens, Jr.
R. W. Swayne
S. Takaya
R. Vayda

Working Group on MANDE (SG-RIM) (BPV XI)

H. M. Stephens, Jr., *Chair*
S. R. Doctor, *Vice Chair*
M. Turnbow, *Secretary*
T. Anselmi
M. T. Audrain
N. A. Finney
J. T. Fong
D. O. Henry
R. J. McReynolds
R. Meyer
M. Orihuela
K. Yamada

Task Group on Nonmetallic Component Degradation and Failure Monitoring (SG-RIM) (BPV XI)

M. P. Metcalfe, *Chair*
A. Tzelepi, *Secretary*
M. T. Audrain
G. Beirnaert
C. Chen
W. J. Geringer
K. Harris
J. Lang
J. Potgieter

ASME/JSME Joint Working Group on RIM Processes and System-Based Code (SG-RIM) (BPV XI)

S. Takaya, *Chair*
R. J. McReynolds, *Vice Chair*
M. T. Audrain
K. Dozaki
J. T. Fong
J. Hakii
K. Harris
M. Hayashi
S. Kalyanam
D. R. Lee
H. Machida
R. Meyer
T. Muraki
S. Okajima
A. T. Roberts III
C. J. Sallaberry
F. J. Schaaf, Jr.
R. Vayda
D. Watanabe
H. Yada
K. Yamada
T. Asayama, *Contributing Member*

Subgroup on Repair/Replacement Activities (SG-RRA) (BPV XI)

S. L. McCracken, *Chair*
E. V. Farrell, Jr., *Secretary*
J. F. Ball
M. Brandes
S. B. Brown
R. Clow
S. J. Findlan
M. L. Hall
J. Honcharik
A. B. Meichler
L. A. Melder
S. A. Norman
G. T. Olson
J. E. O'Sullivan
G. C. Park
R. R. Stevenson
R. W. Swayne
D. J. Tilly
J. G. Weicks
B. Lin, *Alternate*

Working Group on Design and Programs (SG-RRA) (BPV XI)

S. B. Brown, *Chair*
R. A. Patel, *Secretary*
O. Bhatty
R. Clow
R. R. Croft
E. V. Farrell, Jr.
K. Harris
B. Lin
H. Malikowski
A. B. Meichler
G. C. Park
M. A. Pyne
R. R. Stevenson
K. Sullivan
R. W. Swayne

Task Group on Repair and Replacement Optimization (WG-D&P) (BPV XI)

S. L. McCracken, *Chair*
S. J. Findlan, *Secretary*
T. Basso
R. Clow
K. Dietrich
E. V. Farrell, Jr.
M. J. Ferlisi
R. C. Folley
M. L. Hall
D. Jacobs
H. Malikowski
T. Nuoffer
G. C. Park
A. Patel
R. R. Stevenson
J. G. Weicks

Working Group on Nonmetals Repair/Replacement Activities (SG-RRA) (BPV XI)

J. E. O'Sullivan, *Chair*
S. Schuessler, *Secretary*
M. Brandes
D. R. Dechene
M. Golliet
J. Johnston, Jr.
B. Lin
T. M. Musto
A. Pridmore
F. J. Schaaf, Jr.
R. Stakenborghs
P. Vibien
M. P. Marohl, *Contributing Member*

Task Group on HDPE Piping for Low Safety Significance Systems (WG-NMRRA) (BPV XI)

M. Brandes, *Chair*
J. E. O'Sullivan, *Secretary*
M. Golliet
B. Lin
T. M. Musto
F. J. Schaaf, Jr.
S. Schuessler
R. Stakenborghs

Task Group on Repair by Carbon Fiber Composites (WG-NMRRA) (BPV XI)

J. E. O'Sullivan, *Chair*
S. F. Arnold
S. W. Choi
D. R. Dechene
M. Golliet
L. S. Gordon
P. Krishnaswamy
M. Kuntz
H. Lu
M. P. Marohl
L. Nadeau
C. A. Nove
R. P. Ojdrovic
A. Pridmore
S. Rios
C. W. Rowley
J. Sealey
R. Stakenborghs
N. Stoeva
M. F. Uddin
J. Wen
B. Davenport, *Alternate*

Working Group on Welding and Special Repair Processes (SG-RRA) (BPV XI)

J. G. Weicks, *Chair*
G. T. Olson, *Secretary*
D. Barborak
S. J. Findlan
R. C. Folley
M. L. Hall
J. Honcharik
D. Jacobs
M. Kris
S. E. Marlette
S. L. McCracken
L. A. Melder
J. E. O'Sullivan
D. J. Tilly

Task Group on Temper Bead Welding (WG-W&SRP) (BPV XI)

S. J. Findlan, *Chair*
D. Barborak
R. C. Folley
J. Graham
M. L. Hall
D. Jacobs
H. Kobayashi
S. L. McCracken
N. Mohr
G. T. Olson
J. E. O'Sullivan
A. Patel
J. Tatman
J. G. Weicks

Task Group on Weld Overlay (WG-W&SRP)(BPV XI)

S. L. McCracken, *Chair*
S. Hunter, *Secretary*
D. Barborak
S. J. Findlan
J. Graham
M. L. Hall
D. Jacobs
C. Lohse
S. E. Marlette
G. T. Olson
A. Patel
D. W. Sandusky
D. E. Waskey
J. G. Weicks

Subgroup on Water-Cooled Systems (SG-WCS) (BPV XI)

M. J. Ferlisi, *Chair*
J. Nygaard, *Secretary*
J. M. Boughman
S. T. Chesworth
J. Collins
H. Q. Do
K. W. Hall
P. J. Hennessey
A. E. Keyser
S. D. Kulat
D. W. Lamond
T. Nomura
T. Nuoffer
M. A. Pyne
H. M. Stephens, Jr.
R. Thames
M. Weis
I. A. Anchondo-Lopez, *Alternate*

Task Group on High Strength Nickel Alloys Issues (SG-WCS) (BPV XI)

H. Malikowski, *Chair*
C. Waskey, *Secretary*
E. Blackard
T. Cinson
J. Collins
K. Dietrich
P. R. Donavin
H. Kobayashi
S. E. Marlette
G. C. Park
C. Wax
G. White
K. A. Whitney

Working Group on Containment (SG-WCS) (BPV XI)

M. J. Ferlisi, *Chair*
R. Thames, *Secretary*
P. S. Ghosal
H. T. Hill
S. Johnson
A. E. Keyser
B. Lehman
P. Leininger
J. A. Munshi
M. Sircar
P. C. Smith
S. Walden
M. Weis
S. G. Brown, *Alternate*

Working Group on Inspection of Systems and Components (SG-WCS) (BPV XI)

H. Q. Do, *Chair*
M. Weis, *Secretary*
I. A. Anchondo-Lopez
R. W. Blyde
K. Caver
C. Cueto-Felgueroso
M. J. Ferlisi
M. L. Garcia Heras
K. W. Hall
J. Howard
A. Keller
S. D. Kulat
E. Lantz
A. Maekawa
T. Nomura
J. C. Nygaard
S. Orita
A. W. Wilkens

Working Group on Pressure Testing (SG-WCS) (BPV XI)

J. M. Boughman, *Chair*
S. A. Norman, *Secretary*
T. Anselmi
M. J. Homiack
A. E. Keyser
D. W. Lamond
M. Moenssens
R. A. Nettles
C. Thomas
K. Whitney

Working Group on Risk-Informed Activities (SG-WCS) (BPV XI)

M. A. Pyne, *Chair*
S. T. Chesworth, *Secretary*
G. Brouette
C. Cueto-Felgueroso
R. Haessler
J. Hakii
K. W. Hall
M. J. Homiack
S. D. Kulat
D. W. Lamond
E. Lantz
P. J. O'Regan
N. A. Palm
D. Vetter

Working Group on General Requirements (BPV XI)

T. Nuoffer, *Chair*
J. Mayo, *Secretary*
J. F. Ball
T. L. Chan
P. J. Hennessey
K. A. Kavanagh
G. Ramaraj
T. N. Rezk
A. T. Roberts III
S. R. Scott
D. Vetter
S. E. Woolf
B. Harris, *Alternate*
R. S. Spencer, *Alternate*

COMMITTEE ON TRANSPORT TANKS (BPV XII)

N. J. Paulick, *Chair*
M. D. Rana, *Vice Chair*
J. Oh, *Staff Secretary*
A. N. Antoniou
K. W. A. Cheng
P. Chilukuri
W. L. Garfield
P. Miller
M. Pitts
J. Roberts
T. A. Rogers
R. C. Sallash
M. Shah
S. Staniszewski
A. P. Varghese
R. Meyers, *Contributing Member*

Executive Committee (BPV XII)

M. D. Rana, *Chair*
N. J. Paulick, *Vice Chair*
J. Oh, *Staff Secretary*
M. Pitts
T. A. Rogers
R. C. Sallash
S. Staniszewski
A. P. Varghese

Subgroup on Design and Materials (BPV XII)

R. C. Sallash, *Chair*
D. K. Chandiramani
K. W. A. Cheng
P. Chilukuri
S. L. McWilliams
N. J. Paulick
M. D. Rana
T. J. Rishel
T. A. Rogers
M. Shah
S. Staniszewski
A. P. Varghese
K. Xu
Y. Doron, *Contributing Member*
A. T. Duggleby, *Contributing Member*
R. D. Hayworth, *Contributing Member*
B. E. Spencer, *Contributing Member*
J. Zheng, *Contributing Member*

Subgroup on Fabrication, Inspection, and Continued Service (BPV XII)

M. Pitts, *Chair*
K. W. A. Cheng
P. Chilukuri
M. Koprivnak
P. Miller
O. Mulet
T. J. Rishel
J. Roberts
T. A. Rogers
R. C. Sallash
S. Staniszewski
Y. Doron, *Contributing Member*
R. D. Hayworth, *Contributing Member*
G. McRae, *Contributing Member*

Subgroup on General Requirements (BPV XII)

S. Staniszewski, *Chair*
A. N. Antoniou
P. Chilukuri
H. Ebben III
J. L. Freiler
W. L. Garfield
O. Mulet
B. F. Pittel
M. Pitts
R. C. Sallash
Y. Doron, *Contributing Member*
T. J. Hitchcock, *Contributing Member*
S. L. McWilliams, *Contributing Member*
T. A. Rogers, *Contributing Member*
D. G. Shelton, *Contributing Member*

Subgroup on Nonmandatory Appendices (BPV XII)

T. A. Rogers, *Chair*
S. Staniszewski, *Secretary*
P. Chilukuri
N. J. Paulick
M. Pitts
T. J. Rishel
R. C. Sallash
D. G. Shelton
D. D. Brusewitz, *Contributing Member*
Y. Doron, *Contributing Member*

COMMITTEE ON OVERPRESSURE PROTECTION (BPV XIII)

B. K. Nutter, *Chair*
A. Donaldson, *Vice Chair*
C. E. Rodrigues, *Staff Secretary*
J. F. Ball
J. Burgess
B. Calderon
D. B. DeMichael
J. W. Dickson
J. M. Levy
D. Miller
T. Patel
B. F. Pittel
T. R. Tarbay
D. E. Tompkins
Z. Wang
J. A. West
B. Engman, *Alternate*
H. Aguilar, *Contributing Member*
R. W. Barnes, *Contributing Member*
R. D. Danzy, *Contributing Member*
A. Frigerio, *Contributing Member*
J. P. Glaspie, *Contributing Member*
S. F. Harrison, Jr., *Contributing Member*
A. Hassan, *Contributing Member*
P. K. Lam, *Contributing Member*
M. Mengon, *Contributing Member*
J. Mize, *Contributing Member*
M. Mullavey, *Contributing Member*
S. K. Parimi, *Contributing Member*
J. Phillips, *Contributing Member*
M. Reddy, *Contributing Member*
S. Ruesenberg, *Contributing Member*
K. Shores, *Contributing Member*
D. E. Tezzo, *Contributing Member*
A. Wilson, *Contributing Member*

Executive Committee (BPV XIII)

A. Donaldson, *Chair*
B. K. Nutter, *Vice Chair*
C. E. Rodrigues, *Staff Secretary*
J. F. Ball
D. B. DeMichael
K. R. May
D. Miller

Subgroup on Design and Materials (BPV XIII)

D. Miller, *Chair*
T. Patel, *Vice Chair*
T. K. Acharya
C. E. Beair
W. E. Chapin
J. L. Freiler
B. Joergensen
V. Kalyanasundaram
R. Krithivasan
B. J. Mollitor
T. R. Tarbay
J. A. West
A. Williams
D. J. Azukas, *Contributing Member*
R. D. Danzy, *Contributing Member*
A. Hassan, *Contributing Member*
R. Miyata, *Contributing Member*
M. Mullavey, *Contributing Member*
S. K. Parimi, *Contributing Member*
G. Ramirez, *Contributing Member*
K. Shores, *Contributing Member*

Subgroup on General Requirements (BPV XIII)

A. Donaldson, *Chair*
B. F. Pittel, *Vice Chair*
J. M. Levy, *Secretary*
R. Antoniuk
D. J. Azukas
J. F. Ball
J. Burgess
D. B. DeMichael
S. T. French
J. Grace
C. Haldiman
J. Horne
R. Klimas, Jr.
Z. E. Kumana
P. K. Lam
D. Mainiero-Cessna
K. R. May
J. Mize
L. Moedinger
M. Mullavey
K. Shores
D. E. Tezzo
D. E. Tompkins
J. F. White
B. Calderon, *Contributing Member*
P. Chavdarov, *Contributing Member*
T. M. Fabiani, *Contributing Member*
J. L. Freiler, *Contributing Member*
J. P. Glaspie, *Contributing Member*
G. D. Goodson, *Contributing Member*
B. Joergensen, *Contributing Member*
C. Lasarte, *Contributing Member*
M. Mengon, *Contributing Member*
D. E. Miller, *Contributing Member*
R. Miyata, *Contributing Member*
B. Mruk, *Contributing Member*
J. Phillips, *Contributing Member*
M. Reddy, *Contributing Member*
S. Ruesenberg, *Contributing Member*
R. Sadowski, *Contributing Member*
A. Swearingin, *Contributing Member*
A. P. Varghese, *Contributing Member*

Subgroup on Nuclear (BPV XIII)

K. R. May, *Chair*
J. F. Ball, *Vice Chair*
R. Krithivasan, *Secretary*
M. Brown
J. W. Dickson
S. Jones
R. Lack
D. Miller
T. Patel
K. Shores
I. H. Tseng
B. J. Yonsky
J. M. Levy, *Alternate*
Y. Wong, *Alternate*
J. Yu, *Alternate*
S. T. French, *Contributing Member*
D. B. Ross, *Contributing Member*

Subgroup on Testing (BPV XIII)

B. K. Nutter, *Chair*
J. W. Dickson, *Vice Chair*
R. Houk, *Secretary*
T. P. Beirne
M. Brown
B. Calderon
V. Chicola III
B. Engman
R. J. Garnett
R. Lack
M. Mengon
C. Sharpe
J. R. Thomas, Jr.
Z. Wang
D. Nelson, *Alternate*
J. Mize, *Contributing Member*
M. Mullavey, *Contributing Member*
S. Ruesenberg, *Contributing Member*
K. Shores, *Contributing Member*
A. Strecker, *Contributing Member*
A. Wilson, *Contributing Member*

US TAG to ISO TC 185 Safety Devices for Protection Against Excessive Pressure (BPV XIII)

D. Miller, *Chair*
C. E. Rodrigues, *Staff Secretary*
J. F. Ball
T. J. Bevilacqua
D. B. DeMichael
J. W. Dickson
B. K. Nutter
T. Patel
J. R. Thomas, Jr.
D. Tuttle
J. A. West
J. F. White

COMMITTEE ON BOILER AND PRESSURE VESSEL CONFORMITY ASSESSMENT (CBPVCA)

R. V. Wielgoszinski, *Chair*
G. Scribner, *Vice Chair*
G. Moino, *Staff Secretary*
M. Blankinship
J. P. Chicoine
T. E. Hansen
W. Hibdon
B. L. Krasiun
L. E. McDonald
N. Murugappan
I. Powell
D. E. Tuttle
E. A. Whittle
P. Williams
T. P. Beirne, *Alternate*
N. Caputo, *Alternate*
P. Chavdarov, *Alternate*
J. M. Downs, *Alternate*
P. D. Edwards, *Alternate*
Y.-S. Kim, *Alternate*
B. Morelock, *Alternate*
M. Prefumo, *Alternate*
R. Rockwood, *Alternate*
K. Roewe, *Alternate*
B. C. Turczynski, *Alternate*
J. Yu, *Alternate*
D. Cheetham, *Contributing Member*
A. J. Spencer, *Honorary Member*

COMMITTEE ON NUCLEAR CERTIFICATION (CNC)

R. R. Stevenson, *Chair*
M. A. Lockwood, *Vice Chair*
S. Khan, *Staff Secretary*
A. Appleton
J. F. Ball
G. Claffey
N. DeSantis
C. Dinic
G. Gobbi
J. W. Highlands
K. A. Kavanagh
J. C. Krane
T. McGee
E. L. Pleins
T. E. Quaka
T. N. Rezk
D. M. Vickery
E. A. Whittle
T. Aldo, *Alternate*
M. Blankinship, *Alternate*
G. Brouette, *Alternate*
M. Burke, *Alternate*
P. J. Coco, *Alternate*
Y. Diaz-Castillo, *Alternate*
P. D. Edwards, *Alternate*
J. Grimm, *Alternate*
K. M. Hottle, *Alternate*
P. Krane, *Alternate*
S. J. Montano, *Alternate*
I. Olson, *Alternate*
L. Ponce, *Alternate*
M. Wilson, *Alternate*
S. Yang, *Alternate*
S. F. Harrison, Jr., *Contributing Member*

CORRESPONDENCE WITH THE COMMITTEE

(23)

General

ASME codes and standards are developed and maintained by committees with the intent to represent the consensus of concerned interests. Users of ASME codes and standards may correspond with the committees to propose revisions or cases, report errata, or request interpretations. Correspondence for this Section of the ASME Boiler and Pressure Vessel Code (BPVC) should be sent to the staff secretary noted on the Section's committee web page, accessible at https://go.asme.org/CSCommittees.

NOTE: See ASME BPVC Section II, Part D for guidelines on requesting approval of new materials. See Section II, Part C for guidelines on requesting approval of new welding and brazing materials ("consumables").

Revisions and Errata

The committee processes revisions to this Code on a continuous basis to incorporate changes that appear necessary or desirable as demonstrated by the experience gained from the application of the Code. Approved revisions will be published in the next edition of the Code.

In addition, the committee may post errata and Special Notices at http://go.asme.org/BPVCerrata. Errata and Special Notices become effective on the date posted. Users can register on the committee web page to receive e-mail notifications of posted errata and Special Notices.

This Code is always open for comment, and the committee welcomes proposals for revisions. Such proposals should be as specific as possible, citing the paragraph number(s), the proposed wording, and a detailed description of the reasons for the proposal, including any pertinent background information and supporting documentation.

Cases

(a) The most common applications for cases are

(1) to permit early implementation of a revision based on an urgent need

(2) to provide alternative requirements

(3) to allow users to gain experience with alternative or potential additional requirements prior to incorporation directly into the Code

(4) to permit use of a new material or process

(b) Users are cautioned that not all jurisdictions or owners automatically accept cases. Cases are not to be considered as approving, recommending, certifying, or endorsing any proprietary or specific design, or as limiting in any way the freedom of manufacturers, constructors, or owners to choose any method of design or any form of construction that conforms to the Code.

(c) The committee will consider proposed cases concerning the following topics only:

(1) equipment to be marked with the ASME Single Certification Mark, or

(2) equipment to be constructed as a repair/replacement activity under the requirements of Section XI

(d) A proposed case shall be written as a question and reply in the same format as existing cases. The proposal shall also include the following information:

(1) a statement of need and background information

(2) the urgency of the case (e.g., the case concerns a project that is underway or imminent)

(3) the Code Section and the paragraph, figure, or table number(s) to which the proposed case applies

(4) the edition(s) of the Code to which the proposed case applies

(e) A case is effective for use when the public review process has been completed and it is approved by the cognizant supervisory board. Cases that have been approved will appear in the next edition or supplement of the Code Cases books, "Boilers and Pressure Vessels" or "Nuclear Components." Each Code Cases book is updated with seven Supplements.

Supplements will be sent or made available automatically to the purchasers of the Code Cases books until the next edition of the Code. Annulments of Code Cases become effective six months after the first announcement of the annulment in a Code Case Supplement or Edition of the appropriate Code Case book. The status of any case is available at http://go.asme.org/BPVCCDatabase. An index of the complete list of Boiler and Pressure Vessel Code Cases and Nuclear Code Cases is available at http://go.asme.org/BPVCC.

Interpretations

(a) Interpretations clarify existing Code requirements and are written as a question and reply. Interpretations do not introduce new requirements. If a revision to resolve conflicting or incorrect wording is required to support the interpretation, the committee will issue an intent interpretation in parallel with a revision to the Code.

(b) Upon request, the committee will render an interpretation of any requirement of the Code. An interpretation can be rendered only in response to a request submitted through the online Interpretation Submittal Form at http://go.asme.org/InterpretationRequest. Upon submitting the form, the inquirer will receive an automatic e-mail confirming receipt.

(c) ASME does not act as a consultant for specific engineering problems or for the general application or understanding of the Code requirements. If, based on the information submitted, it is the opinion of the committee that the inquirer should seek assistance, the request will be returned with the recommendation that such assistance be obtained. Inquirers may track the status of their requests at http://go.asme.org/Interpretations.

(d) ASME procedures provide for reconsideration of any interpretation when or if additional information that might affect an interpretation is available. Further, persons aggrieved by an interpretation may appeal to the cognizant ASME committee or subcommittee. ASME does not “approve,” “certify,” “rate,” or “endorse” any item, construction, proprietary device, or activity.

(e) Interpretations are published in the ASME Interpretations Database at http://go.asme.org/Interpretations as they are issued.

Committee Meetings

The ASME BPVC committees regularly hold meetings that are open to the public. Persons wishing to attend any meeting should contact the secretary of the applicable committee. Information on future committee meetings can be found at http://go.asme.org/BCW.

ORGANIZATION OF SECTION III

(23)

1 GENERAL

Section III consists of Division 1, Division 2, Division 3, Division 4, and Division 5. These Divisions are broken down into Subsections and are designated by capital letters preceded by the letter "N" for Division 1, by the letter "C" for Division 2, by the letter "W" for Division 3, by the letter "F" for Division 4, and by the letter "H" for Division 5. Each Subsection is published separately, with the exception of those listed for Divisions 2, 3, 4, and 5.

- Subsection NCA — General Requirements for Division 1 and Division 2
- Appendices
- Division 1
  - Subsection NB — Class 1 Components
  - Subsection NCD — Class 2 and Class 3 Components
  - Subsection NE — Class MC Components
  - Subsection NF — Supports
  - Subsection NG — Core Support Structures
- Division 2 — Code for Concrete Containments
  - Subsection CC — Concrete Containments
- Division 3 — Containment Systems for Transportation and Storage of Spent Nuclear Fuel and High-Level Radioactive Material
  - Subsection WA — General Requirements for Division 3
  - Subsection WB — Class TC Transportation Containments
  - Subsection WC — Class SC Storage Containments
  - Subsection WD — Class ISS Internal Support Structures
- Division 4 — Fusion Energy Devices
  - Subsection FA — Fusion Energy Device Facilities
  - Subsection FB — Pressure Boundary Components
- Division 5 — High Temperature Reactors
  - Subsection HA — General Requirements
    - Subpart A — Metallic Materials
    - Subpart B — Graphite Materials
    - Subpart C — Composite Materials
  - Subsection HB — Class A Metallic Pressure Boundary Components
    - Subpart A — Low Temperature Service
    - Subpart B — Elevated Temperature Service
  - Subsection HC — Class B Metallic Pressure Boundary Components
    - Subpart A — Low Temperature Service
    - Subpart B — Elevated Temperature Service
  - Subsection HF — Class A and B Metallic Supports
    - Subpart A — Low Temperature Service
  - Subsection HG — Class SM Metallic Core Support Structures
    - Subpart A — Low Temperature Service
    - Subpart B — Elevated Temperature Service
  - Subsection HH — Class SN Nonmetallic Core Components
    - Subpart A — Graphite Materials
    - Subpart B — Composite Materials

2 SUBSECTIONS

Subsections are divided into Articles, subarticles, paragraphs, and, where necessary, subparagraphs and subsubparagraphs.

3 ARTICLES

Articles are designated by the applicable letters indicated above for the Subsections followed by Arabic numbers, such as NB-1000. Where possible, Articles dealing with the same topics are given the same number in each Subsection, except NCA, in accordance with the following general scheme:

Article Number	Title
1000	Introduction or Scope
2000	Material
3000	Design
4000	Fabrication and Installation
5000	Examination
6000	Testing
7000	Overpressure Protection
8000	Nameplates, Stamping With Certification Mark, and Reports

The numbering of Articles and the material contained in the Articles may not, however, be consecutive. Due to the fact that the complete outline may cover phases not applicable to a particular Subsection or Article, the rules have been prepared with some gaps in the numbering.

4 SUBARTICLES

Subarticles are numbered in units of 100, such as NB-1100.

5 SUBSUBARTICLES

Subsubarticles are numbered in units of 10, such as NB-2130, and generally have no text. When a number such as NB-1110 is followed by text, it is considered a paragraph.

6 PARAGRAPHS

Paragraphs are numbered in units of 1, such as NB-2121.

7 SUBPARAGRAPHS

Subparagraphs, when they are *major* subdivisions of a paragraph, are designated by adding a decimal followed by one or more digits to the paragraph number, such as NB-1132.1. When they are *minor* subdivisions of a paragraph, subparagraphs may be designated by lowercase letters in parentheses, such as NB-2121(a).

8 SUBSUBPARAGRAPHS

Subsubparagraphs are designated by adding lowercase letters in parentheses to the *major* subparagraph numbers, such as NB-1132.1(a). When further subdivisions of *minor* subparagraphs are necessary, subsubparagraphs are designated by adding Arabic numerals in parentheses to the subparagraph designation, such as NB-2121(a)(1).

9 REFERENCES

References used within Section III generally fall into one of the following four categories:

(a) References to Other Portions of Section III. When a reference is made to another Article, subarticle, or paragraph, all numbers subsidiary to that reference shall be included. For example, reference to Article NB-3000 includes all material in Article NB-3000; reference to NB-3100 includes all material in subarticle NB-3100; reference to NB-3110 includes all paragraphs, NB-3111 through NB-3113.

(b) References to Other Sections. Other Sections referred to in Section III are the following:

(1) Section II, Materials. When a requirement for a material, or for the examination or testing of a material, is to be in accordance with a specification such as SA-105, SA-370, or SB-160, the reference is to material specifications in Section II. These references begin with the letter "S."

(2) Section V, Nondestructive Examination. Section V references begin with the letter "T" and relate to the nondestructive examination of material or welds.

(3) Section IX, Welding and Brazing Qualifications. Section IX references begin with the letter "Q" and relate to welding and brazing requirements.

(4) Section XI, Rules for Inservice Inspection of Nuclear Power Plant Components. When a reference is made to inservice inspection, the rules of Section XI shall apply.

(c) Reference to Specifications and Standards Other Than Published in Code Sections

(1) Specifications for examination methods and acceptance standards to be used in connection with them are published by the American Society for Testing and Materials (ASTM). At the time of publication of Section III, some such specifications were not included in Section II of this Code. A reference to ASTM E94 refers to the specification so designated by and published by ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428.

(2) Dimensional standards covering products such as valves, flanges, and fittings are sponsored and published by The American Society of Mechanical Engineers and approved by the American National Standards Institute.* When a product is to conform to such a standard, for example ASME B16.5, the standard is approved by the American National Standards Institute. The applicable year of issue is that suffixed to its numerical designation in Table NCA-7100-1, for example ASME B16.5-2003. Standards published by The American Society of Mechanical Engineers are available from ASME (https://www.asme.org/).

(3) Dimensional and other types of standards covering products such as valves, flanges, and fittings are also published by the Manufacturers Standardization Society of the Valve and Fittings Industry and are known as Standard Practices. When a product is required by these rules to conform to a Standard Practice, for example MSS SP-100, the Standard Practice referred to is published by the Manufacturers Standardization Society of the Valve and Fittings Industry, Inc. (MSS), 127 Park Street, NE, Vienna, VA 22180. The applicable year of issue of such a Standard Practice is that suffixed to its numerical designation in Table NCA-7100-1, for example MSS SP-58-2009.

(4) Specifications for welding and brazing materials are published by the American Welding Society (AWS), 8669 NW 36 Street, No. 130, Miami, FL 33166. Specifications of this type are incorporated in Section II and are identified by the AWS designation with the prefix "SF," for example SFA-5.1.

(5) Standards applicable to the design and construction of tanks and flanges are published by the American Petroleum Institute and have designations such as API-605. When documents so designated are referred to in Section III, for example API-605–1988, they are standards published by the American Petroleum Institute and are listed in Table NCA-7100-1.

(d) References to Appendices. Section III uses two types of appendices that are designated as either Section III Appendices or Subsection Appendices. Either of these appendices is further designated as either Mandatory or Nonmandatory for use. Mandatory Appendices are referred to in the Section III rules and contain requirements that must be followed in construction. Nonmandatory Appendices provide additional information or guidance when using Section III.

(1) Section III Appendices are contained in a separate book titled "Appendices." These appendices have the potential for multiple subsection applicability. Mandatory Appendices are designated by a Roman numeral followed, when appropriate, by Arabic numerals to indicate various articles, subarticles, and paragraphs of the appendix, such as II-1500 or XIII-1210. Nonmandatory Appendices are designated by a capital letter followed, when appropriate, by Arabic numerals to indicate various articles, subarticles, and paragraphs of the appendix, such as D-1200 or Y-1440.

* The American National Standards Institute (ANSI) was formerly known as the American Standards Association. Standards approved by the Association were designated by the prefix "ASA" followed by the number of the standard and the year of publication. More recently, the American National Standards Institute was known as the United States of America Standards Institute. Standards were designated by the prefix "USAS" followed by the number of the standard and the year of publication. While the letters of the prefix have changed with the name of the organization, the numbers of the standards have remained unchanged.

(2) Subsection Appendices are specifically applicable to just one subsection and are contained within that subsection. Subsection-specific mandatory and nonmandatory appendices are numbered in the same manner as Section III Appendices, but with a subsection identifier (e.g., NF, NH, D2, etc.) preceding either the Roman numeral or the capital letter for a unique designation. For example, NF-II-1100 or NF-A-1200 would be part of a Subsection NF mandatory or nonmandatory appendix, respectively. For Subsection CC, D2-IV-1120 or D2-D-1330 would be part of a Subsection CC mandatory or nonmandatory appendix, respectively.

(3) It is the intent of this Section that the information provided in both Mandatory and Nonmandatory Appendices may be used to meet the rules of any Division or Subsection. In case of conflict between Appendix rules and Division/Subsection rules, the requirements contained in the Division/Subsection shall govern. Additional guidance on Appendix usage is provided in the front matter of Section III Appendices.

SUMMARY OF CHANGES

Changes listed below are identified on the pages by a margin note, **(23)**, placed next to the affected area. In addition, gender pronouns have been eliminated throughout this Subsection.

Page	*Location*	*Change*
vii	List of Sections	(1) Under Section III, Division 4 added (2) Title of Section XI and subtitle of Section XI, Division 2 revised (3) Information on interpretations and Code cases moved to "Correspondence With the Committee"
xi	Personnel	Updated
xxxiii	Correspondence With the Committee	Added (replaces "Submittal of Technical Inquiries to the Boiler and Pressure Vessel Standards Committees")
xxxv	Organization of Section III	In para. 1, Division 4 added
xli	Cross-Referencing in the ASME BPVC	Updated
7	NB-2121	In subpara. (a), last sentence added
9	NB-2130	Cross-references to NCA updated
9	NB-2160	Revised
13	NB-2321.2	Last sentence revised
19	NB-2432.2	In subpara. (c), cross-references to NCA updated
36	NB-2610	Cross-references to NCA updated
38	NB-3125	First paragraph revised
42	NB-3324	Revised
43	NB-3332.1	First paragraph revised
49	Figure NB-3339.1(b)-1	Revised
51	Figure NB-3339.4-1	In General Note (a)(3), t_m corrected by errata to t_{rn}
55	NB-3411.1	Lead-in sentence revised, and subparas. (k) through (n) added
61	NB-3441.7	Added
62	Figure NB-3441.7-1	Added
63	Figure NB-3441.7-2	Added
67	NB-3534	Definitions of C_2, C_3, C_4, C_5, C_6, and C_7 revised
73	Figure NB-3545.1(a)-1	Illustration (e) corrected by errata
77	NB-3545.2(c)(2)	Text below first equation revised
83	NB-3554	First sentence revised
90	NB-3622.2	First sentence revised
90	Figure NB-3622.2-1	Former Figure NB-3622-1 redesignated by errata
90	NB-3622.4	First sentence revised
91	NB-3630	Subparagraphs (d)(1) and (d)(2) corrected by errata
125	NB-4121.1	Cross-references to NCA updated
126	NB-4125	Paragraph corrected by errata
132	NB-4250	Subparagraph (d) added and subsequent subparagraph redesignated
143	Figure NB-4250-2	Revised in its entirety
149	NB-4413	Added
150	NB-4422	Revised
150	NB-4423	Subparagraph (d) added
150	NB-4424	NB-4424.1(b), NB-4424.2(a), and NB-4424.2(c) revised
151	Figure NB-4424.2-1	Title revised
155	NB-4451	First sentence revised
160	Table NB-4622.1-1	"Minimum Holding Time" column heading revised
159	NB-4622.3	Last sentence revised

Page	Location	Change
162	Table NB-4622.7(b)-1	Revised
168	NB-5111	Subparagraph (b) revised
168	Table NB-5111-1	First two rows revised
172	NB-5280	Revised in its entirety
173	NB-5320	Subparagraph (d) revised
173	NB-5332	Revised in its entirety
175	NB-5510	Cross-references revised
175	NB-5521	(1) Subparagraph (a)(6) revised (2) Subparagraph (a)(7) added (3) Endnote 19 revised
176	NB-5523	Cross-reference to NCA updated
176	NB-5540	Added
177	NB-6112.1	Subparagraph (c) added
180	NB-6412	Revised
180	NB-6413	Revised

CROSS-REFERENCING IN THE ASME BPVC

(23)

Paragraphs within the ASME BPVC may include subparagraph breakdowns, i.e., nested lists. The following is a guide to the designation and cross-referencing of subparagraph breakdowns:

(a) Hierarchy of Subparagraph Breakdowns

(1) First-level breakdowns are designated as (a), (b), (c), etc.

(2) Second-level breakdowns are designated as (1), (2), (3), etc.

(3) Third-level breakdowns are designated as (-a), (-b), (-c), etc.

(4) Fourth-level breakdowns are designated as (-1), (-2), (-3), etc.

(5) Fifth-level breakdowns are designated as (+a), (+b), (+c), etc.

(6) Sixth-level breakdowns are designated as (+1), (+2), etc.

(b) Cross-References to Subparagraph Breakdowns. Cross-references within an alphanumerically designated paragraph (e.g., PG-1, UIG-56.1, NCD-3223) do not include the alphanumerical designator of that paragraph. The crossreferences to subparagraph breakdowns follow the hierarchy of the designators under which the breakdown appears. The following examples show the format:

(1) If X.1(c)(1)(-a) is referenced in X.1(c)(1), it will be referenced as (-a).

(2) If X.1(c)(1)(-a) is referenced in X.1(c)(2), it will be referenced as (1)(-a).

(3) If X.1(c)(1)(-a) is referenced in X.1(e)(1), it will be referenced as (c)(1)(-a).

(4) If X.1(c)(1)(-a) is referenced in X.2(c)(2), it will be referenced as X.1(c)(1)(-a).

INTENTIONALLY LEFT BLANK

ARTICLE NB-1000
INTRODUCTION

NB-1100 SCOPE

NB-1110 ASPECTS OF CONSTRUCTION COVERED BY THESE RULES

(a) Subsection NB contains rules for the material, design, fabrication, examination, testing, overpressure relief, marking, stamping, and preparation of reports by the Certificate Holder of items that are intended to conform to the requirements for Class 1 construction.

(b) The rules of Subsection NB cover the requirements for strength and pressure integrity of items, the failure of which would violate the pressure-retaining boundary. The rules cover initial construction requirements, but do not cover deterioration that may occur in service as a result of corrosion, radiation effects, or instability of material. NCA-1130 gives further limitations to the rules of this Subsection.

NB-1120 TEMPERATURE LIMITS

The rules of Subsection NB shall not be used for items that are to be subjected to metal temperatures that exceed the temperature limit in the applicability column shown in Section II, Part D, Subpart 1, Tables 2A, 2B, and 4 for design stress intensity values. Above those temperatures, the creep and stress rupture characteristics of materials permitted to be used become significant factors that are not presently covered by the rules of this Subsection. Fatigue design curves and specified methods for fatigue analysis are not applicable above 700°F (370°C) for materials covered by Section III Appendices, Mandatory Appendix I, Figures I-9.1 and I-9.4, and above 800°F (425°C) for materials covered by Section III Appendices, Mandatory Appendix I, Figures I-9.2 and I-9.3.

NB-1130 BOUNDARIES OF JURISDICTION APPLICABLE TO THIS SUBSECTION

NB-1131 Boundary of Components

The Design Specification shall define the boundary of a component to which piping or another component is attached. The boundary shall be not closer to a vessel, tank, pump, or valve than:

(a) the first circumferential joint in welded connections (the connecting weld shall be considered part of the piping);

(b) the face of the first flange in bolted connections (the bolts shall be considered part of the piping);

(c) the first threaded joint in screwed connections.

NB-1132 Boundary Between Components and Attachments

NB-1132.1 Attachments.

(a) An *attachment* is an element in contact with or connected to the inside or outside of the pressure-retaining portion of a component.

(b) Attachments may have either a pressure-retaining or a non-pressure-retaining function.

(1) Attachments with a pressure-retaining function include items such as pressure boundary stiffeners and branch pipe and vessel opening reinforcement.

(2) Attachments with a non-pressure-retaining function include items such as:

(-a) valve guides, thermal sleeves, and turning vanes

(-b) core support structures, internal structures, or other permanent structures within the reactor pressure vessel; and

(-c) vessel saddles, support and shear lugs, brackets, pipe clamps, trunnions, skirts, and other items in the support load path.

(c) Attachments may also have either a structural or nonstructural function.

(1) Attachments with a structural function (structural attachments):

(-a) perform a pressure-retaining function;

(-b) are core support structures, internal structures, or other permanent structures within the reactor pressure vessel; or

(-c) are in the support load path.

(2) Attachments with a nonstructural function (nonstructural attachments):

(-a) do not perform a pressure-retaining function;

(-b) are not in the support load path;

(-c) may be permanent or temporary.

Nonstructural attachments include items such as nameplates, insulation supports, and locating and lifting lugs.

NB-1132.2 Jurisdictional Boundary. The jurisdictional boundary between a pressure-retaining component and an attachment defined in the Design Specification shall not be any closer to the pressure-retaining portion of the component than as defined in (a) through (g) below. Figures NB-1132.2-1 through NB-1132.2-4 are provided as an aid in defining the boundary and construction requirements of this Subsection.

(a) Attachments cast or forged with the component and weld buildup on the component surface shall be considered part of the component.

(b) Attachments, welds, and fasteners having a pressure-retaining function shall be considered part of the component.

(c) Except as provided in (d) and (e) below, the boundary between a pressure-retaining component and an attachment not having a pressure-retaining function shall be at the surface of the component.

(d) The first connecting weld of a non-pressure-retaining structural attachment to a component shall be considered part of the component unless the weld is more than $2t$ from the pressure-retaining portion of the component, where t is the nominal thickness of the pressure-retaining material. Beyond $2t$ from the pressure-retaining portion of the component, the first weld shall be considered part of the attachment.

(e) The first connecting weld of a welded nonstructural attachment to a component shall be considered part of the attachment. At or within $2t$ from the pressure-retaining portion of the component, the first connecting weld shall conform to NB-4430.

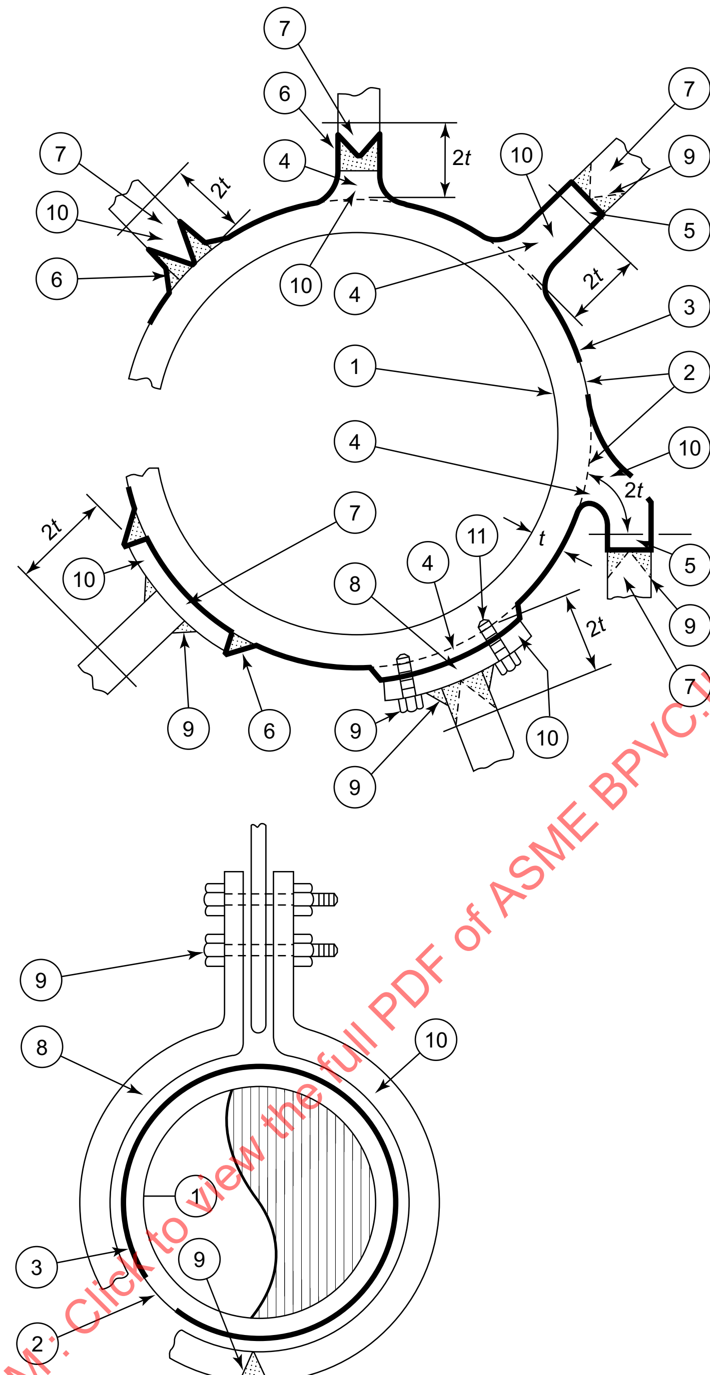
(f) Mechanical fasteners used to connect a non-pressure-retaining attachment to the component shall be considered part of the attachment.

(g) The boundary may be located further from the pressure-retaining portion of the component than as defined in (a) through (f) above when specified in the Design Specification.

NB-1140 ELECTRICAL AND MECHANICAL PENETRATION ASSEMBLIES

Electrical and mechanical penetration assemblies shall be constructed in accordance with the rules for vessels, except that the design and the material performing the electrical conducting and insulating functions need not meet the requirements of this Subsection.

Figure NB-1132.2-1
Attachments in the Component Support Load Path That Do Not Perform a Pressure-Retaining Function



(1) Component shall conform to Subsection NB.

(2) Pressure-retaining portion of the component.

(3) Jurisdictional boundary (heavy line).

(4) Cast or forged attachment or weld buildup shall conform to Subsection NB.

(5) Beyond $2t$ from the pressure-retaining portion of the component, the design rules of Article NF-3000 may be used as a substitute for the design rules of Article NB-3000.

(6) At or within $2t$ from the pressure-retaining portion of the component, the first connecting weld shall conform to Subsection NB.

(7) Beyond $2t$ from the pressure-retaining portion of the component or beyond the first connecting weld, the attachment shall conform to Subsection NF [see Note (1)].

(8) Bearing, clamped, or fastened attachment shall conform to Subsection NF [see Note (1)].

(9) Attachment connection shall conform to Subsection NF [see Note (1)].

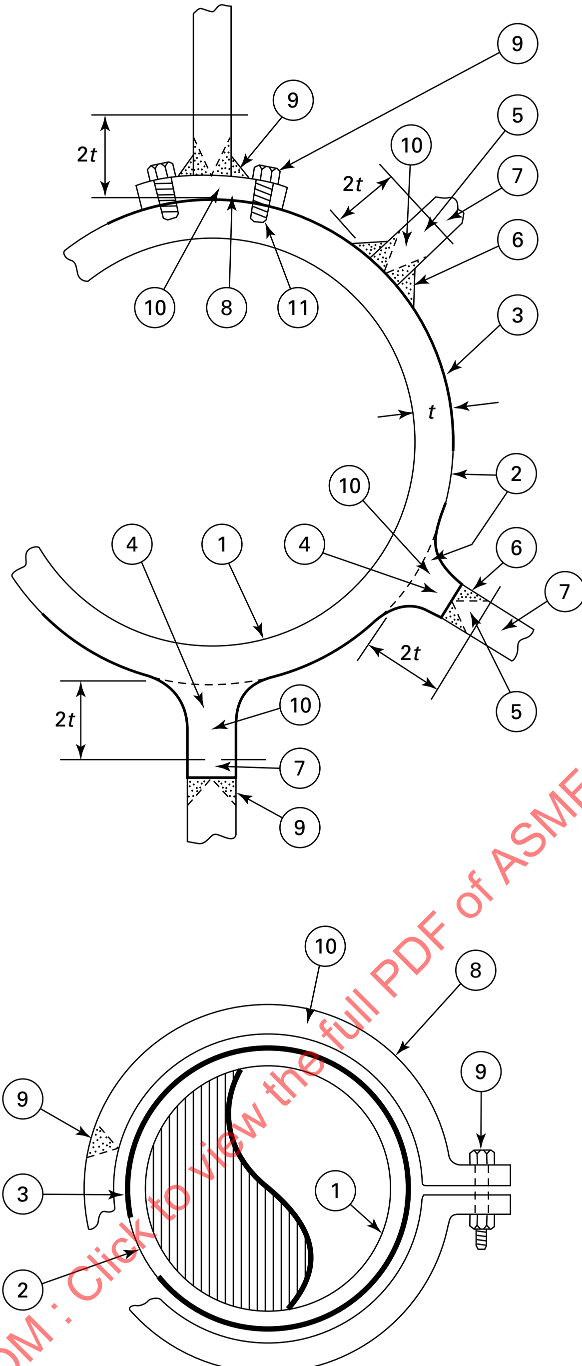
(10) At or within $2t$ from the pressure-retaining portion of the component, the interaction effects of the attachment shall be considered in accordance with NB-3135.

(11) Drilled holes shall conform to Subsection NB.

GENERAL NOTE: These sketches are intended to show jurisdictional concepts and should not be considered as recommended configurations.

NOTE: (1) If the attachment is an intervening element [NF-1110(c)], material, design, and connections, as appropriate, are outside Code jurisdiction.

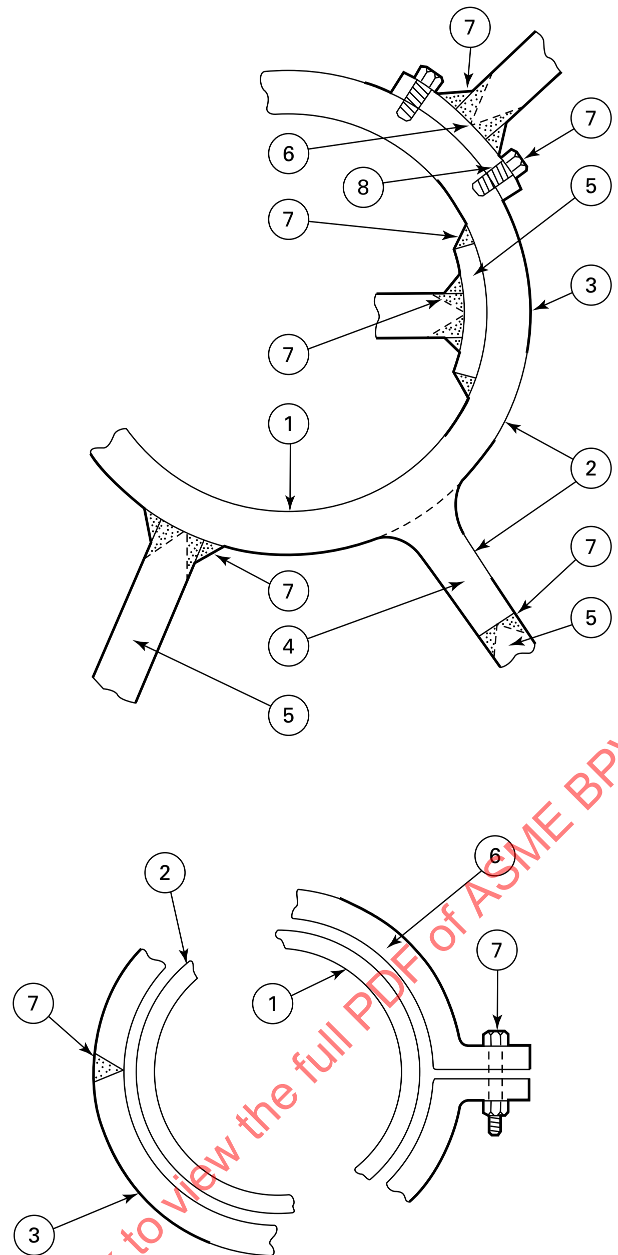
Figure NB-1132.2-2
Attachments That Do Not Perform a Pressure-Retaining Function and Are Not in the Component Support Load Path (Nonstructural Attachments)



1. Component shall conform to Subsection NB.
2. Pressure-retaining portion of the component.
3. Jurisdictional boundary (heavy line).
4. Cast or forged attachment or weld buildup shall conform to Subsection NB.
5. At or within 2*t* from the pressure-retaining portion of the component, the material of the first welded nonstructural attachment shall conform to NB-2190; design is outside Code jurisdiction.
6. At or within 2*t* from the pressure-retaining portion of the component, the first connecting weld shall conform to NB-4430.
7. Beyond 2*t* from the pressure-retaining portion of the component, the nonstructural attachment is outside Code jurisdiction.
8. Bearing, clamped, or fastened nonstructural attachment is outside Code jurisdiction.
9. Nonstructural attachment connection is outside Code jurisdiction.
10. At or within 2*t* from the pressure-retaining portion of the component, the interaction effects of the nonstructural attachment shall be considered in accordance with NB-3135.
11. Drilled holes shall conform to Subsection NB.

GENERAL NOTE: These sketches are intended to show jurisdictional concepts and should not be considered as recommended configurations.

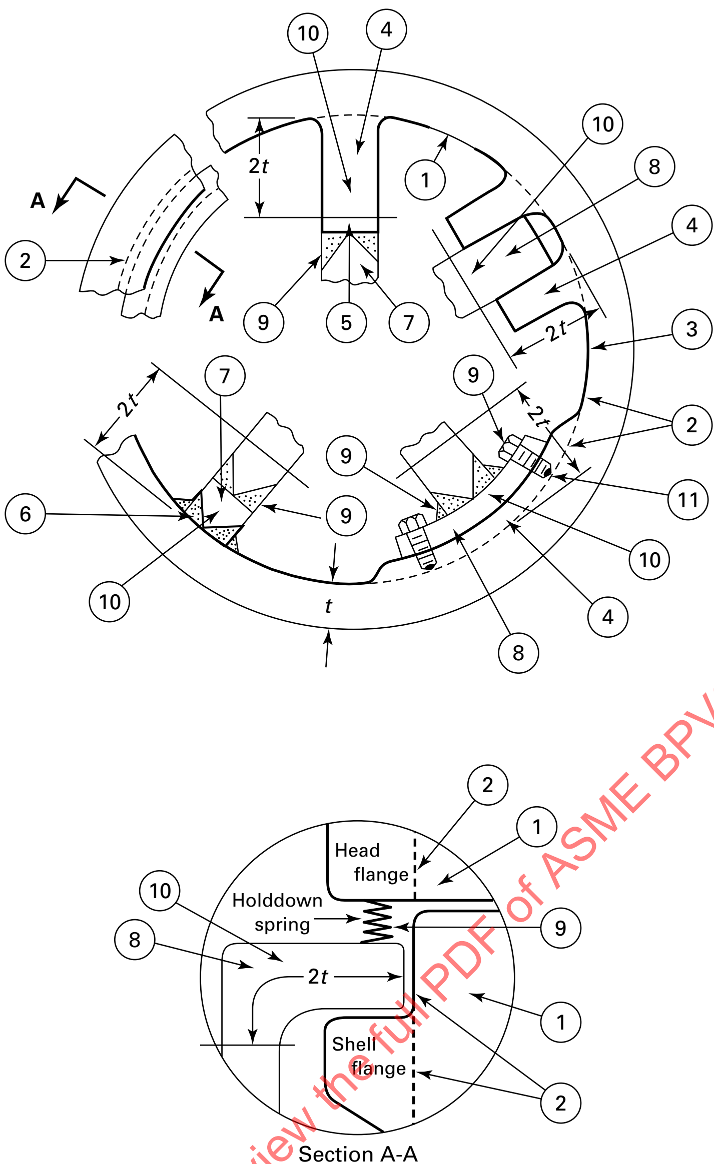
Figure NB-1132.2-3
Attachments That Perform a Pressure-Retaining Function



(1) Component shall conform to Subsection NB.
(2) Pressure-retaining portion of the component.
(3) Jurisdictional boundary (heavy line).
(4) Cast or forged attachment or weld buildup shall conform to Subsection NB.
(5) Welded attachment shall conform to Subsection NB.
(6) Bearing, clamped, or fastened attachment shall conform to Subsection NB.
(7) Attachment connection shall conform to Subsection NB.
(8) Drilled holes shall conform to Subsection NB.

GENERAL NOTE: These sketches are intended to show jurisdictional concepts and should not be considered as recommended configurations.

Figure NB-1132.2-4
Attachments Within the Reactor Pressure Vessel (Core Support Structures) That Do Not Perform a Pressure-Retaining Function



(1) Reactor pressure vessel conforms to Subsection NB.

(2) Pressure-retaining portion of the reactor pressure vessel.

(3) Jurisdictional boundary (heavy line).

(4) Cast or forged attachment or weld buildup shall conform to Subsection NB.

(5) Beyond 2*t* from the pressure-retaining portion of the reactor pressure vessel, the design rules of Article NG-3000 may be used as a substitute for the design rules of Article NB-3000.

(6) At or within 2*t* from the pressure-retaining portion of the reactor pressure vessel, the first connecting weld shall conform to Subsection NB.

(7) Beyond 2*t* from the pressure-retaining portion of the reactor pressure vessel or beyond the first connecting weld, the attachment shall conform to Subsection NG [see Note (1)].

(8) Bearing, clamped, or fastened attachment shall conform to Subsection NG [see Note (1)].

(9) Attachment connection shall conform to Subsection NG [see Note (1)].

(10) At or within 2*t* from the pressure-retaining portion of the component, the interaction effects of the attachment on the reactor pressure vessel shall be considered in accordance with NB-3135.

(11) Drilled holes within the jurisdictional boundary shall conform to Subsection NB.

GENERAL NOTE: These sketches are intended to show jurisdictional concepts and should not be considered as recommended configurations.

NOTE: (1) If the attachment is an internal structure (NG-1122), material, design, and connections, as appropriate, are outside Code jurisdiction except when the core support structure Design Specification requires the internal structure to conform to Subsection NG.

ARTICLE NB-2000
MATERIAL

NB-2100 GENERAL REQUIREMENTS FOR MATERIAL

NB-2110 SCOPE OF PRINCIPAL TERMS EMPLOYED

(a) The term *material* as used in this Subsection is defined in NCA-1220. The term *Material Organization* is defined in Article NCA-9000.

(b) The term *pressure-retaining material* as used in this Subsection applies to items such as vessel shells, heads, and nozzles; pipes, tubes, and fittings; valve bodies, bonnets, and disks; pump casings and covers; and bolting that joins pressure-retaining items.

(c) The requirements of this Article make reference to the term *thickness*. For the purpose intended, the following definitions of nominal thickness apply:

(1) *plate*: the thickness is the dimension of the short transverse direction.

(2) *forgings*: the thickness is the dimension defined as follows:

(-a) *hollow forgings*: the nominal thickness is measured between the inside and outside surfaces (radial thickness).

(-b) *disk forgings* (axial length less than the outside diameter): the nominal thickness is the axial length.

(-c) *flat ring forgings* (axial length less than the radial thickness): for axial length ≤2 in. (50 mm), the axial length is the nominal thickness. For axial length >2 in. (50 mm), the radial thickness is the nominal thickness.

(-d) *rectangular solid forgings*: the least rectangular dimension is the nominal thickness.

(3) *castings*

(-a) Thickness *t* for fracture toughness testing is defined as the nominal pipe wall thickness of the connecting piping.

(-b) Thickness *t* for heat treatment purposes is defined as the thickness of the pressure-retaining wall of the casting, excluding flanges and sections designated by the designer as nonpressure retaining.

NB-2120 PRESSURE-RETAINING MATERIAL

(23) #### NB-2121 Permitted Material Specifications

(a) Pressure-retaining material shall conform to the requirements of one of the specifications for material given in Section II, Part D, Subpart 1, Tables 2A, 2B, and 4, including all applicable footnotes in the table, and to all of the requirements of this Article that apply to the product form in which the material is used. Alternatively, items manufactured using Advanced Manufacturing shall conform to the requirements of Section III Appendices, Mandatory Appendix XXVIII.

(b) The requirements of this Article do not apply to material for items not associated with the pressure-retaining function of a component, such as shafts, stems, trim, spray nozzles, bearings, bushings, springs, and wear plates, nor to seals, packing, gaskets, valve seats, and ceramic insulating material and special alloys used as seal material in electrical penetration assemblies.

(c) Material made to specifications other than those specified in Section II, Part D, Subpart 1, Tables 2A and 2B may be used for the following applications:

(1) safety valve disks and nozzles, when the nozzles are internally contained by the external body structure;

(2) control valve disks and cages, when the valves function for flow control only;

(3) line valve disks in valves whose inlet connections are NPS 2 (DN 50) and smaller.

(d) Material for instrument line fittings and valves, NPS 1 (DN 25) and less, may be of material made to specifications other than those listed in Section II, Part D, Subpart 1, Tables 2A and 2B, provided that the fittings are in conformance with the requirements of NB-3671.4, the valves meet the requirements of NB-3500, and the material is determined to be adequate for the service conditions by the piping system designer for fittings.

(e) Welding and brazing material used in the manufacture of items shall comply with an SFA specification in Section II, Part C, except as otherwise permitted in Section IX, and shall also comply with the applicable requirements of this Article. The requirements of this Article do not apply to material used as backing rings or backing strips in welded joints.

(f) The requirements of this Article do not apply to hard surfacing or corrosion-resistant weld metal overlay that is 10% or less of the thickness of the base material (see NB-3122).

NB-2122 Special Requirements Conflicting With Permitted Material Specifications

Special requirements stipulated in this Article shall apply in lieu of the requirements of the material specification wherever the special requirements conflict with the material specification requirements (NCA-4256). Where the special requirements include an examination, test, or treatment that is also required by the material specification, the examination, test, or treatment need be performed only once. Required nondestructive examinations shall be performed as specified for each product form in NB-2500. Any examination, repair, test, or treatment required by the material specification or by this Article may be performed by the Material Organization or the Certificate Holder as provided in NB-4121. Any hydrostatic or pneumatic pressure test required by a material specification need not be performed, provided the material is identified as not having been pressure tested and it is subsequently pressure tested in the system in accordance with NB-6114, except where the location of the material in the component or the installation would prevent performing any nondestructive examination required by the material specification to be performed subsequent to the hydrostatic or pneumatic test.

(a) The stress rupture test of SA-453 and SA-638 for Grade 660 (UNS S66286) is not required for design temperatures of 800°F (427°C) and below.

NB-2124 Size Ranges

Material outside the limits of size or thickness given in any specification in Section II may be used if the material is in compliance with the other requirements of the specification and no size limitation is given in the rules for construction. In those specifications in which chemical composition or mechanical properties are indicated to vary with size or thickness, any material outside the specification range shall be required to conform to the composition and mechanical properties shown for the nearest specified range (NCA-4256).

NB-2125 Fabricated Hubbed Flanges

Fabricated hubbed flanges shall be in accordance with the following:

(a) Hubbed flanges may be machined from a hot rolled or forged billet. The axis of the finished flange shall be parallel to the long axis of the original billet. (This is not intended to imply that the axis of the finished flange and the original billet must be concentric.)

(b) Hubbed flanges, except as permitted in (a) above, 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 must be present in the finished flange);

(2) the joints in the ring are welded butt joints that conform to the requirements of this Section. Thickness to be used to determine postweld heat treatment and radiography requirements shall be the lesser of t, or $(A - B)/2$, where these symbols are as defined in Section III Appendices, Mandatory Appendix XI, XI-3130.

(c) The back of the flange and the outer surface of the hub shall be examined by the magnetic particle method or the liquid penetrant method in accordance with NB-2540 to ensure that these surfaces are free from defects.

NB-2126 Finned Tubes

NB-2126.1 Integrally Finned Tubes. Integrally finned tubes may be made from tubes that conform to one of the specifications for tubes listed in Section II, Part D, Subpart 1, Tables 2A and 2B, and to all of the special requirements of this Article that apply to that product form. In addition, the following requirements shall apply:

(a) The requirements of NB-2550 shall be met by the tube before finning.

(b) The tubes after finning shall conform to the applicable heat treatment requirements of the basic material specification.

(c) The design stress intensity values, design values of yield strength, and tensile strength values shall be those given in Section II, Part D, Subpart 1, Tables 2A and 2B, Y-1 and Y-2, and U, respectively, for the tube material from which the finned tube is made.

(d) After finning, each tube shall be subjected to one of the following tests:

(1) an internal pneumatic pressure test at not less than 250 psi (1.7 MPa) without evidence of leakage. The test method, such as immersion of the tube underwater during the test, shall permit visual detection of any leakage.

(2) an individual tube hydrostatic test at 1.25 times the Design Pressure that permits complete examination of the tube for leakage.

(e) A visual examination shall be performed after finning. Material having discontinuities, such as laps, seams, or cracks, is unacceptable. The visual examination personnel shall be trained and qualified in accordance with the Material Organization's Quality System Program or the Certificate Holder's Quality Assurance Program. These examinations are not required to be performed either in accordance with procedures qualified to NB-5100 or by personnel qualified in accordance with NB-5500.

NB-2126.2 Welded Finned Tubes. Welded finned tubes may be made from P-No.1 and P-No. 8 tubular products (pipe or tubing) that conform to one of the specifications for tubes listed in Section II, Part D, Subpart 1, Table 2A, and to all of the special requirements of this Article that apply to that product form. Heat transfer fins shall be of the same P-Number as the tube and shall be attached by a machine welding process, such as the electric resistance welding or the high frequency resistance welding process. In addition, the following requirements shall apply:

(a) The heat transfer fins need not be certified material. The material for the heat transfer fins shall be identified and suitable for welding; however, Certified Material Test Reports are not required.

(b) The machine welding process used to weld the heat transfer fins to the tubular material shall be performed in accordance with a Welding Procedure Specification.

(c) The procedure qualification shall require that a minimum of 12 cross-sections through the weld zone shall be examined at 5X minimum magnification. There shall be no cracks in the base material or weld; and the weld penetration shall be limited to 20% of the nominal tube wall thickness.

(d) For P-No. 1 material, the weld that attaches the fins to the tubing shall be heat treated after welding to a minimum temperature of 1,000°F (540°C).

(e) The fin is not considered to provide any support to the tube under pressure loading.

NB-2127 Seal Membrane Material

Seal membrane material (see NB-4360) shall conform to the requirements of one of the material specifications listed in Section II, Part D, Subpart 1, Tables 2A and 2B. The requirements of NB-2500 are applicable for the appropriate product form when the material thickness is greater than ¼ in. (6 mm).

NB-2128 Bolting Material

(a) Material for bolts and studs shall conform to the requirements of one of the specifications listed in Section II, Part D, Subpart 1, Table 4. Material for nuts shall conform to SA-194 or to the requirements of one of the specifications for nuts or bolting listed in Section II, Part D, Subpart 1, Table 4.

(b) The use of washers is optional. When used, they shall be made of wrought material with mechanical properties compatible with the nuts with which they are to be employed.

(23) NB-2130 CERTIFICATION OF MATERIAL

All material used in construction of components shall be certified as required in NCA-1224 and NCA-1225. Certified Material Test Reports are required for pressure-retaining material except as provided by NCA-1224.1. A Certificate of Compliance may be provided in lieu of a Certified Material Test Report for all other material. Copies of all Certified Material Test Reports and Certificates of Compliance applicable to material used in a component shall be furnished with the material.

NB-2140 WELDING MATERIAL

For the requirements governing the material to be used for welding, see NB-2400.

NB-2150 MATERIAL IDENTIFICATION

The identification of pressure-retaining material and materials welded thereto shall meet the requirements of NCA-4256. Material for small items shall be controlled during manufacture and installation of a component so that they are identifiable as acceptable material at all times. Welding and brazing material shall be controlled during the repair of material and the manufacture and installation so that they are identifiable as acceptable until the material is actually consumed in the process (see NB-4122).

NB-2160 DETERIORATION OF MATERIAL IN SERVICE (23)

Consideration of deterioration of material caused by service is generally outside the scope of this Subsection. It is the responsibility of the Owner to select material suitable for the conditions stated in the Design Specifications (NCA-3211.19), with specific attention being given to the effects of service conditions upon the properties of the material and the effects of fabrication used during construction that may result in detrimental through-wall residual stresses. Special consideration shall be given to the influence of elements such as copper and phosphorus on the effects of irradiation on the properties of material (including welding material) in the core belt line region of the reactor vessel. Special consideration shall be given to the influences of weld residual stresses on in-service material degradation, such as stress corrosion cracking. Any special requirement shall be specified in the Design Specifications [NCA-3211.19(b) and NB-3124]. When so specified, the material check analysis shall be made in accordance with the base metal specification and in accordance with NB-2420 for the welding material.

NB-2170 HEAT TREATMENT TO ENHANCE IMPACT PROPERTIES

Carbon steels, low alloy steels, and high alloy chromium (Series 4XX) steels may be heat treated by quenching and tempering to enhance their impact properties. Postweld heat treatment of the component at a temperature of not less than 1,100°F (595°C) may be considered to be the tempering phase of the heat treatment.

NB-2180 PROCEDURES FOR HEAT TREATMENT OF MATERIAL

When heat treating temperature or time is required by the material specification and the rules of this Subsection, the heat treating shall be performed in temperature-surveyed and temperature-calibrated furnaces or the heat treating shall be controlled by measurement of material temperature by thermocouples in contact with the material or attached to blocks in contact with the material or by calibrated pyrometric instruments. Heat treating shall be performed under furnace loading conditions such that the heat treatment is in accordance with the material specification and the rules of this Subsection.

NB-2190 NON-PRESSURE-RETAINING MATERIAL

(a) Material in the component support load path and not performing a pressure-retaining function (see NB-1130) welded to pressure-retaining material shall meet the requirements of Article NF-2000.

(b) Material not performing a pressure-retaining function and not in the component support load path (nonstructural attachments) welded at or within $2t$ of the pressure-retaining portion of the component need not comply with Article NB-2000 or Article NF-2000, provided the requirements of NB-4430 are met.

(c) Structural steel rolled shapes, which are permitted by this Subsection to be furnished with a Certificate of Compliance, may be repaired by welding using the welders, documentation, and examination requirements specified in SA-6.

NB-2200 MATERIAL TEST COUPONS AND SPECIMENS FOR FERRITIC STEEL MATERIAL

NB-2210 HEAT TREATMENT REQUIREMENTS

NB-2211 Test Coupon Heat Treatment for Ferritic Material[1]

Where ferritic steel material is subjected to heat treatment during fabrication or installation of a component, the material used for the tensile and impact test specimens shall be heat treated in the same manner as the component, except that test coupons and specimens for P-No. 1 Group Nos. 1 and 2 material with a nominal thickness of 2 in. (50 mm) or less are not required to be so heat treated. The Certificate Holder shall provide the Material Organization with the temperature and heating and cooling rate to be used. In the case of postweld heat treatment, the total time at temperature or temperatures for the test material shall be at least 80% of the total time at temperature or temperatures during actual postweld heat treatment of the material, and the total time at temperature or temperatures for the test material, coupon, or specimen may be performed in a single cycle.

NB-2212 Test Coupon Heat Treatment for Quenched and Tempered Material

NB-2212.1 Cooling Rates. Where ferritic steel material is subjected to quenching from the austenitizing temperature, the test coupons representing that material shall be cooled at a rate similar to and no faster than the main body of the material except in the case of certain forgings and castings (see NB-2223.2 and NB-2226). This rule shall apply to coupons taken directly from the material as well as to separate test coupons representing the material, and one of the general procedures described in NB-2212.2 or one of the specific procedures described in NB-2220 shall be used for each product form.

NB-2212.2 General Procedures. One of the general procedures stipulated in (a), (b), and (c) below may be applied to quenched and tempered material or test coupons representing the material, provided the specimens are taken relative to the surface of the product in accordance with NB-2220. Further specific details of the methods to be used shall be the obligation of the Material Organization and the Certificate Holder.

(a) Any procedure may be used that can be demonstrated to produce a cooling rate in the test material that matches the cooling rate of the main body of the product at the region midway between midthickness and the surface ($^1/_4t$) and no nearer any heat-treated edge than a distance equal to the nominal thickness t being quenched within 25°F (14°C) and 20 sec at all temperatures after cooling begins from the austenitizing temperature.

(b) If cooling rate data for the material and cooling rate control devices for the test specimens are available, the test specimens may be heat treated in the device to represent the material, provided that the provisions of (a) above are met.

(c) When any of the specific procedures described in NB-2220 are used, faster cooling rates at the edges may be compensated for by

(1) taking the test specimens at least t from a quenched edge, where t equals the material thickness;

(2) attaching a steel pad at least t wide by a partial penetration weld (which completely seals the buffered surface) to the edge where specimens are to be removed; or

(3) using thermal barriers or insulation at the edge where specimens are to be removed.

It shall be demonstrated (and this information shall be included in the Certified Material Test Report) that the cooling rates are equivalent to (a) or (b) above.

NB-2220 PROCEDURE FOR OBTAINING TEST COUPONS AND SPECIMENS FOR QUENCHED AND TEMPERED MATERIAL

NB-2221 General Requirements

The procedure for obtaining test coupons and specimens for quenched and tempered material is related to the product form. Coupon and specimen location and the number of tension test specimens shall be in accordance with the material specifications, except as required by the following paragraphs. References to dimensions signify nominal values.

NB-2222 Plates

NB-2222.1 Number of Tension Test Coupons. The number of tension test coupons required shall be in accordance with the material specification and with SA-20, except that from carbon steel plates weighing 42,000 lb (19 000 kg) and over and alloy steel plates weighing 40,000 lb (18 000 kg) and over, two tension test coupons shall be taken, one representing the top end of the plate and one representing the bottom end of the plate.

NB-2222.2 Orientation and Location of Coupons. Coupons shall be taken so that specimens shall have their longitudinal axes at least $^1\!/_4t$ from a rolled surface and with the midlength of the specimen at least t from any heat-treated edge, where t is the nominal thickness of the material.

NB-2222.3 Requirements for Separate Test Coupons. Where a separate test coupon is used to represent the component material, it shall be of sufficient size to ensure that the cooling rate of the region from which the test coupons are removed represents the cooling rate of the material at least $^1\!/_4t$ deep and t from any edge of the product. Unless cooling rates applicable to the bulk pieces or product are simulated in accordance with NB-2212.2(b), the dimensions of the coupon shall be not less than $3t \times 3t \times t$, where t is the nominal material thickness.

NB-2223 Forgings

NB-2223.1 Location of Coupons. Coupons shall be taken so that specimens shall have their longitudinal axes at least $^1\!/_4t$ from any surface and with the midlength of the specimens at least t from any second surface, where t is the maximum heat-treated thickness. A thermal buffer as described in NB-2212.2(c) may be used to achieve these conditions, unless cooling rates applicable to the bulk forgings are simulated as otherwise provided in NB-2212.2.

NB-2223.2 Very Thick and Complex Forgings. Test coupons for forgings that are both very thick and complex, such as contour nozzles, thick tubesheets, flanges, nozzles, pump and valve bodies, and other complex forgings that are contour shaped or machined to essentially the finished product configuration prior to heat treatment may be removed from prolongations or other stock provided on the product. The Certificate Holder shall specify the surfaces of the finished product subjected to high tensile stresses in service. The coupons shall be taken so that specimens shall have their longitudinal axes at a distance below the nearest heat-treated surface, equivalent at least to the greatest distance that the indicated high tensile stress surface will be from the nearest surface during heat treatment, and with the midlength of the specimens a minimum of twice this distance from a second heat-treated surface. In any case, the longitudinal axes of the specimens shall not be nearer than $^3\!/_4$ in. (19 mm) to any heat-treated surface and the midlength of the specimens shall be at least $1^1\!/_2$ in. (38 mm) from any second heat-treated surface.

NB-2223.3 Coupons From Separately Produced Test Forgings. Test coupons representing forgings from one heat and one heat treatment lot may be taken from a separately forged piece under the conditions given in (a) through (e) below.

(a) The separate test forging shall be of the same heat of material and shall be subjected to substantially the same reduction and working as the production forging it represents.

(b) The separate test forging shall be heat treated in the same furnace charge and under the same conditions as the production forging.

(c) The separate test forging shall be of the same nominal thickness as the production forging.

(d) Test coupons for simple forgings shall be taken so that specimens shall have their longitudinal axes at the region midway between midthickness and the surface, and with the midlength of the specimens no nearer any heat-treated edge than a distance equal to the forging thickness, except when the thickness–length ratio of the production forging does not permit, in which case a production forging shall be used as the test forging and the midlength of the specimens shall be at the midlength of the test forging.

(e) Test coupons for complex forgings shall be taken in accordance with NB-2223.2.

NB-2223.4 Test Specimens for Forgings. When test specimens for forgings are to be taken under the applicable specification, the Inspector shall have the option of witnessing the selection, placing an identifying stamping on them, and witnessing the testing of these specimens.

NB-2224 Bar and Bolting Material

(a) Bars. Coupons shall be taken so that specimens shall have their longitudinal axes at least $\frac{1}{4}t$ from the outside or rolled surface and with the midlength of the specimens at least t from a heat-treated end, where t is either the bar diameter or thickness.

(b) Bolting. For bolting materials, tests shall be made of either full-size bolts or test coupons as required by the base specification. The gage length of the tension specimens and the area under the notch of Charpy specimens shall be at least one diameter or thickness from the heat-treated end.

NB-2225 Tubular Products and Fittings

NB-2225.1 Location of Coupons. Coupons shall be taken so that specimens shall have their longitudinal axes at least $\frac{1}{4}t$ from the inside or outside surface and with the midlength of the specimens at least t from a heat-treated end, where t is the nominal wall thickness of the tubular product.

NB-2225.2 Separately Produced Coupons Representing Fittings. Separately produced test coupons representing fittings may be used. When separately produced coupons are used, the requirements of NB-2223.3 shall be met.

NB-2226 Tensile Test Specimen Location (for Quenched and Tempered Ferritic Steel Castings)

NOTE: Users of this requirement should note that the hardenability of some grades may limit the usable section size.

(a) This section applies only to quenched and tempered ferritic steel castings with a thickness t exceeding 2 in. (50 mm) where t is the thickness of the pressure-retaining wall of the casting, excluding flanges and sections designated by the designer as nonpressure retaining. The order, inquiry, and drawing shall designate what the thickness t is for the casting.

(b) One of the following shall apply:

(1) The longitudinal centering of the thickness of the tension test specimen shall be taken at least $\frac{1}{4}t$ from the t dimension surface. For cylindrical castings, the longitudinal center line of the specimens shall be taken at least $\frac{1}{4}t$ from the outside or inside surface and the gage length at least t from the as-heat-treated end.

(2) Where separately cast test coupons are used, their dimensions shall be not less than $3t \times 3t \times t$ and each specimen cut from it shall meet the requirements of (1) above. The test coupon shall be of the same heat of steel and shall receive substantially the same casting practices as the production casting it represents. (Centrifugal castings may be represented by statically cast coupons.) The test coupon shall be heat treated under the same conditions as the production casting(s). The t dimension of the test coupon shall be the same maximum thickness t as defined in (a) above. Where separate test blocks require reheat treatment, thermal buffers in accordance with (1) above may be used.

(3) Where specimens are to be removed from the body of the casting, a steel, thermal buffer pad $1t \times 1t \times$ at least $3t$ shall be joined to the casting surface by a partial penetration weld completely sealing the buffered surface prior to the heat treatment process. The test specimens shall be removed from the casting in a location adjacent to the center third of the buffer pad. They shall be located at a minimum distance of $\frac{1}{2}$ in. (13 mm) from the buffered surface and $\frac{1}{4}t$ from the other heat-treated surfaces.

(4) Where specimens are to be removed from the body of the casting, thermal insulation or other thermal barriers shall be used during the heat treatment process adjacent to the casting edge where specimens are to be removed. It shall be demonstrated that the cooling rate of the test specimen is no faster than that of specimens taken by the method described in (1) above. This information shall be included in the test reports.

(5) Where castings are cast or machined to essentially the finished product configuration prior to heat treatment, the test specimens shall be removed from a casting prolongation or other stock on the product at a location below the nearest heat-treated surface indicated on the order. The specimens shall be located with their longitudinal axes a distance below the nearest heat-treated surface equivalent to at least the greatest distance that the indicated high tensile stress surface will be from the nearest heat-treated surface and with their midlength a minimum of twice this distance from a second heat-treated surface. In any case, the longitudinal axes of the test specimens shall be no nearer than $\frac{1}{4}$ in. (6 mm) to a heat-treated surface and the midlength shall be at least $1\frac{1}{2}$ in. (38 mm) from a second heat-treated surface. The component manufacturer shall specify the surfaces of the finished product subjected to high tensile stress in service.

NB-2300 FRACTURE TOUGHNESS REQUIREMENTS FOR MATERIAL

NB-2310 MATERIAL TO BE IMPACT TESTED

NB-2311 Material for Which Impact Testing Is Required

(a) Pressure-retaining material and material welded thereto shall be impact tested in accordance with the requirements of this subarticle, except that the material listed in (1) through (7) below is not to be impact tested as a requirement of this Subsection:

(1) material with a nominal section thickness of $\frac{5}{8}$ in. (16 mm) and less where the thicknesses shall be taken as defined in (-a) through (-e) below:

(-a) for pumps, valves, and fittings, use the largest nominal pipe wall thickness of the connecting pipes;

(-b) for vessels and tanks, use the nominal thickness of the shell or head, as applicable;

(-c) for nozzles or parts welded to vessels, use the lesser of the vessel shell thickness to which the item is welded or the maximum radial thickness of the item exclusive of integral shell butt welding projections;

(-d) for flat heads, tubesheets, or flanges, use the maximum shell thickness associated with the butt welding hub;

(-e) for integral fittings used to attach process piping to the containment vessel or a containment vessel nozzle, use the larger nominal thickness of the pipe connections;

(2) bolting, including studs, nuts, and bolts, with a nominal size of 1 in. (25 mm) and less

(3) bars with a nominal cross-sectional area of 1 in.^{2} (650 mm^2) and less;

(4) all thicknesses of material for a pipe, tube, fittings, pumps, and valves with a nominal pipe size NPS 6 (DN 150) and smaller;

(5) material for pumps, valves, and fittings with all pipe connections of $^5\!/_8$ in. (16 mm) nominal wall thickness and less;

(6) austenitic stainless steels, including precipitation hardened austenitic Grade 660 (UNS S66286);

(7) nonferrous material.

(b) Drop weight tests are not required for the martensitic high alloy chromium (Series 4XX) steels and precipitation hardening steels listed in Section II, Part D, Subpart 1, Table 2A. The other requirements of NB-2332 apply for these steels. For nominal wall thicknesses greater than 2$^1\!/_2$ in. (64 mm), the required Charpy V-notch values shall be 40 mils (1 mm) lateral expansion.

NB-2320 IMPACT TEST PROCEDURES

NB-2321 Types of Tests

NB-2321.1 Drop Weight Tests. The drop weight test, when required, shall be performed in accordance with ASTM E208. Specimen types P-No. 1, P-No. 2, or P-No. 3 may be used. The results, orientation, and location of all tests performed to meet the requirements of NB-2330 shall be reported in the Certified Material Test Report.

(23) **NB-2321.2 Charpy V-Notch Tests.** The Charpy V-notch test (C_v), when required, shall be performed in accordance with SA-370. Specimens shall be in accordance with SA-370, Figure 11, Type A. A test shall consist of a set of three full-size 10 mm × 10 mm specimens and meet the requirements of NB-2330. When the material being tested is expected to exceed 80% of the testing machine's full-scale capacity, standard subsize specimens may be used as permitted in SA-370. When subsize specimens are used, the average lateral expansion and absorbed energy results shall be a minimum of 50 mils (1.27 mm) and 75 ft-lb (100 J), respectively. The test location, orientation, size, test temperature, lateral expansion, and absorbed energy shall be reported in the Certified Material Test Report.

NB-2321.3 Transition Temperature Fracture Toughness Tests. When the alternative of NB-2331(a)(5) is used, the fracture toughness test shall be performed in accordance with ASTM E1921. The set of tests shall meet the validity requirements of ASTM E1921, and specimen geometries having a suspected T_0 constraint difference from C(T) shall be adjusted to represent C(T) constraint as recommended in ASTM E1921. The results, orientation, and location of all tests performed to meet the requirements of NB-2330 shall be reported in the Certified Material Test Report.

NB-2322 Test Specimens

NB-2322.1 Location of Test Specimens. Impact test specimens for quenched and tempered material shall be removed from the locations in each product form specified in NB-2220 for tensile test specimens. For material in other heat-treated conditions, impact test specimens shall be removed from the locations specified for tensile test specimens in the material specification. For all material, the number of tests shall be in accordance with NB-2340. For bolting, the C_v impact test specimen shall be taken with the longitudinal axis of the specimen located at least one-half radius or 1 in. (25 mm) below the surface plus the machining allowance per side, whichever is less. The fracture plane of the specimens shall be at least one diameter or thickness from the heat-treated end. When the studs, nuts, or bolts are not of sufficient length, the midlength of the specimen shall be at the midlength of the studs, nuts, or bolts. The studs, nuts, or bolts selected to provide test coupon material shall be identical with respect to the quenched contour and size except for length, which shall equal or exceed the length of the represented studs, nuts, or bolts.

NB-2322.2 Orientation of Impact Test Specimens.

(a) Specimens for C_v impact tests shall be oriented as follows:

(1) Specimens for forgings, other than bolting and bars used for pressure-retaining parts of vessels, pumps, and valves, shall be oriented in a direction normal to the principal direction in which the material was worked. Specimens are neither required nor prohibited from the thickness direction.

(2) Specimens from material for pipe, tube, and fittings, except for those made from plate and castings, shall be oriented in the axial direction. Specimens from pipe material used for nozzles in vessels shall be oriented in a direction normal to the principal direction in which

the material was worked, other than the thickness direction.

(3) Specimens from bolting material and bars shall be oriented in the axial direction.

(4) Specimens for all plate material, including that used for pipe, tube, and fittings, shall be oriented in a direction normal to the principal rolling direction, other than thickness direction.

(5) Specimens for cast material shall have their axes oriented the same as the axes of the tensile specimens (see NB-2226).

(6) In (1) through (5) above, the notch of the C_v specimen shall be normal to the surface of the material.

(b) Specimens for drop weight tests may have their axes oriented in any direction. The orientation used shall be reported in the Certified Material Test Report.

NB-2330 TEST REQUIREMENTS AND ACCEPTANCE STANDARDS[2]

NB-2331 Material for Vessels

Pressure-retaining material for vessels, other than bolting, shall be tested as follows:

(a) Establish a reference temperature RT_{NDT}; this shall be done as follows:

(1) Determine a temperature T_{NDT} that is at or above the nil-ductility transition temperature by drop weight tests.

(2) At a temperature not greater than T_{NDT} + 60°F (T_{NDT} + 33°C), each specimen of the C_v test (see NB-2321.2) shall exhibit at least 35 mils (0.89 mm) lateral expansion and not less than 50 ft-lb (68 J) absorbed energy. Retesting in accordance with NB-2350 is permitted. When these requirements are met, T_{NDT} is the reference temperature RT_{NDT}.

(3) In the event that the requirements of (2) above are not met, conduct additional C_v tests in groups of three specimens (see NB-2321.2) to determine the temperature T_{C_v} at which they are met. In this case the reference temperature $RT_{NDT} = T_{C_v} - 60°F$ (T_{C_v} − 33°C). Thus, the reference temperature RT_{NDT} is the higher of T_{NDT} and [T_{C_v} − 60°F (T_{C_v} − 33°C)].

(4) When a C_v test has not been performed at T_{NDT} + 60°F (T_{NDT} + 33°C), or when the C_v test at T_{NDT} + 60°F (T_{NDT} + 33°C) does not exhibit a minimum of 50 ft-lb (68 J) and 35 mils (0.89 mm) lateral expansion, a temperature representing a minimum of 50 ft-lb (68 J) and 35 mils (0.89 mm) lateral expansion may be obtained from a full C_v impact curve developed from the minimum data points of all the C_v tests performed.

(5) Alternatively, a fracture toughness-based reference temperature, RT_{T0}, may be used in place of RT_{NDT}. The reference temperature RT_{T0} is defined as

(U.S. Customary Units)

$$RT_{T0} = T_0 + 35°F$$

(SI Units)

$$RT_{T0} = T_0 + 19.4°C$$

Determination of T_0 shall be per NB-2321.3, and twice the margin adjustment defined in ASTM E1921 shall be added.

(b) Apply the procedures of (a) to (1), (2), and (3) below:

(1) the base material;[3]

(2) the base material, the heat-affected zone, and weld metal from the weld procedure qualification tests in accordance with NB-4330;

(3) the weld metal of NB-2431.

(c) Bars having a width or diameter of 2 in. (50 mm) and less that prohibit obtaining drop weight test specimens shall be tested in accordance with NB-2332.

(d) Some nozzles or appurtenances in vessels, regardless of product form, have insufficient material for obtaining impact tests after heat treatment (except postweld heat treatment). In this case, it is not necessary to perform both the drop weight and transverse C_v impact tests as required by (a). Instead, this material may be tested by only using axial C_v specimens. The three C_v specimens so removed shall be tested at a temperature lower than or equal to the lowest service temperature but no higher than the required RT_{NDT} + 60°F (RT_{NDT} + 33°C) for the vessel material to which the nozzle or appurtenance is attached. Each specimen shall exhibit at least 35 mils (0.89 mm) lateral expansion and not less than 50 ft-lb (68 J) absorbed energy.

(e) Consideration shall be given to the effects of irradiation (see NB-3124) on material toughness properties in the core belt line region of the reactor vessel. The Design Specifications shall include additional requirements, as necessary, to ensure adequate fracture toughness for the service lifetime of the vessel. The toughness properties may be verified in service periodically by a material surveillance program using the methods of ASTM E185 and the material conditions monitored by the inservice inspection requirements of Section XI.

(f) Consideration shall be given to the test temperature requirements of hydrostatic testing of the vessel (see NB-6212).

NB-2332 Material for Piping, Pumps, and Valves, Excluding Bolting Material

(a) Pressure-retaining material, other than bolting, with nominal wall thickness $2\frac{1}{2}$ in. (64 mm) and less for piping (pipe and tubes) and material for pumps, valves, and fittings with all pipe connections of nominal wall thickness $2\frac{1}{2}$ in. (64 mm) and less shall be tested as required in (1) and (2) below.

(1) Test three C_v specimens at a temperature lower than or equal to the lowest service temperature as established in the design specification (see NB-3210). All three

Table NB-2332(a)-1
Required C_v Values for Piping, Pumps, and Valves

Nominal Wall Thickness, in. (mm) [Note (1)]	Lateral Expansion, mils (mm)
5/8 (16) or less	No test required
Over 5/8 to 3/4 (16 to 19), incl.	20 (0.50)
Over 3/4 to 1 1/2 (19 to 38), incl.	25 (0.64)
Over 1 1/2 to 2 1/2 (38 to 64), incl.	40 (1.00)

NOTE: (1) For pumps, valves, and fittings, use the nominal pipe wall thickness of the connecting piping.

specimens shall meet the requirements of Table NB-2332(a)-1.

(2) Apply the procedures of (a) to

(-a) the base material;[3]

(-b) the base material, the heat-affected zone, and weld metal from the weld procedure qualification tests in accordance with NB-4330; and

(-c) the weld metal of NB-2431.

(b) Pressure-retaining material, other than bolting, with nominal wall thickness over 2 1/2 in. (64 mm) for piping (pipe and tubes) and material for pumps, valves, and fittings with any pipe connections of nominal wall thickness greater than 2 1/2 in. (64 mm) shall meet the requirements of NB-2331. The lowest service temperature shall not be lower than RT_{NDT} + 100°F (56°C) unless a lower temperature is justified by following methods similar to those contained in Section III Appendices, Nonmandatory Appendix G.

NB-2333 Bolting Material

For bolting material, including studs, nuts, and bolts, test three C_v specimens at a temperature no higher than the preload temperature or the lowest service temperature, whichever is less. All three specimens shall meet the requirements of Table NB-2333-1.

Table NB-2333-1
Required C_v Values for Bolting Material

Nominal Diameter, in. (mm)	Lateral Expansion, mils (mm)	Absorbed Energy, ft-lb (J)
1 (25) or less	No test required	No test required
Over 1 to 4 (25 to 100), incl.	25 (0.64)	No requirements
Over 4 (100)	25 (0.64)	45 (61)

NB-2340 NUMBER OF IMPACT TESTS REQUIRED

NB-2341 Plates

One test shall be made from each plate as heat treated. Where plates are furnished in the unheat-treated condition and qualified by heat-treated test specimens, one test shall be made for each plate as-rolled. The term *as-rolled* refers to the plate rolled from a slab or directly from an ingot, not to its heat-treated condition.

NB-2342 Forgings and Castings

(a) Where the weight of an individual forging or casting is less than 1,000 lb (450 kg), one test shall be made to represent each heat in each heat treatment lot.

(b) When heat treatment is performed in a continuous type furnace with suitable temperature controls and equipped with recording pyrometers so that complete heat treatment records are available, a heat treatment charge shall be considered as the lesser of a continuous run not exceeding 8 hr duration or a total weight, so treated, not exceeding 2,000 lb (900 kg).

(c) One test shall be made for each forging or casting of 1,000 lb (450 kg) to 10,000 lb (4 500 kg) in weight.

(d) As an alternative to (c), a separate test forging or casting may be used to represent forgings or castings of different sizes in one heat and heat treat lot, provided the test piece is a representation of the greatest thickness in the heat treat lot. In addition, test forgings shall have been subjected to substantially the same reduction and working as the forgings represented.

(e) Forgings or castings larger than 10,000 lb (4 500 kg) shall have two tests per part for Charpy V-notch and one test for drop weights. The location of drop weight or C_v impact test specimens shall be selected so that an equal number of specimens is obtained from positions in the forging or casting 180 deg apart.

(f) As an alternative to (e) for static castings, a separately cast test coupon [see NB-2226(b)(2)] may be used; one test shall be made for Charpy V-notch and one test for drop weight.

NB-2343 Bars

One test shall be made for each lot of bars with cross-sectional area greater than 1 in.^{2} (650 mm^2), where a lot is defined as one heat of material heat treated in one charge or as one continuous operation, not to exceed 6,000 lb (2 700 kg).

NB-2344 Tubular Products and Fittings

On products that are seamless or welded without filler metal, one test shall be made from each lot. On products that are welded with filler metal, one additional test with the specimens taken from the weld area shall also be made on each lot. A lot shall be defined as stated in the applicable material specification, but in no case shall a lot consist of products from more than one heat of material and of more than one diameter, with the nominal thickness of any product included not exceeding that to be impact tested by more than $^{1}/_{4}$ in. (6 mm); such a lot shall be in a single heat treatment load or in the same continuous run in a continuous furnace controlled within a 50°F (28°C) range and equipped with recording pyrometers.

NB-2345 Bolting Material

One test shall be made for each lot of material, where a lot is defined as one heat of material heat treated in one charge or as one continuous operation, not to exceed in weight (mass) the following:

Diameter, in. (mm)	Weight, lb (kg)
$1^{3}/_{4}$ (44) and less	1,500 (400)
Over $1^{3}/_{4}$ to $2^{1}/_{2}$ (44 to 64)	3,000 (1 350)
Over $2^{1}/_{2}$ to 5 (64 to 125)	6,000 (2 700)
Over 5 (125)	10,000 (4 500)

NB-2346 Test Definitions

Unless otherwise stated in NB-2341 through NB-2345, the term *one test* is defined to include the combination of the drop weight test and the C_v test when RT_{NDT} is required [see NB-2331 and NB-2332(b)] and only the C_v test when determination of RT_{NDT} is not required [see NB-2332(a) and NB-2333].

NB-2350 RETESTS

(a) For C_v tests required by NB-2330, one retest at the same temperature may be conducted provided the requirements of (1) through (3) below are met:

(1) the average value of the test results meets the minimum requirements;

(2) not more than one specimen per test is below the minimum requirements;

(3) the specimen not meeting the minimum requirements is not lower than 10 ft-lb (14 J) or 5 mils (0.13 mm) below the specified requirements.

(b) A retest consists of two additional specimens taken as near as practicable to the failed specimens. For acceptance of the retest, both specimens shall meet the minimum requirements.

NB-2360 CALIBRATION OF INSTRUMENTS AND EQUIPMENT

Calibration of temperature instruments and C_v impact test machines used in impact testing shall be performed at the frequency given in (a) and (b) below.

(a) Temperature instruments used to control the test temperature of specimens shall be calibrated and the results recorded to meet the requirements of NCA-4258.2 at least once in each 3-month interval.

(b) C_v impact test machines shall be calibrated and the results recorded to meet the requirements of NCA-4258.2. The calibrations shall be performed using the frequency and methods outlined in ASTM E23 and employing standard specimens obtained from the National Institute of Standards and Technology, or any supplier of subcontracted calibration services accredited in accordance with the requirements of NCA-3126 and NCA-4255.3(c).

NB-2400 WELDING MATERIAL

NB-2410 GENERAL REQUIREMENTS

(a) All welding material used in the construction and repair of components or material, except welding material used for cladding or hard surfacing, shall conform to the requirements of the welding material specification or to the requirements for other welding material as permitted in Section IX. In addition, welding material shall conform to the requirements stated in this subarticle and to the rules covering identification in NB-2150.

(b) The Certificate Holder shall provide the organization performing the testing with the information listed below, as applicable.

(1) welding process;

(2) SFA Specification and classification;

(3) other identification if no SFA Specification applies;

(4) minimum tensile strength [see NB-2431.1(e)] in the as-welded or heat-treated condition or both [see NB-2431.1(c)];

(5) drop weight test for material as-welded or heat treated, or both (see NB-2332);

(6) Charpy V-notch test for material as-welded or heat treated, or both (see NB-2331); the test temperature and the lateral expansion or the absorbed energy shall be provided;

(7) the preheat and interpass temperatures to be used during welding of the test coupon [see NB-2431.1(c)];

(8) postweld heat treatment time, temperature range, and maximum cooling rate, if the production weld will be heat treated [see NB-2431.1(c)];

(9) elements for which chemical analysis is required per the SFA Specification or Welding Procedure Specification and NB-2432;

(10) minimum delta ferrite (see NB-2433).

NB-2420 REQUIRED TESTS

The required tests shall be conducted for each lot of covered, flux-cored, or fabricated electrodes; for each heat of bare electrodes, rod, or wire for use with the OFW, GMAW, GTAW, PAW, and EGW (electrogas welding) processes (Section IX, QG-109); for each heat of consumable inserts; for each combination of heat of bare electrodes and lot of submerged arc flux; for each combination of lot of fabricated electrodes and lot of submerged arc flux; for each combination of heat of bare electrodes or lot of fabricated electrodes, and dry blend of supplementary powdered filler metal, and lot of submerged arc flux; or for each combination of heat of bare electrodes and lot of electroslag flux. The definitions in SFA-5.01 and the Lot Classes specified in (a) through (e) below shall apply.

(a) each Lot Class C3 of covered electrodes.

(b) each Lot Class T2 of tubular-cored electrodes and rods (flux cored or fabricated).

(c) each Lot Class S2 of fully metallic solid welding consumables (bare electrode, rod, wire, consumable insert, or powdered filler metal).

(d) each Lot Class S2 of fully metallic solid welding electrodes or each Lot Class T2 of tubular-cored (fabricated) electrodes and each Lot Class F2 of submerged arc or electroslag welding flux.

(e) each Lot Class S2 of fully metallic solid welding electrodes or each Lot Class T2 of tubular-cored (fabricated) electrodes and each Lot Class F2 of submerged arc or electroslag welding flux and each Lot Class S2 of supplementary powdered filler metal. The chemical analysis range of the supplemental powdered filler metal shall be the same as that of the welding electrode, and the ratio of powder to electrode used to make the test coupon shall be the maximum permitted for production welding.

In all cases, when filler metal of controlled chemical composition (as opposed to heat control) is used, each container of welding consumable shall be coded for identification and shall be traceable to the production period, the shift, the manufacturing line, and the analysis of the steel rod or strip. Carbon, manganese, silicon, and other intentionally added elements shall be identified to ensure that the material conforms to the SFA or user's material specification. The use of controlled chemical composition is only permitted for carbon and low alloy steel consumables. Tests performed on welding material in the qualification of weld procedures will satisfy the testing requirements for the lot, heat, or combination of heat and batch of welding material used, provided the tests required by Article NB-4000 and this subarticle are made and the results conform to the requirements of this Article.

NB-2430 WELD METAL TESTS

NB-2431 Mechanical Properties Test

Tensile and impact tests shall be made, in accordance with this paragraph, of welding materials that are used to join P-Nos. 1, 3, 4, 5, 6, 7, 9, and 11 base materials in any combination, with the exceptions listed in (a) through (d) below:

(a) austenitic stainless steel and nonferrous welding material used to join the listed P-Numbers;

(b) consumable inserts (backing filler material);

(c) welding material used for GTAW root deposits with a maximum of two layers;

(d) welding material to be used for the welding of base material exempted from impact testing by NB-2311 shall likewise be exempted from the impact testing required by NB-2330 and this paragraph.

NB-2431.1 General Test Requirements. The welding test coupon shall be made in accordance with (a) through (f) below, using each process with which the weld material will be used in production welding.

(a) Test coupons shall be of sufficient size and thickness such that the test specimens required herein can be removed.

(b) The weld metal to be tested for all processes except electroslag welding shall be deposited in such a manner as to eliminate substantially the influence of the base material on the results of the tests. Weld metal to be used with the electroslag process shall be deposited in such a manner as to conform to one of the applicable Welding Procedure Specifications (WPS) for production welding. The base material shall conform to the requirements of Section IX, QW-403.1 or QW-403.4, as applicable.

(c) The welding of the test coupon shall be performed within the range of preheat and interpass temperatures that will be used in production welding. Coupons shall be tested in the as-welded condition, or they shall be tested in the applicable postweld heat-treated condition when the production welds are to be postweld heat treated. The postweld heat treatment holding time[1] shall be at least 80% of the maximum time to be applied to the weld metal in production application. The total time for postweld heat treatment of the test coupon may be applied in one heating cycle. The cooling rate from the postweld heat treatment temperature shall be of the same order as that applicable to the weld metal in the component. In addition, weld coupons for weld metal to be used with the electroslag process, which are tested in the as-welded condition or following a postweld heat treatment within the holding temperature ranges of Table NB-4622.1-1 or Table NB-4622.4(c)-1, shall have a thickness within the range of 0.5 to 1.1 times the thickness of the welds to be made in production. Electroslag weld coupons to be tested following a postweld heat treatment, which will include heating the coupon to a temperature above the Holding Temperature Range of Table NB-4622.1-1 for the type of material being tested, shall have a thickness within the range of 0.9 to 1.1 times the thickness of the welds to be made in production.

(d) The tensile specimens, and the C_v impact specimens where required, shall be located and prepared in accordance with the requirements of SFA-5.1 or the applicable SFA specification. Drop weight impact test specimens, where required, shall be oriented so that the longitudinal axis is transverse to the weld with the notch in the weld face or in a plane parallel to the weld face. For impact specimen preparation and testing, the applicable parts

of NB-2321.1 and NB-2321.2 shall apply. The longitudinal axis of the specimen shall be at a minimum depth of $^1/_4t$ from a surface, where t is the thickness of the test weld.

(e) One all weld metal tensile specimen shall be tested and shall meet the specified minimum tensile strength requirements of the base material specification. When base materials of different specifications are to be welded, the tensile strength requirements shall conform to the specified minimum tensile strength requirements of either of the base material specifications.

(f) Impact specimens of the weld metal shall be tested where impact tests are required for either of the base materials of the production weld. The weld metal shall conform to the parts of NB-2331(a) or NB-2332 applicable to the base material. Where different requirements exist for the two base materials, the weld metal may conform to either of the two requirements.

NB-2431.2 Standard Test Requirements. In lieu of the use of the General Test Requirements specified in NB-2431.1, tensile and impact tests may be made in accordance with this subparagraph where they are required for mild and low alloy steel covered electrodes; the material combinations to require weld material testing, as listed in NB-2431, shall apply for this Standard Test Requirements option. The limitations and testing under this Standard Test option shall be in accordance with (a) through (f) below.

(a) Testing to the requirements of this subparagraph shall be limited to electrode classifications included in Specifications SFA-5.1 or SFA-5.5.

(b) The test assembly required by SFA-5.1 or SFA-5.5, as applicable, shall be used for test coupon preparation, except that it shall be increased in size to obtain the number of C_v specimens and the drop weight test specimens required by NB-2331(a) or NB-2332, where applicable.

(c) The welding of the test coupon shall conform to the requirements of the SFA Specification for the classification of electrode being tested. Coupons shall be tested in the as-welded condition and also in the postweld heat-treated condition. The PWHT temperatures shall be in accordance with Table NB-4622.1-1 for the applicable P-Number equivalent. The time at PWHT temperature shall be 8 hr. (This qualifies PWHT of 10 hr or less.) When the PWHT of the production weld exceeds 10 hr, or the PWHT temperature is other than that required above, the general test of NB-2431.1 shall be used.

(d) The tensile and C_v specimens shall be located and prepared in accordance with the requirements of SFA-5.1 or SFA-5.5, as applicable. Drop weight impact test specimens, where required, shall be located and oriented as specified in NB-2431.1(d).

(e) One all weld metal tensile specimen shall be tested and shall meet the specified minimum tensile strength requirement of the SFA Specification for the applicable electrode classification.

(f) The requirements of NB-2431.1(f) shall be applicable to the impact testing of this option.

NB-2432 Chemical Analysis Test

Chemical analysis of filler metal or weld deposits shall be made in accordance with NB-2420 and as required by the following subparagraphs.

NB-2432.1 Test Method. The chemical analysis test shall be performed in accordance with this subparagraph and Table NB-2432.1-1, and the results shall conform to NB-2432.2.

(a) A-No. 8 welding material to be used with GTAW and PAW processes and any other welding material to be used with any GTAW, PAW, or GMAW process shall have chemical analysis performed either on the filler metal or on a weld deposit made with the filler metal in accordance with (c) or (d).

(b) A-No. 8 welding material to be used with other than the GTAW and PAW processes and other welding material to be used with other than the GTAW, PAW, or GMAW process shall have chemical analysis performed on a weld deposit of the material or combination of materials being certified in accordance with (c) or (d) below. The removal of chemical analysis samples shall be from an undiluted weld deposit made in accordance with (c). As an alternative, the deposit shall be made in accordance with (d) for material that will be used for corrosion-resistant overlay cladding. Where the Welding Procedure Specification or the welding material specification specifies percentage composition limits for analysis, it shall state that the specified limits apply for the filler metal analysis, the undiluted weld deposit analysis, or *in situ* cladding deposit analysis in conformance with the above required certification testing.

(c) The preparation of samples for chemical analysis of undiluted weld deposits shall comply with the method given in the applicable SFA Specification. Where a weld deposit method is not provided by the SFA specification, the sample shall be removed from a weld pad, groove, or other test weld[4] made using the welding process that will be followed when the welding material or combination of welding materials being certified is consumed. The weld for A-No. 8 material to be used with the GMAW or EGW process shall be made using the shielding gas composition specified in the Welding Procedure Specifications that will

Table NB-2432.1-1
Sampling of Welding Materials for Chemical Analysis

Welding Material	GTAW/PAW	GMAW	All Other Processes
A-No. 8 filler metal	Filler metal or weld deposit	Weld deposit	Weld deposit
All other filler metal	Filler metal or weld deposit	Filler metal or weld deposit	Weld deposit

Table NB-2432.2(a)-1
Chemical Analysis for Reactor Vessel Welding Material

Materials	Elements
Carbon and low alloy materials	C, Cr, Mo, Ni, Mn, Si, P, S, V, Cu
Chromium and Cr–Ni stainless material	C, Cr, Mo, Ni, Mn, Si, P, S, V, Cb + Ta, Ti, Cu

be followed when the material is consumed. The test sample for ESW shall be removed from the weld metal of the mechanical properties test coupon. Where a chemical analysis is required for a welding material that does not have a mechanical properties test requirement, a chemical analysis test coupon shall be prepared as required by NB-2431.1(c), except that heat treatment of the coupon is not required and the weld coupon thickness requirements of NB-2431.1(c) do not apply.

(d) The alternative method provided in (b) above for the preparation of samples for chemical analysis of welding material to be used for corrosion resistant overlay cladding shall require a test weld made in accordance with the essential variables of the Welding Procedure Specification that will be followed when the welding material is consumed. The test weld shall be made in conformance with the requirements of Section IX, QW-214.1. The removal of chemical analysis samples shall conform with Section IX, Table QW-453 for the minimum thickness for which the welding procedure specification is qualified.

(23) **NB-2432.2 Requirements for Chemical Analysis.** The chemical elements to be determined, the composition requirements of the weld metal, and the recording of results of the chemical analysis shall be in accordance with (a) through (c) below.

(a) See below.

(1) All welding material to be used in the reactor vessel shall be analyzed for the elements listed in Table NB-2432.2(a)-1.

(2) All welding material of ferrous alloys A-No. 8 and A-No. 9 (Section IX, Table QW-442) to be used in other components shall be analyzed for the elements listed in Table NB-2432.2(a)-2 and for any other elements specified in the welding material specification referenced by the WPS or in the WPS.

(3) All other welding material shall be analyzed for the elements specified in either the welding material specification referenced by the WPS or in the WPS.

Table NB-2432.2(a)-2
Chemical Analysis for Welding Material for Other Than Reactor Vessel Welds

Material	Elements
Chromium–Nickel stainless steels	C, Cr, Mo, Ni, Mn, Si, Cb + Ta

(b) The chemical composition of the weld metal or filler metal shall conform to the welding material specification for elements having specified percentage composition limits. Where the Welding Procedure Specification contains a modification of the composition limits of SFA or other referenced welding material specifications, or provides limits for additional elements, these composition limits of the welding procedure specification shall apply for acceptability.

(c) The results of the chemical analysis shall be reported in accordance with NCA-1225.1. Elements listed in Table NB-2432.2(a)-1 or Table NB-2432.2(a)-2 but not specified in the welding material specification or WPS shall be reported for information only.

NB-2433 Delta Ferrite Determination

A determination of delta ferrite shall be performed on A-No. 8 weld material (Section IX, Table QW-442) backing filler metal (consumable inserts); bare electrode, rod, or wire filler metal, or weld metal, except that delta ferrite determinations are not required for SFA-5.9 and SFA-5.4, Type 16-8-2, or A-No. 8 weld filler metal to be used for weld metal cladding.

NB-2433.1 Method. Delta ferrite determinations of welding material, including consumable insert material, shall be made using a magnetic measuring instrument and weld deposits made in accordance with (b) below. Alternatively, the delta ferrite determinations for welding materials may be performed by the use of chemical analysis of NB-2432 in conjunction with Figure NB-2433.1-1.

(a) Calibration of magnetic instruments shall conform to AWS-A4.2.

(b) The weld deposit for magnetic delta ferrite determination shall be made in accordance with NB-2432.1(c).

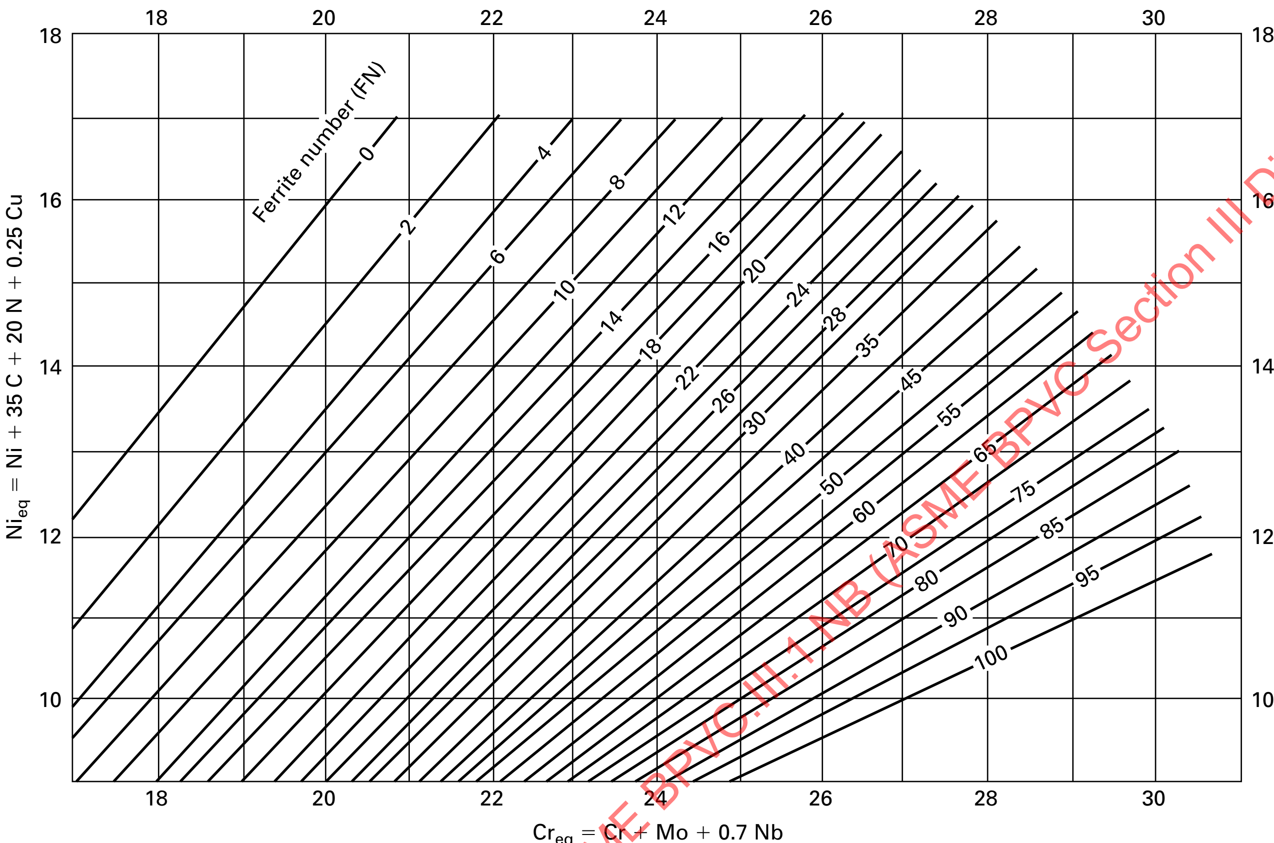
(c) A minimum of six ferrite readings shall be taken on the surface of the weld deposit. The readings obtained shall be averaged to a single Ferrite Number (FN).

NB-2433.2 Acceptance Standards. The minimum acceptable delta ferrite shall be 5FN. The results of the delta ferrite determination shall be included in the Certified Material Test Report of NB-2130 or NB-4120.

NB-2440 STORAGE AND HANDLING OF WELDING MATERIAL

Suitable storage and handling of electrodes, flux, and other welding material shall be maintained. Precautions shall be taken to minimize absorption of moisture by fluxes and cored, fabricated, and coated electrodes.

Figure NB-2433.1-1
Weld Metal Delta Ferrite Content



GENERAL NOTES:

(a) The actual nitrogen content is preferred. If this is not available, the following applicable nitrogen value shall be used:

(1) GMAW welds — 0.08%, except that when self-shielding flux cored electrodes are used — 0.12%.

(2) Welds made using other processes — 0.06%.

(b) This diagram is identical to the WRC-1992 Diagram, except that the solidification mode lines have been removed for ease of use.

NB-2500 EXAMINATION AND REPAIR OF PRESSURE-RETAINING MATERIAL

NB-2510 EXAMINATION OF PRESSURE-RETAINING MATERIAL

(a) Pressure-retaining material and material welded thereto shall be examined by nondestructive methods applicable to the material and product form as required by the rules of this subarticle, except for pumps and valves with inlet piping connections NPS 2 (DN 50) and less. Seamless pipe, tubes, and fittings, NPS 1 (DN 25) and less, need not be examined by the rules of this subarticle. The NPS 1 (DN 25) size exemption does not apply to heat exchanger tubing.

(b) For forged and cast pumps and valves with inlet piping connections over NPS 2 (DN 50), up to and including NPS 4 (DN 100), magnetic particle or liquid penetrant examinations may be performed in lieu of volumetric examination, except that the welding ends for cast pumps and valves shall be radiographed for a minimum distance of t (when t is the design section thickness of the weld) from the final welding end.

(c) The requirements of this subarticle for repair by welding, including examination of the repair welds, shall be met wherever repair welds are made to pressure-retaining material and material welded thereto. The exceptions in (a) and (b) above do not apply to repair welds.

NB-2520 EXAMINATION AFTER QUENCHING AND TEMPERING

Ferritic steel products that have their properties enhanced by quenching and tempering shall be examined by the methods specified in this subarticle for each product form after the quenching and tempering phase of the heat treatment.

NB-2530 EXAMINATION AND REPAIR OF PLATE

NB-2531 Required Examination

All plates 2 in. (50 mm) nominal thickness and less used for piping, pumps, and valves shall be examined by the angle beam ultrasonic method in accordance with NB-2532.2. All plates for vessels and all plates greater than 2 in. (50 mm) thickness shall be examined by the straight beam ultrasonic method in accordance with NB-2532.1.

NB-2532 Examination Procedures

NB-2532.1 Straight Beam Examination. The requirements for straight beam examination shall be in accordance with SA-578, Specification for Straight Beam Wave Ultrasonic Testing and Inspection of Plain and Clad Steel Plates for Special Applications, as shown in Section V, except that the extent of examination and the acceptance standards to be applied are given in (a) and (b) below.

(a) Extent of Examination. One hundred percent of one major plate surface shall be covered by moving the search unit in parallel paths with not less than a 10% overlap.

(b) Acceptance Standards

(1) Any area where one or more imperfections produce a continuous total loss of back reflection accompanied by continuous indications on the same plane that cannot be encompassed within a circle whose diameter is 3 in. (75 mm) or one-half of the plate thickness, whichever is greater, is unacceptable.

(2) In addition, two or more imperfections smaller than described in (1) above shall be unacceptable unless separated by a minimum distance equal to the greatest diameter of the larger imperfection, or unless they may be collectively encompassed by the circle described in (1) above.

NB-2532.2 Angle Beam Examination. The requirements for angle beam examination shall be in accordance with SA-577, Specification for Ultrasonic Beam Wave Inspection of Steel Plates, as shown in Section V and supplemented by (a) and (b) below. The calibration notch, extent of examination, and acceptance standards to be applied are given in (a) through (c) below.

(a) Calibration. Angle beam examination shall be calibrated from a notch.

(b) Extent of Examination. One hundred percent of one major plate surface shall be covered by moving the search unit in parallel paths with not less than 10% overlap.

(c) Acceptance Standards. Material that shows one or more imperfections that produce indications exceeding in amplitude the indication from the calibration notch is unacceptable unless additional exploration by the straight beam method shows the imperfections are laminar in nature and are acceptable in accordance with NB-2532.1(b).

NB-2537 Time of Examination

Acceptance examinations shall be performed at the time of manufacture as required in (a) through (c) below.

(a) Ultrasonic examination shall be performed after rolling to size and after heat treatment, except for postweld heat treatment.

(b) Radiographic examination of repair welds, when required, may be performed prior to any required postweld heat treatment.

(c) Magnetic particle or liquid penetrant examination of repair welds shall be performed after final heat treatment, except that the examination may be performed prior to postweld heat treatment of P-No.1 material 2 in. (50 mm) and less nominal thickness.

NB-2538 Elimination of Surface Defects

Surface defects shall be removed by grinding or machining, provided the requirements of (a) through (d) below are met.

(a) The depression, after defect elimination, is blended uniformly into the surrounding surface.

(b) After defect elimination, the area is examined by the magnetic particle method in accordance with NB-2545 or the liquid penetrant method in accordance with NB-2546 to ensure that the defect has been removed or reduced to an imperfection of acceptable size.

(c) Areas ground to remove oxide scale or other mechanically caused impressions for appearance or to facilitate proper ultrasonic testing need not be examined by the magnetic particle or liquid penetrant test method.

(d) When the elimination of the defect reduces the thickness of the section below the minimum required to satisfy Article NB-3000, the product shall be repaired in accordance with NB-2539.

NB-2539 Repair by Welding

The Material Organization may repair by welding material from which defects have been removed, provided the depth of the repair cavity does not exceed one-third the nominal thickness and the requirements of the following subparagraphs are met. Prior approval of the Certificate Holder shall be obtained for the repair of plates to be used in the manufacture of vessels.

NB-2539.1 Defect Removal. The defect shall be removed or reduced to an imperfection of acceptable size by suitable mechanical or thermal cutting or gouging methods and the cavity prepared for repair (see NB-4211.1).

NB-2539.2 Qualification of Welding Procedures and Welders. The welding procedure and welders or welding operators shall be qualified in accordance with Article NB-4000 and Section IX.

NB-2539.3 Blending of Repaired Areas. After repair, the surface shall be blended uniformly into the surrounding surface.

NB-2539.4 Examination of Repair Welds. Each repair weld shall be examined by the magnetic particle method (see NB-2545) or by the liquid penetrant method (see NB-2546). In addition, when the depth of the repair cavity exceeds the lesser of $^3\!/_8$ in. (10 mm) or 10% of the section thickness, the repair weld shall be radiographed after repair in accordance with NB-5110 and to the acceptance standards of NB-5320. The image quality indicator (IQI) and the acceptance standards for radiographic examination of repair welds shall be based on the section thickness at the repair area.

NB-2539.5 Heat Treatment After Repairs. The product shall be heat treated after repair in accordance with the heat treatment requirements of NB-4620.

NB-2539.6 Material Report Describing Defects and Repairs. Each defect repair exceeding in depth the lesser of $^3\!/_8$ in. (10 mm) or 10% of the section thickness shall be described in the Certified Material Test Report. The Certified Material Test Report for each piece shall include a chart that shows the location and size of the prepared cavity, the welding material identification, the welding procedure, the heat treatment, and the examination results, including radiographs.

NB-2539.7 Repair of Cladding by Welding. The Material Organization may repair defects in cladding by welding, provided the requirements of (a) through (d) below are met.

(a) Qualification of Welding Procedures and Welders. The welding procedure and the welders or welding operators shall be qualified in accordance with Article NB-4000 and with Section IX.

(b) Defect Removal and Examination of Cavity. The defect shall be removed, and the cavity prepared for repair shall be examined by the liquid penetrant method (see NB-2546).

(c) Examination of Repaired Areas. The repaired area shall be examined by a liquid penetrant method (see NB-2546).

(d) Report of Repairs. Each defect repair shall be described in the Certified Material Test Report for each piece, including a chart that shows the location and size of the repair, the welding material identification, welding procedure, heat treatment, and examination results.

NB-2540 EXAMINATION AND REPAIR OF FORGINGS AND BARS

NB-2541 Required Examinations

(a) Forgings and bars shall be examined by the ultrasonic method in accordance with NB-2542, except forgings or sections of forgings that have coarse grains, or configurations that do not yield meaningful examination results by ultrasonic methods, shall be examined by radiographic methods in accordance with Section V, Article 2, using the acceptance standards of NB-5320. In addition, all external surfaces and accessible internal surfaces shall be examined by a magnetic particle method (see NB-2545) or a liquid penetrant method (see NB-2546).

(b) Forged flanges and fittings, such as elbows, tees, and couplings, shall be examined in accordance with the requirements of NB-2550.

(c) Bar material used for bolting shall be examined in accordance with NB-2580.

(d) Forgings and forged or rolled bars that are to be bored to form tubular products or fittings shall be examined in accordance with the requirements of NB-2550 after boring.

(e) Forgings and forged or rolled bars that will subsequently be bored to form pump and valve parts shall be examined in accordance with (a) after boring.

NB-2542 Ultrasonic Examination

NB-2542.1 Examination Procedure. All forgings in the rough-forged or finished condition, and bars, shall be examined in accordance with Section V, Article 5 and the following supplemental requirements. The techniques of (a) through (d) below are required, as applicable.

(a) Forgings may be examined by the use of alternative ultrasonic methods that use distance amplitude corrections, provided the acceptance standards are shown to be equivalent to those listed in NB-2542.2.

(b) Cylindrical section bars shall be scanned from the entire external circumference.

(c) Noncylindrical section bars shall be scanned in two perpendicular directions to the maximum extent possible (through each pair of parallel sides).

(d) Bar products do not require recording and reporting of indications smaller than the acceptance standard, except when so specified for specialized applications.

NB-2542.2 Acceptance Standards.

(a) Straight Beam General Rule. A forging shall be unacceptable if the results of straight beam examinations show one or more reflectors that produce indications accompanied by a complete loss of back reflection not associated with or attributable to geometric configurations. Complete loss of back reflection is assumed

when the back reflection falls below 5% of full calibration screen height.

(b) Straight Beam Special Rule for Vessel Shell Sections

(1) A ring forging made to fine grain melting practice and used for vessel shell sections shall be unacceptable if the results of the straight beam radial examination show one or more reflectors producing a continuous complete loss of back reflection accompanied by continuous indications on the same plane that cannot be encompassed with a circle whose diameter is 3 in. (75 mm) or one-half of the wall thickness, whichever is greater.

(2) In addition, two or more reflectors smaller than described in (1) above shall be unacceptable unless separated by a minimum distance equal to the greatest diameter of the larger reflector or unless they may be collectively encompassed by the circle described in (1) above.

(c) Angle Beam Rule. A forging shall be unacceptable if the results of angle beam examinations show one or more reflectors that produce indications exceeding in amplitude the indication from the appropriate calibration notches.

NB-2545 Magnetic Particle Examination

NB-2545.1 Examination Procedure. The procedure for magnetic particle examination shall be in accordance with the methods of Section V, Article 7. In lieu of magnetic particle examination methods required by the material specification, magnetic particle examination using the alternating current yoke technique is permitted in accordance with Section V, Article 7, when performed on final machined surfaces of the material.

NB-2545.2 Evaluation of Indications.

(a) Mechanical discontinuities at the surface are revealed by the retention of the examination medium. All indications are not necessarily defects, however, since certain metallurgical discontinuities and magnetic permeability variations may produce similar indications that are not relevant.

(b) Any indication in excess of the NB-2545.3 acceptance standards, which is believed to be nonrelevant, shall be reexamined by the same or other nondestructive examination methods to verify whether or not actual defects are present. Surface conditioning may precede the reexamination. Nonrelevant indications that would mask defects are unacceptable.

(c) Relevant indications are indications that result from imperfections. Linear indications are indications in which the length is more than three times the width. Rounded indications are indications that are circular or elliptical with the length equal to or less than three times the width.

NB-2545.3 Acceptance Standards.

(a) Only imperfections producing indications with major dimensions greater than $^1/_{16}$ in. (1.5 mm) shall be considered relevant imperfections.

(b) Imperfections producing the following relevant indications are unacceptable:

(1) any linear indications greater than $^1/_{16}$ in. (1.5 mm) long for material less than $^5/_8$ in. (16 mm) thick, greater than $^1/_8$ in. (3 mm) long for material from $^5/_8$ in. (16 mm) thick to under 2 in. (50 mm) thick, and $^3/_{16}$ in. (5 mm) long for material 2 in. (50 mm) thick and greater;

(2) rounded indications with dimensions greater than $^1/_8$ in. (3 mm) for thicknesses less than $^5/_8$ in. (16 mm) and greater than $^3/_{16}$ in. (5 mm) for thicknesses $^5/_8$ in. (16 mm) and greater;

(3) four or more relevant indications in a line separated by $^1/_{16}$ in. (1.5 mm) or less edge to edge;

(4) ten or more relevant indications in any 6 in.^{2} (4 000 mm^2) of area whose major dimension is no more than 6 in. (150 mm) with the dimensions taken in the most unfavorable location relative to the indications being evaluated.

NB-2546 Liquid Penetrant Examination

NB-2546.1 Examination Procedure. The procedure for liquid penetrant examination shall be in accordance with the methods of Section V, Article 6.

NB-2546.2 Evaluation of Indications.

(a) Mechanical discontinuities at the surface are revealed by bleeding out of the penetrant; however, localized surface discontinuities, such as may occur from machining marks, surface conditions, or an incomplete bond between base metal and cladding, may produce similar indications that are not relevant.

(b) Any indication in excess of the NB-2546.3 acceptance standards, which is believed to be nonrelevant, shall be reexamined to verify whether or not actual defects are present. Surface conditioning may precede the reexamination. Nonrelevant indications and broad areas of pigmentation, which would mask defects, are unacceptable.

(c) Relevant indications are indications that result from imperfections. *Linear indications* are indications in which the length is more than three times the width. *Rounded indications* are indications that are circular or elliptical with the length equal to or less than three times the width.

NB-2546.3 Acceptance Standards.

(a) Only imperfections producing indications with major dimensions greater than $^1/_{16}$ in. (1.5 mm) shall be considered relevant imperfections.

(b) Imperfections producing the following relevant indications are unacceptable:

(1) any linear indications greater than 1/16 in. (1.5 mm) long for material less than 5/8 in. (16 mm) thick, greater than 1/8 in. (3 mm) long for material from 5/8 in. (16 mm) thick to under 2 in. (50 mm) thick, and 3/16 in. (5 mm) long for material 2 in. (50 mm) thick and greater;

(2) rounded indications with dimensions greater than 1/8 in. (3 mm) for thicknesses less than 5/8 in. (16 mm) and greater than 3/16 in. (5 mm) for thicknesses 5/8 in. (16 mm) and greater;

(3) four or more relevant indications in a line separated by 1/16 in. (1.5 mm) or less edge to edge;

(4) ten or more relevant indications in any 6 $in.^2$ (4 000 mm^2) of area whose major dimension is no more than 6 in. (150 mm) with the dimensions taken in the most unfavorable location relative to the indications being evaluated.

NB-2547 Time of Examination

Acceptance examinations, including those for repair welds, shall be performed at the time of manufacture as required in (a) through (f) below.

(a) Ultrasonic examination may be performed at any time after forging [see NB-2541(d)], and the maximum practical volume, including weld repairs, if required, shall be examined after final heat treatment, excluding postweld heat treatment.

(b) Radiographic examination of repair welds, if required, may be performed prior to any required postweld heat treatment.

(c) Magnetic particle or liquid penetrant examination shall be performed in the finished condition, except repair welds of P-No. 1 material, 2 in. (50 mm) nominal thickness and less, may be examined prior to postweld heat treatment.

(d) Forgings and rolled bars that are to be bored or turned to form tubular parts or fittings shall be examined after boring or turning, except for threading.

(e) Forgings and forged or rolled bars that will subsequently be bored or turned to form pump and valve parts shall be examined after boring or turning, except for threading.

(f) The requirement for surface examination may be postponed for bars, 1 in. (25 mm) and less in diameter, [see NB-2541(a)] for material used to fabricate tube plugs for heat exchangers. Bar material, 1 in. (25 mm) and less in diameter, shall be surface-examined after final machining into tube plugs for heat exchangers.

NB-2548 Elimination of Surface Defects

Elimination of surface defects shall be made in accordance with NB-2538.

NB-2549 Repair by Welding

Repair by welding shall be in accordance with NB-2539, except that:

(a) the depth of repair that is permitted is not limited; and

(b) for ferritic steel forgings, the completed repair may be examined by the ultrasonic method in accordance with the requirements of NB-2542 in lieu of radiography.

NB-2550 EXAMINATION AND REPAIR OF SEAMLESS AND WELDED (WITHOUT FILLER METAL) TUBULAR PRODUCTS AND FITTINGS

NB-2551 Required Examination

In addition to the requirements of the material specification and of this Article, seamless and welded (without filler metal) tubular products (including pipe flanges and fittings machined from forgings and bars) shall comply with the following:

(a) Wrought seamless and welded (without filler metal) pipe and tubing shall be examined over the entire volume[5] of the material in accordance with (1), (2), (3), or (4), as follows. Tubular products may require both outside and inside surface conditioning prior to examination.

(1) Pipe and Tubing

(-a) Pipe and tubing smaller than 2½ in. (64 mm) O.D. shall be examined by the ultrasonic method in accordance with NB-2552(a)(1) in two opposite circumferential directions[5] and by the eddy current method in accordance with NB-2554, provided the product is limited to sizes, materials, and thicknesses for which meaningful results can be obtained by eddy current examination as evidenced by detection of required standards.

(-b) As an alternative to the eddy current examination or when the eddy current examination does not yield meaningful results, an axial scan ultrasonic examination in two opposite axial directions,[6] in accordance with NB-2552(a)(2), shall be made.

(2) Pipe and tubing 2½ in. (64 mm) O.D. and larger shall be examined by the ultrasonic method in accordance with NB-2552(a)(1) in two opposite circumferential directions, and in accordance with NB-2552(a)(2) in two opposite axial directions. Alternatively, for welded without filler metal pipe larger than 6¾ in. (170 mm) O.D., the plate shall be examined by the ultrasonic method in accordance with NB-2530 prior to forming and the weld shall be examined by the radiographic method in accordance with NB-2553. Radiographic examination of welds, including repair welds, shall be performed after final rolling and forming and may be performed prior to any required postweld heat treatment.

(3) Copper–nickel alloy and nickel alloy seamless pipe and tubing shall be examined as follows:

(-a) Except as provided in (-d) below, each pipe and tube, all sizes shall be ultrasonically examined in accordance with NB-2552(a)(1) in two opposite circumferential directions.

(-b) Except as provided in (-d) below, pipe and tubing smaller than $2\frac{1}{2}$ in. (64 mm) O.D. shall be examined by the eddy current method in accordance with NB-2554 if meaningful indications can be obtained from the reference specimen notches. If meaningful indications cannot be obtained from the reference specimen, an axial scan ultrasonic examination in two opposite axial directions, in accordance with NB-2552(a)(2), shall be made.

(-c) Except as provided in (-d) below, pipe and tubing $2\frac{1}{2}$ in. (64 mm) O.D. and larger shall be examined by an axial scan ultrasonic examination in two opposite axial directions in accordance with NB-2552(a)(2).

(-d) For pipe and tubing that is specified to be coarse grain structure, radiographic examination in accordance with NB-2553 may be performed in lieu of ultrasonic examination.

(4) Tubing used in steam generator fabrication shall be examined as follows:

(-a) each tube shall be ultrasonically examined in accordance with NB-2552(a)(1) in two opposite circumferential directions, and

(-b) by eddy current in accordance with NB-2554 if meaningful indications can be obtained from the reference specimen notches. If meaningful results cannot be obtained from the reference specimen, an axial scan ultrasonic examination in two opposite axial directions, in accordance with NB-2552(a)(2), shall be made.

(b) Wrought seamless and welded without filler metal fittings (including pipe flanges and fittings machined from forgings and bars) shall be examined in accordance with the material specification, and in addition by the magnetic particle method in accordance with NB-2555, or the liquid penetrant method in accordance with NB-2556 on all external surfaces and all accessible internal surfaces (excluding bolt holes and threads). Additionally, for fittings over NPS 6 (DN 150) nominal size, the entire volume shall be examined by the ultrasonic method, if feasible, in accordance with NB-2552, or the radiographic method in accordance with NB-2553. Alternatively, the plate shall be examined by the ultrasonic method in accordance with NB-2530 prior to forming and the weld shall be examined by the radiographic method in accordance with NB-2553. Radiographic examination of welds, including repair welds, shall be performed after final rolling and forming, and may be performed prior to any required postweld heat treatment.

(c) Tubular products used for vessel nozzles shall be examined over the entire volume of material by either the ultrasonic method in two opposite circumferential directions in accordance with NB-2552(b) or the radiographic method in accordance with NB-2553, and shall be examined on all external and all accessible internal surfaces by either the magnetic particle method in accordance with NB-2555 or the liquid penetrant method in accordance with NB-2556.

NB-2552 Ultrasonic Examination[5]

(a) Examination Procedure for Pipe and Tubing. Independent channels or instruments shall be employed for circumferential and axial scans.

(1) Circumferential Direction. The procedure for ultrasonic examination of pipe and tubing in the circumferential direction shall be in accordance with SE-213. The procedure shall provide a sensitivity that will consistently detect defects that produce indications equal to, or greater than, the indications produced by the standard defects specified in (c).

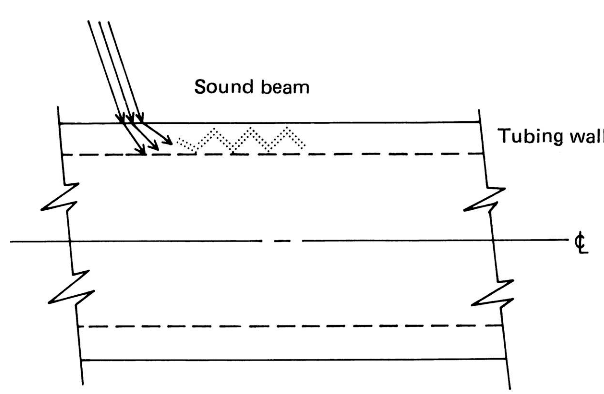
(2) Axial Direction. When required by NB-2551, the ultrasonic examination of pipe and tubing shall include angle beam scanning in the axial direction. The procedure for the axial scans shall be in accordance with SE-213, except that the propagation of sound in the tube or pipe wall shall be in the axial direction instead of the circumferential direction. Figure NB-2552-1 illustrates the characteristic oblique entry of sound into the pipe or tube wall and the axial direction of ultrasonic energy propagation to detect transverse notches or similar surface discontinuities.

(3) Acceptance Standards. Products with defects that produce indications in excess of the indications produced by the standard defects in the reference specimen are unacceptable unless the defects are eliminated or repaired in accordance with NB-2558 or NB-2559.

(b) Examination Procedure for Fittings

(1) Procedure. The procedure for ultrasonic examination of fittings shall be in accordance with Section V, Article 5 for straight beam examination and, where feasible, angle-beam examination in two circumferential directions.

Figure NB-2552-1
Axial Propagation of Sound in Tube Wall



(2) Acceptance Standards. Fittings shall be unacceptable if straight beam examination shows one or more reflectors that produce indications accompanied by complete loss of back reflection not associated with or attributable to the geometric configuration, or if angle beam examination results show one or more reflectors that produce indications exceeding in amplitude the indications from the calibrated notch. Complete loss of back reflection is assumed when the back reflection falls below 5% of full calibration screen height.

(c) Reference Specimens

(1) The reference specimen shall be of the same nominal diameter and thickness, and of the same nominal composition and heat-treated condition as the product that is being examined. For circumferential scanning, the standard defects shall be axial notches or grooves on the outside and inside surfaces of the reference specimen, and shall have a length of approximately 1 in. (25 mm) or less, a width not to exceed $^1/_{16}$ in. (1.5 mm) for a square notch or U-notch, a width proportional to the depth for a V-notch, and a depth not greater than the larger of 0.004 in. (0.10 mm) or 5% of the nominal wall thickness. For axial scanning in accordance with SE-213, a transverse (circumferential) notch shall be introduced on the inner and outer surfaces of the standard. Dimensions of the transverse notch shall not exceed those of the longitudinal notch. The reference specimen may be the product being examined.

(2) The reference specimen shall be long enough to simulate the handling of the product being examined through the examination equipment. When more than one standard defect is placed in a reference specimen, the defects shall be located so that indications from each defect are separate and distinct without mutual interference or amplification. All upset metal and burrs adjacent to the reference notches shall be removed.

(d) Checking and Calibration of Equipment. The proper functioning of the examination equipment shall be checked and the equipment shall be calibrated by the use of the reference specimens, as a minimum:

(1) at the beginning of each production run of a given size and thickness of a given material.

(2) after each 4 hr or less during the production run.

(3) at the end of the production run.

(4) at any time that malfunctioning is suspected. If, during any check, it is determined that the examination equipment is not functioning properly, all of the products that have been examined since the last valid equipment calibration shall be reexamined.

NB-2553 Radiographic Examination

(a) General. When radiographic examination is performed as an alternative for ultrasonic examination of the entire volume of the material, it shall apply to the entire volume of the pipe, tube, or fitting material. Acceptance standards specified for welds shall apply to the entire volume of material examined.

(b) Examination Procedure. The radiographic examination shall be performed in accordance with Section V, Article 2, as modified by NB-5111.

(c) Acceptance Standard. Welds that are shown by radiography to have any of the following types of discontinuities are unacceptable:

(1) any type of crack or zone of incomplete fusion or penetration;

(2) any other elongated indication that has a length greater than:

(-a) $^1/_4$ in. (6 mm) for t up to $^3/_4$ in. (19 mm), inclusive

(-b) $^1/_3 t$ for t from $^3/_4$ in. (19 mm) to $2^1/_4$ in. (57 mm), inclusive

(-c) $^3/_4$ in. (19 mm) for t over $2^1/_4$ in. (57 mm)

where t is the thickness of the thinner portion of the weld;

(3) any group of aligned indications having an aggregate length greater than t in a length of $12t$, unless the minimum distance between successive indications exceeds $6L$, in which case the aggregate length is unlimited, L being the length of the largest indication;

(4) rounded indications in excess of that shown as acceptable in Section III Appendices, Mandatory Appendix VI.

NB-2554 Eddy Current Examination

(a) General. This examination method is restricted to materials with uniform magnetic properties and of sizes for which meaningful results can be obtained.

(b) Examination Procedure. The procedure for eddy current examination shall be in accordance with ASTM E426 or ASTM E571. The procedure shall provide a sensitivity that will consistently detect defects by comparison with the standard defects included in the reference specimen in (d).

(c) Acceptance Standards. Products with defects that produce indications in excess of the reference standards are unacceptable.

(d) Reference Specimens. The reference specimen shall be of the same nominal diameter and thickness, and of the same nominal composition and heat-treated condition as the product that is being examined. The standard shall contain transverse (circumferential) notches on the outside surface plus a $^1/_{16}$ in. (1.5 mm) diameter hole drilled through the wall. For copper–nickel alloy and nickel alloy materials, the standard shall have one notch extending circumferentially on the outside surface and one notch extending circumferentially on the inside surface plus a $^1/_{16}$ in. (1.5 mm) diameter hole drilled through the wall. These shall be used to establish the rejection level for the product to be tested. The reference notches shall have a depth not greater than the larger of 0.004 in. (0.10 mm) or 5% of the wall thickness.

The width of the notch shall not exceed $^1\!/_{16}$ in. (1.5 mm). The length shall be approximately 1 in. (25 mm) or less. The size of reference specimens shall be as specified in NB-2552(c). Additional examination using either transverse notches or axial notches shall be performed when required by the design specification.

(e) Checking and Calibration of Equipment. The checking and calibration of examination equipment shall be the same as in NB-2552(d).

NB-2555 Magnetic Particle Examination

Magnetic particle examination shall be performed in accordance with the requirements of NB-2545.

NB-2556 Liquid Penetrant Examination

Liquid penetrant examination shall be performed in accordance with the requirements of NB-2546.

NB-2557 Time of Examination

(a) Products that are quenched and tempered shall be examined, as required, after the quenching and tempering heat treatment.

(b) Products that are not quenched and tempered shall receive the required examinations as follows:

(1) Ultrasonic or eddy current examination, when required, shall be performed after final heat treatment required by Section II material specification. Other heat treament including postweld treament, may be performed either prior to or after the examination.

(2) Radiographic examination, when required, may be performed prior to any required postweld heat treatment.

(3) Magnetic particle or liquid penetrant examination, including repair welds, shall be performed after final heat treatment, except that the examination may be performed prior to postweld heat treatment for P-No. 1 (Section IX of the Code) materials of 2 in. (50 mm) and less nominal thickness.

(4) Forgings and rolled bars that are to be bored and/or turned to form tubular parts or fittings shall be examined after boring and/or turning, except for threading. Fittings shall be examined after final forming.

NB-2558 Elimination of Surface Defects

Surface defects shall be removed by grinding or machining, provided the requirements of (a) through (c) below are met.

(a) The depression, after defect elimination, is blended uniformly into the surrounding surface.

(b) After defect elimination, the area is examined by the method that originally disclosed the defect to ensure that the defect has been removed or reduced to an imperfection of acceptable size.

(c) If the elimination of the defect reduces the thickness of the section below the minimum required to satisfy the rules of Article NB-3000, the product shall be repaired in accordance with NB-2559.

NB-2559 Repair by Welding

Repair of defects shall be in accordance with NB-2539, except repair by welding is not permitted on copper–nickel alloy and nickel alloy heat exchanger tubes.

NB-2560 EXAMINATION AND REPAIR OF TUBULAR PRODUCTS AND FITTINGS WELDED WITH FILLER METAL

NB-2561 Required Examinations

(a) Welded tubular products (with filler metal) such as pipe made in accordance with SA-358, SA-409, SA-671, SA-672, and SA-691, and fittings made in accordance with the WPW grades of SA-234, SA-403, and SA-420, which are made by welding with filler metal, shall be treated as material; however, inspection by an Inspector and stamping with a Certification Mark with NPT Designator shall be in accordance with Section III requirements. In addition to the Certification Mark with NPT Designator, a numeral 1 shall be stamped below and outside the official Certification Mark.

(b) In addition to the requirements of the material specification and of the Article, pipe and fittings shall comply with the following:

(1) The plate shall be examined in accordance with NB-2530 prior to forming, or alternatively, the finished product shall be examined by the ultrasonic method in accordance with NB-2562.

(2) All welds shall be examined 100% by radiography in accordance with the method and acceptance requirements of the base material specification, and by either the magnetic particle method in accordance with NB-2565 or the liquid penetrant method in accordance with NB-2566. If radiographic examination of welds is not specified in the basic material specification, the welds shall be examined by the radiographic method in accordance with NB-2563. The radiographs and a radiographic report showing exposure locations shall be provided with the Certified Material Test Report.

NB-2562 Ultrasonic Examination

The ultrasonic examination shall be performed in accordance with the requirements of NB-2552.

NB-2563 Radiographic Examination

The radiographic examination shall be performed in accordance with the requirements of NB-2553.

NB-2565 Magnetic Particle Examination

The magnetic particle examination shall be performed in accordance with the requirements of NB-2545.

NB-2566 Liquid Penetrant Examination

The liquid penetrant examination shall be performed in accordance with the requirements of NB-2546.

NB-2567 Time of Examination

The time of examination shall be in accordance with the requirements of NB-2557, except that for magnetic particle or liquid penetrant examination of welds, including repair welds, for P-No. 1 (Section IX of the Code), examination may be performed prior to postweld heat treatment.

NB-2568 Elimination of Surface Defects

Unacceptable surface defects shall be removed in accordance with the requirements of NB-2558.

NB-2569 Repair by Welding

When permitted by the basic material specification, base material defects shall be repair welded in accordance with the requirements of NB-2559. Repair welding of weld seam defects shall be in accordance with NB-4450.

NB-2570 EXAMINATION AND REPAIR OF STATICALLY AND CENTRIFUGALLY CAST PRODUCTS

In addition to the requirements of the material specification and of this Article, statically and centrifugally cast products shall comply with the following subparagraphs.

NB-2571 Required Examination

Cast products shall be examined by the radiographic method, except cast ferritic steels that shall be examined by either the radiographic or ultrasonic method, or a combination of both methods, as required for the product form by Table NB-2571-1.

In addition, all cast products shall be examined on all external surfaces and all accessible internal surfaces by either the magnetic particle or liquid penetrant method. Machined surfaces, except threaded surfaces, of a cast product shall be examined by either the liquid penetrant or magnetic particle method after machining.

NB-2572 Time of Nondestructive Examination

NB-2572.1 Acceptance Examinations. Acceptance examinations shall be performed at the time of manufacture as stipulated in the following and Table NB-2571-1.

(a) *Ultrasonic Examination*. Ultrasonic examination, if required, shall be performed at the same stage of manufacture as required for radiography.

(b) *Radiographic Examination*. Radiography may be performed prior to heat treatment and may be performed prior to or after finish machining at the following limiting thicknesses.

(1) For finished thicknesses under $2\frac{1}{2}$ in. (64 mm), castings shall be radiographed within $\frac{1}{2}$ in. (13 mm) or 20% of the finished thickness, whichever is greater. The IQI and the acceptance reference radiographs shall be based on the finished thickness.

(2) For finished thickness from $2\frac{1}{2}$ in. (64 mm) up to 6 in. (150 mm), castings shall be radiographed within 20% of the finished thickness. The IQI and the acceptance reference radiographs shall be based on the finished thickness.

(3) For finished thicknesses over 6 in. (150 mm), castings shall be radiographed within $\frac{1}{2}$ in. (13 mm) or 15% of the finished thickness, whichever is greater. The IQI and the acceptance reference radiographs shall be based on the finished thickness.

(c) Radiography of castings for pumps and valves may be performed in as-cast or rough machined thickness exceeding the limits of (b)(1), (b)(2), or (b)(3) above, subject to the following conditions.

(1) When the thickness of the as-cast or rough machined section exceeds 2 in. (50 mm), acceptance shall be based on reference radiographs for the next lesser thickness; e.g., if the section being radiographed exceeds $4\frac{1}{2}$ in. (114 mm), use reference radiographs of ASTM E186. The IQI shall be based on the thickness of the section being radiographed.

(2) When the thickness of the as-cast or rough machined section is 2 in. (50 mm) or less, the reference radiographs of ASTM E446 shall be used, and the IQI shall be based on the final section thickness.

(3) Weld ends for a minimum distance of t or $\frac{1}{2}$ in. (13 mm), whichever is less (where t is the design section thickness of the weld), from the final welding end shall be radiographed at a thickness within the limits given in (b)(1), (b)(2), or (b)(3) above as applicable. As an alternative, the weld ends may be radiographed in the as-cast or rough machined thickness in accordance with (1) and (2) above, and the IQI shall be based on the final section thickness.

(d) *Magnetic Particle or Liquid Penetrant Examination*. Magnetic particle or liquid penetrant examination shall be performed after the final heat treatment required by the material specification. Repair weld areas shall be examined after postweld heat treatment when a postweld heat treatment is performed, except that repair welds in P-No. 1 (see Section IX of the Code) material 2 in. (50 mm) nominal thickness and less may be examined prior to postweld heat treatment. For cast products with machined surfaces, all finished machined surfaces, except threaded surfaces and

Table NB-2571-1
Required Examinations

Nominal Pipe Size	Item	Applicable Special Requirements for Class 1 Castings
Inlet piping connections of NPS 2 (DN 50) and less	Cast products other than pumps and valves	Cast products shall be examined by the radiographic method, except cast ferritic steels, which shall be examined by either the radiographic or ultrasonic method, or a combination of both methods. Castings or sections of castings that have coarse grains or configurations that do not yield meaningful examination results by the ultrasonic method shall be examined by the radiographic method. In addition, all cast products shall be examined on all external surfaces and all accessible internal surfaces by either the magnetic particle or the liquid penetrant method. Machined surfaces, except threaded surfaces, of a cast product shall be examined by either the liquid penetrant or the magnetic particle method after machining.
	Cast pumps and valves	None
	Repair welds in pumps and valves of P-No. 1 or P-No. 8 material	None
	Repair welds in cast products, excluding repair welds in pumps and valves of P-No. 1 or P-No. 8 material	Each repair weld shall be examined by the magnetic particle method or by the liquid penetrant method. In addition, repair welds in cavities the depth of which exceed the lesser of $^{3}/_{8}$ in. (10 mm) or 10% of the section thickness shall be radiographed in accordance with NB-2575.
Inlet piping connections over NPS 2 (DN 50) up to and including NPS 4 (DN 100)	Cast products — See *Cast pumps and valves* below for exceptions	Cast products shall be examined by the radiographic method, except cast ferritic steels, which shall be examined by either the radiographic or the ultrasonic method, or a combination of both methods. Castings or sections of castings that have coarse grains or configurations that do not yield meaningful examination results by the ultrasonic method shall be examined by the radiographic method. In addition, all cast products shall be examined on all external surfaces and all accessible internal surfaces by either the magnetic particle or the liquid penetrant method. Machined surfaces, except threaded surfaces, of a cast product shall be examined by either the liquid penetrant or the magnetic particle method after machining.
	Cast pumps and valves	Magnetic particle or liquid penetrant examination may be performed, in lieu of volumetric examination, except the welding ends of cast pumps and valves shall be radiographed for a minimum distance of t (when t is the design section thickness of the weld) from the final weld end.
	Repair welds	Each repair weld shall be examined by the magnetic particle method or by the liquid penetrant method. In addition, repair welds in cavities the depth of which exceed the lesser of $^{3}/_{8}$ in. (10 mm) or 10% of the section thickness shall be radiographed in accordance with NB-2575.

Table NB-2571-1
Required Examinations (Cont'd)

Nominal Pipe Size	Item	Applicable Special Requirements for Class 1 Castings
Inlet piping connections over NPS 4 (DN 100)	Cast products	Cast products shall be examined by the radiographic method, except cast ferritic steels, which shall be examined by either the radiographic or the ultrasonic method, or a combination of both methods. Castings or sections of castings that have coarse grains or configurations that do not yield meaningful examination results by the ultrasonic method shall be examined by the radiographic method. In addition, all cast products shall be examined on all external surfaces and all accessible internal surfaces by either the magnetic particle or the liquid penetrant method. Machined surfaces, except threaded surfaces, of a cast product shall be examined by either the liquid penetrant or the magnetic particle method after machining.
	Repair welds	Each repair weld shall be examined by the magnetic particle method or by the liquid penetrant method. In addition, repair welds in cavities the depth of which exceed the lesser of $^3/_8$ in. (10 mm) or 10% of the section thickness shall be radiographed in accordance with NB-2575.

small deep holes, shall also be examined by the magnetic particle or the liquid penetrant method.

NB-2573 Provisions for Repair of Base Material by Welding

The Material Organization may repair, by welding, products from which defects have been removed, provided the requirements of this Article are met.

NB-2573.1 Defect Removal. The defects shall be removed or reduced to an imperfection of acceptable size by suitable mechanical or thermal cutting or gouging methods, and the cavity prepared for repair. When thermal cutting is performed, consideration shall be given to preheating the material.

NB-2573.2 Repair by Welding. The Material Organization may repair castings by welding after removing the material containing unacceptable defects. The depth of the repair is not limited. A cored hole or access hole may be closed by the Material Organization by welding in accordance with the requirements of this paragraph, provided the hole is closed by filler metal only. If the hole is closed by welding in a metal insert, the welding shall be performed by a holder of a Certificate of Authorization in accordance with the requirements of the Code.

NB-2573.3 Qualification of Welding Procedures and Welders. Each manufacturer is responsible for the welding done by its organization and shall establish the procedures and conduct the tests required by Article NB-4000 and by Section IX of the Code in order to qualify both the welding procedures and the performance of welders and welding operators who apply these procedures. Each manufacturer is also responsible for the welding performed by its subcontractors and shall ensure that the subcontractors conduct the tests required by Article NB-4000 and by Section IX of the Code in order to qualify its welding procedures and the performance of its welders and welding operators.

NB-2573.4 Blending of Repaired Areas. After repair, the surface shall be blended uniformly into the surrounding surface.

NB-2573.5 Examination of Repair Welds.

(a) Each repair weld shall be examined by the magnetic particle method in accordance with the requirements of NB-2577 or by the liquid penetrant method in accordance with the requirements of NB-2576. In addition, when radiography is specified in the order for the original casting, repair cavities, the depth of which exceeds the lesser of $^3/_8$ in. (10 mm) or 10% of the section thickness, shall be radiographed after repair except that weld slag, including elongated slag, shall be considered as inclusions under Category B of the applicable reference radiographs. The total area of all inclusions, including slag inclusions, shall not exceed the limits of the applicable severity level of Category B of the reference radiographs. The IQI and the acceptance standards for radiographic examination of repair welds shall be based on the actual section thickness at the repair area.

(b) Examination of repair welds in P-No. 1 and P-No. 8 material is not required for pumps and valves with inlet piping connections NPS 2 (DN 50) and less.

NB-2573.6 Heat Treatment After Repairs. The material shall be heat treated after repair in accordance with the heat treatment requirements of NB-4620, except that the heating and cooling rate limitations of NB-4623 do not apply.

NB-2573.7 Elimination of Surface Defects. Surface defects shall be removed by grinding or machining provided the requirements of (a) through (c) below are met.

(a) The depression, after defect elimination, is blended uniformly into the surrounding surface.

(b) After defect elimination, the area is reexamined by the magnetic particle method in accordance with NB-2577 or the liquid penetrant method in accordance with NB-2576 to ensure that the defect has been removed or reduced to an imperfection of acceptable size.

(c) If the elimination of the defect reduces the section thickness below the minimum required by the specification or drawing, the casting shall be repaired in accordance with NB-2539.

NB-2573.8 Material Report Describing Defects and Repairs. Each defect repair exceeding in depth the lesser of $^3/_8$ in. (10 mm) or 10% of the section thickness shall be described in the Certified Material Test Report. The Certified Material Test Report for each piece shall include a chart that shows the location and size of the prepared cavity, the welding material identification, the welding procedure, the heat treatment, and the examination results, including radiographs, when radiography is specified in the order for the original casting.

NB-2574 Ultrasonic Examination of Ferritic Steel Castings

Ultrasonic examination shall be performed in accordance with Section V, Article 5, T-571.4. Each manufacturer shall certify that the procedure is in accordance with the requirements of NB-2574 and shall make the procedure available for approval upon request.

NB-2574.1 Acceptance Standards.

(a) The Quality Levels of SA-609 as shown in Section V shall apply for the casting thicknesses indicated

(1) Quality Level 1 for thicknesses up to 2 in. (50 mm)

(2) Quality Level 3 for thicknesses 2 in. (50 mm) to 4 in. (100 mm)

(3) Quality Level 4 for thicknesses greater than 4 in. (100 mm)

(b) In addition to the Quality Level requirements stated in (a) above, the requirements in (1) through (5) below shall apply for both straight beam and angle beam examination.

(1) Areas giving indications exceeding the Amplitude Reference Line with any dimension longer than those specified in the following tabulation are unacceptable:

UT Quality Level	Longest Dimension of Area, in. (mm) [Notes (1)–(3)]
1	1.5 (38)
2	2.0 (50)
3	2.5 (64)
4	3.0 (75)

NOTES:
(1) The areas for the Ultrasonic Quality Levels in SA-609 refer to the surface area on the casting over which continuous indication, exceeding the transfer corrected distance amplitude curve, is maintained.
(2) Areas are to be measured from dimensions of the movement of the search unit, using the center of the search unit as the reference point.
(3) In certain castings, because of very long metal path distances or curvature of the examination surfaces, the surface area over which a given discontinuity is detected may be considerably larger or smaller than the actual area of the discontinuity in the casting; in such cases, other criteria that incorporate a consideration of beam angles or beam spread must be used for realistic evaluation of the discontinuity.

(2) Quality Level 1 shall apply for the volume of castings within 1 in. (25 mm) of the surface regardless of the overall thickness.

(3) Discontinuities indicated to have a change in depth equal to or greater than one-half the wall thickness or 1 in. (25 mm) (whichever is less) are unacceptable.

(4) Two or more imperfections producing indications in the same plane with amplitudes exceeding the Amplitude Reference Line and separated by a distance less than the longest dimension of the larger of the adjacent indications are unacceptable if they cannot be encompassed within an area less than that of the Quality Level specified in (1) above.

(5) Two or more imperfections producing indications greater than permitted for Quality Level 1 for castings less than 2 in. (50 mm) in thickness, greater than permitted for Quality Level 2 for thicknesses 2 in. (50 mm) through 4 in. (100 mm), and greater than permitted for Level 3 for thicknesses greater than 4 in. (100 mm), separated by a distance less than the longest dimension of the larger of the adjacent indications are unacceptable, if they cannot be encompassed in an area less than that of the Quality Level requirements stated in (a) above.

NB-2575 Radiographic Examination

NB-2575.1 Examination. Cast pressure-retaining materials shall be examined by the radiographic method when specified in the order for the original castings, except that cast ferritic steels may be examined by either the radiographic or ultrasonic method, or a combination of both methods. Castings or sections of castings that have coarse grains or configurations that do not yield meaningful examination results by ultrasonic methods shall be examined by the radiographic method.

NB-2575.2 Extent. Radiographic examination shall be performed on pressure-retaining castings such as vessel heads and flanges, valve bodies, bonnets and disks, pump casings and covers, and piping and fittings. The extent of radiographic coverage shall be of the maximum feasible volume and, when the shape of the casting precludes complete coverage, the coverage shall be at least as exemplified in the typical sketches as shown in Figure NB-2575.2-1.

NB-2575.3 Examination Requirements. Radiographic examination shall be performed in accordance with Section V, Article 2, Mandatory Appendix VII, Radiographic Examination of Metallic Castings, with the following modifications:

(a) The geometric unsharpness limitations of Section V, Article 2, T-274.2 need not be met.

(b) The examination procedure or report shall also address the following:

(1) type and thickness of filters, if used

(2) for multiple film techniques, whether viewing is to be single or superimposed, if used

(3) blocking or masking technique, if used

(4) orientation of location markers

(5) description of how internal markers, when used, locate the area of interest

(c) The location of location markers (e.g., lead numbers or letters) shall be permanently stamped on the surface of the casting in a manner permitting the area of interest on a radiograph to be accurately located on the casting and providing evidence on the radiograph that the extent of coverage required by NB-2575.2 has been obtained. For castings or sections of castings where stamping is not feasible, the radiographic procedure shall so state, and a radiographic exposure map shall be provided.

NB-2575.6 Acceptance Criteria. Castings shall meet the acceptance requirements of Severity Level 2 of ASTM E446, Reference Radiographs for Steel Castings up to 2 in. (50 mm) in Thickness; ASTM E186, Reference Radiographs for Heavy-Walled [2 in. to 4½ in. (50 mm to 114 mm)] Steel Castings; or ASTM E280, Reference Radiographs for Heavy-Walled [4½ in. to 12 in. (114 mm to 300 mm)] Steel Castings, as applicable for the thickness being radiographed except that Category D, E, F, or G defects are not acceptable. The requirements of ASTM E280 shall apply for castings over 12 in. (300 mm) in thickness.

NB-2576 Liquid Penetrant Examination

(a) Castings shall be examined, if required, on all accessible surfaces by the liquid penetrant method in accordance with Section V of the Code.

(b) *Evaluation of Indications.* All indications shall be evaluated in terms of the acceptance standards. Mechanical discontinuities intersecting the surface are indicated by bleeding out of the penetrant; however, localized surface discontinuities as may occur from machining marks, scale, or dents, may produce indications that are not relevant. Any indication in excess of the acceptance standards believed to be nonrelevant shall be reexamined to verify whether actual defects are present. Surface conditioning may precede the reexamination. Nonrelevant indications and broad areas of pigmentation that would mask indications of defects are unacceptable. Relevant indications are those that result from imperfections and have a major dimension greater than $^1/_{16}$ in. (1.5 mm). Linear indications are those whose length is more than three times the width. Rounded indications are those that are circular or elliptical with the length less than three times the width.

(c) *Acceptance Standards.* The following relevant indications are unacceptable:

(1) linear indications greater than $^1/_{16}$ in. (1.5 mm) long for materials less than $^5/_8$ in. (16 mm) thick, greater than $^1/_8$ in. (3 mm) long for materials from $^5/_8$ in. (16 mm) thick to under 2 in. (50 mm) thick, and $^3/_{16}$ in. (5 mm) long for materials 2 in. (50 mm) thick and greater;

(2) rounded indications with dimensions greater than $^1/_8$ in. (3 mm) for thicknesses less than $^5/_8$ in. (16 mm) and greater than $^3/_{16}$ in. (5 mm) for thicknesses $^5/_8$ in. (16 mm) and greater;

(3) four or more indications in a line separated by $^1/_{16}$ in. (1.5 mm) or less edge to edge;

(4) ten or more indications in any 6 in.^{2} (4 000 mm^2) of surface with the major dimension of this area not to exceed 6 in. (150 mm) taken in the most unfavorable orientation relative to the indications being evaluated.

NB-2577 Magnetic Particle Examination (for Ferritic Steel Products Only)

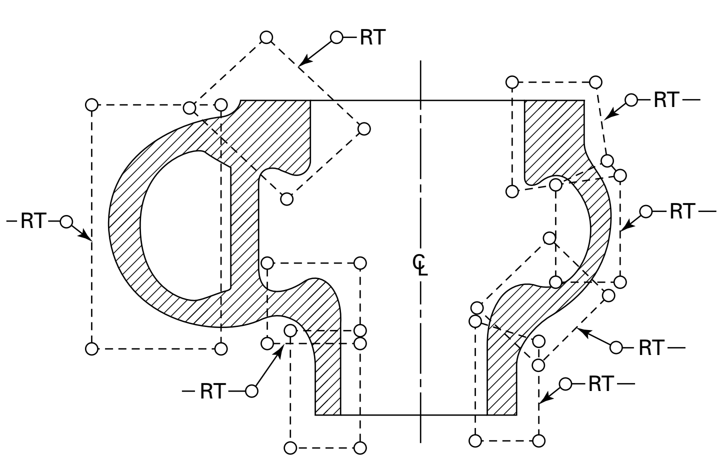
(a) Castings of magnetic material shall be examined, if required, on all accessible surfaces by a magnetic particle method in accordance with Section V of the Code.

(b) *Evaluation of Indications.* All indications shall be evaluated in terms of the acceptance standards. Mechanical discontinuities intersecting the surface are indicated by retention of the examination medium. All indications are not necessarily defects since certain metallurgical discontinuities and magnetic permeability variations may produce indications that are not relevant. Any indication in excess of the acceptance standards believed to be nonrelevant shall be reexamined to verify whether actual defects are present. Nonrelevant indications that would mask indications of defects are unacceptable. Surface conditioning may precede the reexamination. Relevant indications are those that result from imperfections and have a major dimension greater than $^1/_{16}$ in. (1.5 mm). Linear indications are those whose length is more than three times the width. Rounded indications are those that are circular or elliptical with the length less than three times the width.

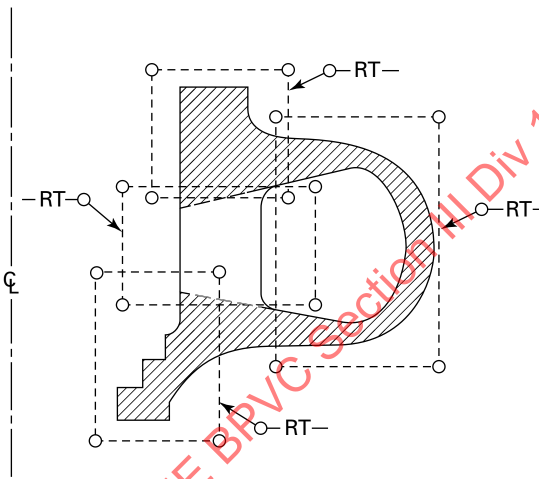
(c) *Acceptance Standards.* The following relevant indications are unacceptable:

(1) linear indications greater than $^1/_{16}$ in. (1.5 mm) long for materials less than $^5/_8$ in. (16 mm) thick, greater than $^1/_8$ in. (3 mm) long for materials from $^5/_8$ in. (16 mm) thick to under 2 in. (50 mm) thick, and $^3/_{16}$ in. (5 mm) long for materials 2 in. (50 mm) thick and greater;

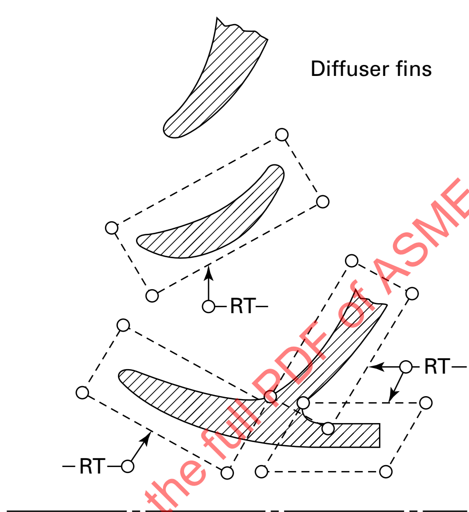
Figure NB-2575.2-1
Typical Pressure-Retaining Parts of Pumps and Valves



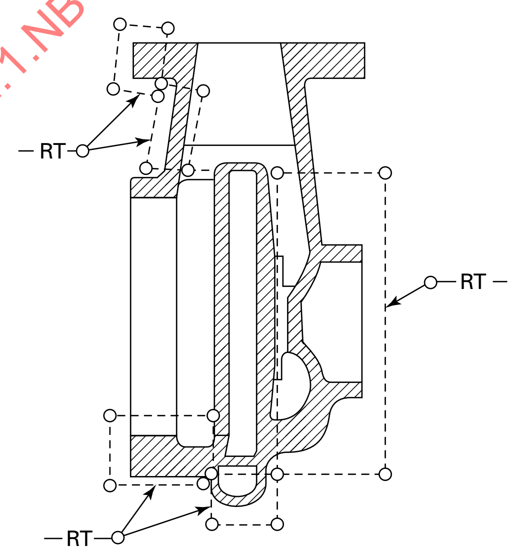
(a) Typical Volute-Type Pump Case



(b) Typical Diffuser-Type Pump Case

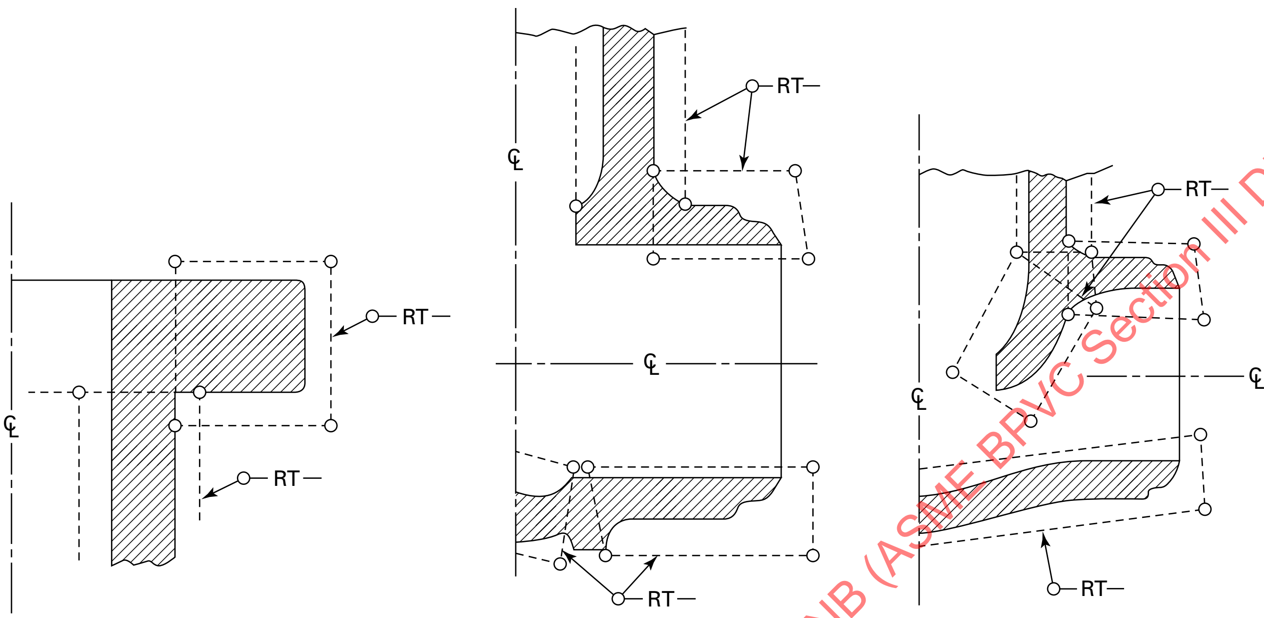


(c) Typical Diffuser-Type Pump Case Detail



(d) Typical Single Stage Pump Case

Figure NB-2575.2-1
Typical Pressure-Retaining Parts of Pumps and Valves (Cont'd)



(e) Typical Flange **(f) Typical Gate Valve** **(g) Typical Globe Valve**

GENERAL NOTES:
(a) Radiographic examination areas shall be indicated by a circle at each change of direction. The examination symbol for radiography shall be indicated as RT.
(b) For nondestructive examination areas or revolution, the area shall be indicated by the examine-all-around symbol: – RT – ○̸.
(c) The sketches are typical and are to be used as a guide for minimum required coverage. Even though a sketch may be titled, "pump" or "valve," the coverage shown by the configurations may be applied interchangeably.

(2) rounded indications with dimensions greater than $^1/_8$ in. (3 mm) for thicknesses less than $^5/_8$ in. (16 mm) and greater than $^3/_{16}$ in. (5 mm) for thicknesses $^5/_8$ in. (16 mm) and greater;

(3) four or more relevant indications in a line separated by $^1/_{16}$ in. (1.5 mm) or less edge to edge;

(4) ten or more relevant indications in any 6 in.^{2} (4 000 mm^2) of surface with the major dimension of this area not to exceed 6 in. (150 mm) taken in the most unfavorable orientation relative to the indications being evaluated.

NB-2580 EXAMINATION OF BOLTS, STUDS, AND NUTS

NB-2581 Required Examination

All bolting material shall be visually examined in accordance with NB-2582. In addition, nominal sizes greater than 1 in. (25 mm) shall be examined by either the magnetic particle method in accordance with NB-2583 or the liquid penetrant method in accordance with NB-2584. In addition, nominal sizes greater than 2 in. (50 mm) but not over 4 in. (100 mm) shall be examined by the ultrasonic method in accordance with NB-2585 and nominal sizes greater than 4 in. (100 mm) shall be examined by the ultrasonic method in accordance with both NB-2585 and NB-2586.

NB-2582 Visual Examination

The final surfaces of threads, shanks, and heads shall be visually examined for workmanship, finish, and appearance in accordance with the requirements of ASTM F788 for bolting material and ASTM F812 for nuts. The visual examination personnel shall be trained and qualified in accordance with the Material Organization's Quality System Program or the Certificate Holder's Quality Assurance Program. These examinations are not required to be performed either in accordance with procedures qualified to NB-5100 or by personnel qualified in accordance with NB-5500.

NB-2583 Magnetic Particle Examination (for Ferritic Steel Bolting Material Only)

NB-2583.1 Examination Procedure. All bolts, studs, and nuts greater than 1 in. (25 mm) nominal bolt size shall be examined by the magnetic particle method in accordance with ASTM A275. If desired, the supplier may perform liquid penetrant examination in accordance with NB-2584 instead of magnetic particle examination. Such examination shall be performed on the finished component after threading or on the materials stock at approximately the finished diameter before threading and after heading (if involved). This examination shall be performed on all accessible surfaces.

NB-2583.2 Evaluation of Indications.

(a) All indications shall be evaluated in terms of the acceptance standards. Linear indications are those indications in which the length is more than three times the width. Rounded indications are those that are circular or elliptical with the length equal to or less than three times the width.

(b) All indications are not necessarily relevant: leakage of magnetic fields and permeability variations may produce indications that are not relevant to the detection of unacceptable discontinuities. Indications with major dimensions of $^1/_{16}$ in. (1.5 mm) or less are not relevant.

(c) Any indication that is believed to be nonrelevant, and that is larger than acceptable, shall be considered to be a defect and shall be reexamined after light surface conditioning.

(d) Any indication observed during such reexamination shall be considered relevant and shall be evaluated in terms of the acceptance standards.

(e) As an alternative to magnetic particle reexamination, other nondestructive examination means (such as liquid penetrant examination for surface discontinuities) may be used to determine relevancy.

NB-2583.3 Acceptance Standard. Linear nonaxial indications are unacceptable. Linear axial indications greater than 1 in. (25 mm) in length are unacceptable.

NB-2584 Liquid Penetrant Examination

NB-2584.1 Examination Procedure. All bolts, studs, and nuts greater than 1 in. (25 mm) nominal bolt size shall be examined by a liquid penetrant method in accordance with the methods of Section V, Article 6. Such examination shall be performed on the finished component after threading or on the materials stock at approximately the finished diameter before threading and after heading (if involved).

NB-2584.2 Evaluation of Indications. All indications shall be evaluated in terms of the acceptance standards. Linear indications are those indications in which the length is more than three times the width. Rounded indications are those that are circular to elliptical with the length equal to or less than three times the width. All penetrant indications are not necessarily relevant. Surface imperfections such as machining marks and scratches may produce indications that are nonrelevant to the detection of unacceptable discontinuities. Broad areas of pigmentation, which could mask indications of defects, are unacceptable. Indications with major dimensions of $^1/_{16}$ in. (1.5 mm) or less are not relevant. Any indication that is believed to be nonrelevant, and that is larger than acceptable, shall be considered to be a defect and shall be reexamined after light surface conditioning. Any area of pigmentation also shall be reexamined after recleaning or light surface conditioning, as appropriate. Any indication observed during such reexamination shall be considered relevant and shall be evaluated in terms of the acceptance standards.

NB-2584.3 Acceptance Standard. Linear nonaxial indications are unacceptable. Linear axial indications greater than 1 in. (25 mm) long are unacceptable.

NB-2585 Ultrasonic Examination for Sizes Greater Than 2 in. (50 mm)

All bolts, studs, and nuts greater than 2 in. (50 mm) nominal bolt size shall be ultrasonically examined over the entire cylindrical surface prior to threading in accordance with the following requirements.

NB-2585.1 Ultrasonic Method. Examination shall be carried out by the straight beam, radial-scan method in accordance with Section V, Article 23, SA-388.

NB-2585.2 Examination Procedure. Examination shall be performed at a nominal frequency of 2.25 MHz unless variables such as production material grain structure require the use of other frequencies to ensure adequate penetration or better resolution. The search unit area shall not exceed 1 in.^{2} (650 mm).

NB-2585.3 Calibration of Equipment. Calibration sensitivity shall be established by adjustment of the instrument so that the first back reflection is 75% to 90% of full-screen height.

NB-2585.4 Acceptance Standard. Any discontinuity that causes an indication in excess of 20% of the height of the first back reflection or any discontinuity that prevents the production of a first back reflection of 50% of the calibration amplitude is not acceptable.

NB-2586 Ultrasonic Examination for Sizes Over 4 in. (100 mm)

In addition to the requirements of NB-2585, all bolts, studs, and nuts over 4 in. (100 mm) nominal bolt size shall be ultrasonically examined over the entire surface of each end before or after threading in accordance with the following requirements.

NB-2586.1 Ultrasonic Method. Examination shall be carried out by the straight beam, longitudinal-scan method.

NB-2586.2 Examination Procedure. Examination shall be performed at a nominal frequency of 2.25 MHz unless variables such as production material grain structure require the use of other frequencies to ensure adequate penetration or better resolution. The search unit shall have a circular cross section with a diameter not less than $^1/_2$ in. (13 mm) nor greater than $1^1/_8$ in. (29 mm).

NB-2586.3 Calibration of Equipment. Calibration shall be established on a test bar of the same nominal composition and diameter as the production part and a minimum of one-half of the length. A $^3/_8$ in. (10 mm) diameter by 3 in. (75 mm) deep flat-bottom hole shall be drilled in one end of the bar and plugged to full depth. A distance–amplitude curve shall be established by scanning from both ends of the test bar.

NB-2586.4 Acceptance Standard. Any discontinuity that causes an indication in excess of that produced by the calibration hole in the reference specimen as corrected by the distance–amplitude curve is not acceptable.

NB-2587 Time of Examination

Acceptance examinations shall be performed after the final heat treatment required by the basic material specification.

NB-2588 Elimination of Surface Defects

Unacceptable surface defects on finished bolts, studs, and nuts are not permitted, and are cause for rejection.

NB-2589 Repair by Welding

Weld repairs of bolts, studs, and nuts are not permitted.

NB-2600 MATERIAL ORGANIZATIONS' QUALITY SYSTEM PROGRAMS

NB-2610 DOCUMENTATION AND MAINTENANCE OF QUALITY SYSTEM PROGRAMS (23)

(a) Except as provided in (b) below, Material Organizations shall have a Quality System Program that meets the requirements of NCA-3300.

(b) The requirements of NCA-1224, NCA-1225, and NCA-4256 shall be met as required by NB-2130 and NB-2150, respectively. The other requirements of NCA-3300 and NCA-4200 need not be used by Material Organizations for small products, as defined in (c) below, for brazing material, and for material that is allowed by this Subsection to be furnished with a Certificate of Compliance. For these products, the Certificate Holder's Quality Assurance Program (NCA-4100) shall include measures to provide assurance that the material is furnished in accordance with the material specification and with the applicable requirements of this Subsection.

(c) For the purpose of this paragraph, small products are defined as given in (1) through (5) below:

(1) pipe, tube (except heat exchanger tube), pipe fittings, and flanges NPS 2 (DN 50) and less;

(2) bolting material, including studs, nuts, and bolts of 1 in. (25 mm) nominal diameter and less;

(3) bars with a nominal cross-sectional area of 1 in.^{2} (650 mm^2) and less;

(4) material for pumps and valves with inlet pipe connections of NPS 2 (DN 50) and less;

(5) material exempted by NB-2121(c).

NB-2700 DIMENSIONAL STANDARDS

Dimensions of standard items shall comply with the standards and specifications listed in Table NCA-7100-1.

ARTICLE NB-3000 DESIGN

NB-3100 GENERAL DESIGN

NB-3110 LOADING CRITERIA

NB-3111 Loading Conditions

The loadings that shall be taken into account in designing a component include, but are not limited to, those in (a) through (g) below:

(a) internal and external pressure;

(b) impact loads, including rapidly fluctuating pressures;

(c) weight of the component and normal contents under operating or test conditions, including additional pressure due to static and dynamic head of liquids;

(d) superimposed loads such as other components, operating equipment, insulation, corrosion-resistant or erosion resistant linings, and piping;

(e) wind loads, snow loads, vibrations, and earthquake loads where specified;

(f) reactions of supporting lugs, rings, saddles, or other types of supports;

(g) temperature effects.

NB-3112 Design Loadings

The Design Loadings shall be established in accordance with NCA-2142.1 and the following subparagraphs.

NB-3112.1 Design Pressure.

(a) The specified internal and external Design Pressures to be used in this Subsection shall be established in accordance with NCA-2142.1(a). When the occurrence of different pressures during operation can be predicted for different zones of a component, the Design Pressure of the different zones may be based on their predicted pressures.

(b) All pressures referred to in this Article are to be taken as psi (MPa), above atmospheric pressure, unless otherwise stated.

NB-3112.2 Design Temperature.

(a) The specified Design Temperature shall be established in accordance with NCA-2142.1(b). It shall be used in computations involving the Design Pressure and coincidental Design Mechanical Loads. The actual metal temperature at the point under consideration shall be used in all computations where the use of the specified service pressure is required.

(b) All temperatures referred to in this Article are the metal temperatures expressed in degrees Fahrenheit,°F (degrees Celsius, °C) unless otherwise stated.

(c) Where a component is heated by tracing, induction coils, jacketing, or internal heat generation, the effect of such heating shall be incorporated in the establishment of the Design Temperature.

NB-3112.3 Design Mechanical Loads. The specified Design Mechanical Loads shall be established in accordance with NCA-2142.1(c). They shall be used in conjunction with the Design Pressure.

NB-3112.4 Design Stress Intensity Values. Design stress intensity values for materials are listed in Section II, Part D, Subpart 1, Tables 2A, 2B, and 4. The material shall not be used at metal and design temperatures that exceed the temperature limit in the applicability column for which stress intensity values are listed. The values in the Table may be interpolated for intermediate temperatures.

NB-3113 Service Conditions

Each service condition to which the components may be subjected shall be classified in accordance with NCA-2142 and Service Limits [NCA-2142.4(b)] designated in the Design Specifications in such detail as will provide a complete basis for design, construction, and inspection in accordance with this Article. The requirements of (a) and (b) below shall also apply.

(a) Level B Conditions. The estimated duration of service conditions for which Level B Limits are specified shall be included in the Design Specifications.

(b) Level C Conditions. The total number of postulated occurrences for all specified service conditions for which Level C Limits are specified shall not cause more than 25 stress cycles having an S_a value greater than that for 10^6 cycles from the applicable fatigue design curves of Section III Appendices, Mandatory Appendix I.

NB-3120 SPECIAL CONSIDERATIONS

NB-3121 Corrosion

Material subject to thinning by corrosion, erosion, mechanical abrasion, or other environmental effects shall have provision made for these effects during the design or specified life of the component by a suitable increase in or addition to the thickness of the base metal over that determined by the design equations. Material added or included for these purposes need not be of the same thickness for all areas of the component if different rates of attack are expected for the various areas. It should be noted that the tests on which the design fatigue curves (Section III Appendices, Mandatory Appendix I) are based did not include tests in the presence of corrosive environments that might accelerate fatigue failure.

NB-3122 Cladding

The rules of the following subparagraphs apply to the analysis of clad components constructed of material permitted in Section II, Part D, Subpart 1, Tables 2A and 2B.

NB-3122.1 Primary Stresses. No structural strength shall be attributed to the cladding in satisfying Section III Appendices, Mandatory Appendix XIII, XIII-3100.

NB-3122.2 Design Dimensions. The dimensions given in (a) and (b) below shall be used in the design of the component.

(a) For components subjected to internal pressure, the inside diameter shall be taken at the nominal inner face of the cladding.

(b) For components subjected to external pressure, the outside diameter shall be taken at the outer face of the base metal.

NB-3122.3 Secondary and Peak Stresses. In satisfying Section III Appendices, Mandatory Appendix XIII, XIII-3400 and XIII-3500, the presence of the cladding shall be considered with respect to both the thermal analysis and the stress analysis. The stresses in both materials shall be limited to the values specified in Section III Appendices, Mandatory Appendix XIII, XIII-3400 and XIII-3500. However, when the cladding is of the integrally bonded type and the nominal thickness of the cladding is 10% or less of the total thickness of the component, the presence of the cladding may be neglected.

NB-3122.4 Bearing Stresses. In satisfying Section III Appendices, Mandatory Appendix XIII, XIII-3710, the presence of cladding shall be included.

NB-3123 Welding

NB-3123.1 Dissimilar Welds. In satisfying the requirements of this subarticle, caution should be exercised in design and construction involving dissimilar metals having different coefficients of thermal expansion in order to avoid difficulties in service.

NB-3123.2 Fillet Welded Attachments. Fillet welds conforming to Figure NB-4427-1 may be used for attachments to components except as limited by NB-4433. Evaluation for cyclic loading shall be made in accordance with the appropriate subarticle of Article NB-3000, and shall include consideration of temperature differences between the component and the attachment, and of expansion or contraction of the component produced by internal or external pressure.

NB-3124 Environmental Effects

Changes in material properties may occur due to environmental effects. In particular, fast neutron irradiation (>1 MeV) above a certain level may result in significant increase in the brittle fracture transition temperature and deterioration in the resistance to fracture at temperatures above the transition range (upper shelf energy). Therefore, nozzles or other structural discontinuities in ferritic vessels should preferably not be placed in regions of high neutron flux.

NB-3125 Configuration (23)

Accessibility to permit the examinations or MANDE required by the Division and Edition of Section XI as specified in the Design Specification for the component shall be provided in the design of the component.

NB-3130 GENERAL DESIGN RULES

NB-3131 Scope

Design rules generally applicable to all components are provided in the following paragraphs. The design subarticle for the specific component provides rules applicable to that particular component. In case of conflict between NB-3130 and the design rules for a particular component, the component design rules govern.

NB-3132 Dimensional Standards for Standard Products

Dimensions of standard products shall comply with the standards and specifications listed in Table NCA-7100-1 when the standard or specification is referenced in the specific design subarticle. However, compliance with these standards does not replace or eliminate the requirements for stress analysis when called for by the design subarticle for a specific component.

NB-3133 Components Under External Pressure

NB-3133.1 General. Rules are given in this paragraph for determining the stresses under external pressure loading in spherical and cylindrical shells with or without stiffening rings, and tubular products consisting of pipes, tubes, and fittings. Charts for determining the stresses in shells, hemispherical heads, and tubular products are given in Section II, Part D, Subpart 3.

NB-3133.2 Nomenclature. The symbols used in this paragraph are defined as follows:

A = factor determined from Section II, Part D, Subpart 3, Figure G and used to enter the applicable material chart in Section II, Part D, Subpart 3. For the case of cylinders having D_o/T values less than 10, see NB-3133.3(b). Also, factor determined from the applicable chart in Section II, Part D, Subpart 3 for the material used in a stiffening ring, corresponding to the factor B and the design metal temperature for the shell under consideration.

A_s = cross-sectional area of a stiffening ring

B = factor determined from the applicable chart in Section II, Part D, Subpart 3 for the material used in a shell or stiffening ring at the design metal temperature, psi (MPa)

D_o = outside diameter of the cylindrical shell course or tube under consideration

E = modulus of elasticity of material at Design Temperature, psi (MPa). For external pressure and axial compression design in accordance with this Section, the modulus of elasticity to be used shall be taken from the applicable materials chart in Section II, Part D, Subpart 3. (Interpolation may be made between lines for intermediate temperatures.) The modulus of elasticity values shown in Section II, Part D, Subpart 3 for material groups may differ from those values listed in Section II, Part D, Subpart 2, Tables TM for specific materials. Section II, Part D, Subpart 3 values shall be applied only to external pressure and axial compression design.

I = available moment of inertia of the combined ring-shell section about its neutral axis, parallel to the axis of the shell. The width of the shell that is taken as contributing to the combined moment of inertia shall not be greater than $1.10\sqrt{D_o T_n}$ and shall be taken as lying one-half on each side of the centroid of the ring. Portions of shell plates shall not be considered as contributing area to more than one stiffening ring.

I_s = required moment of inertia of the combined ring-shell section about its neutral axis parallel to the axis of the shell

L = total length of a tube between tubesheets, or the design length of a vessel section, taken as the largest of the following:

(a) the distance between head tangent lines plus one-third of the depth of each head if there are no stiffening rings;

(b) the greatest center-to-center distance between any two adjacent stiffening rings; or

(c) the distance from the center of the first stiffening ring to the head tangent line plus one-third of the depth of the head, all measured parallel to the axis of the vessel

L_s = one-half the distance from the center line of the stiffening ring to the next line of support on one side, plus one-half of the center line distance to the next line of support on the other side of the stiffening ring, both measured parallel to the axis of the component. A line of support is:

(a) a stiffening ring that meets the requirements of this paragraph;

(b) a circumferential line on a head at one-third the depth of the head from the head tangent line; or

(c) circumferential connection to a jacket for a jacketed section of a cylindrical shell

P = external design pressure, psi (MPa) (gage or absolute, as required)

P_a = allowable external pressure, psi (MPa) (gage or absolute, as required)

R = inside radius of spherical shell

S = the lesser of 1.5 times the stress intensity at design metal temperature from Section II, Part D, Subpart 1, Tables 2A and 2B, or 0.9 times the tabulated yield strength at design metal temperature from Section II, Part D, Subpart 1, Table Y-1, psi (MPa)

T = minimum required thickness of cylindrical shell or tube, or spherical shell

T_n = nominal thickness used, less corrosion allowance, of cylindrical shell or tube

NB-3133.3 Cylindrical Shells and Tubular Products.

(a) The minimum thickness of cylindrical shells or tubular products under external pressure having D_o/T values equal to or greater than 10 shall be determined by the procedure given in Steps 1 through 8 below.

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

Step 2. Enter Section II, Part D, Subpart 3, Figure G at the value of L/D_o determined in Step 1. For values of L/D_o greater than 50, enter the chart at a value of L/D_o of 50. For values of L/D_o less than 0.05, enter the chart at a value of L/D_o of 0.05.

Step 3. Move horizontally to the line for the value of D_o/T determined in Step 1. Interpolation may be made for intermediate values of D_o/T. From this intersection move vertically downward and read the value of factor A.

Step 4. Using the value of A calculated in Step 3, enter the applicable material chart in Section II, Part D, Subpart 3 for the material/temperature under consideration. Move vertically to an intersection with the material/temperature line for the design temperature. Interpolation may be made between lines for intermediate temperatures. In cases where the value at A falls to the right of the end of the material/temperature line, assume an intersection with the horizontal projection of the upper end of the material/temperature line. For values of A falling to the left of the material line, see Step 7.

Step 5. From the intersection obtained in Step 4 move horizontally to the right and read the value of B.

Step 6. Using this value of B, calculate the maximum allowable external pressure P_a using the following equation:

$$P_a = \frac{4B}{3(D_o/T)}$$

Step 7. For values of A falling to the left of the applicable material/temperature line, the value of P_a can be calculated using the following equation:

$$P_a = \frac{2AE}{3(D_o/T)}$$

Step 8. Compare P_a with P. If P_a is smaller than P, select a larger value for T and repeat the design procedure until a value for P_a is obtained that is equal to or greater than P.

(b) The minimum thickness of cylindrical shells or tubular products under external pressure having D_o/T values less than 10 shall be determined by the procedure given in Steps 1 through 4 below.

Step 1. Using the same procedure as given in (a) above, obtain the value of B. For values of D_o/T less than 4, the value of factor A can be calculated using the following equation:

$$A = \frac{1.1}{(D_o/T)^2}$$

For values of A greater than 0.10 use a value of 0.10.

Step 2. Using the value of B obtained in Step 1, calculate a value P_{a1} using the following equation:

$$P_{a1} = \left[\frac{2.167}{(D_o/T)} - 0.0833\right]B$$

Step 3. Calculate a value P_{a2} using the following equation:

$$P_{a2} = \frac{2S}{(D_o/T)}\left[1 - \frac{1}{(D_o/T)}\right]$$

Step 4. The smaller of the values of P_{a1} calculated in Step 2 or P_{a2} calculated in Step 3 shall be used for the maximum allowable external pressure P_a. Compare P_a with P. If P_a is smaller than P, select a larger value for T and repeat the design procedure until a value for P_a is obtained that is equal to or greater than P.

NB-3133.4 Spherical Shells. The minimum required thickness of a spherical shell under external pressure, either seamless or of built-up construction with butt joints, shall be determined by the procedure given in Steps 1 through 6 below.

Step 1. Assume a value for T and calculate the value of factor A using the following equation:

$$A = \frac{0.125}{(R/T)}$$

Step 2. Using the value of A calculated in Step 1, enter the applicable material chart in Section II, Part D, Subpart 3 for the material under consideration. Move vertically to an intersection with the material/temperature line for the design temperature. Interpolation may be made between lines for intermediate temperatures. In cases where the value of A falls to the right of the end of the material/temperature line, assume an intersection with the horizontal projection of the upper end of the material/temperature line. For values at A falling to the left of the material/temperature line, see Step 5.

Step 3. From the intersection obtained in Step 2, move horizontally to the right and read the value of factor B.

Step 4. Using the value of B obtained in Step 3, calculate the value of the maximum allowable external pressure P_a using the following equation:

$$P_a = \frac{B}{(R/T)}$$

Step 5. For values of A falling to the left of the applicable material/temperature line for the Design Temperature, the value of P_a can be calculated using the following equation:

$$P_a = \frac{0.0625E}{(R/T)^2}$$

Step 6. Compare P_a obtained in Step 4 or 5 with P. If P_a is smaller than P, select a larger value for T, and repeat the design procedure until a value for P_a is obtained that is equal to or greater than P.

NB-3133.5 Stiffening Rings for Cylindrical Shells.

(a) The required moment of inertia of the combined ring-shell section is given by the equation:

$$I_s = \frac{D_o{}^2 L_s (T + A_s/L_s) A}{10.9}$$

The available moment of inertia I for a stiffening ring shall be determined by the procedure given in Steps 1 through 6 below.

Step 1. Assuming that the shell has been designed and D_o, L_s, and T_n are known, select a member to be used for the stiffening ring and determine its area A_s and the value of I defined in NB-3133.2. Then calculate B by the equation:

$$B = \frac{3}{4}\left(\frac{PD_o}{T_n + A_s/L_s}\right)$$

Step 2. Enter the right-hand side of the applicable material chart in Section II, Part D, Subpart 3 for the material under consideration at the value of B determined in Step 1. If different materials are used for the shell and stiffening ring, then use the material chart resulting in the larger value for factor A in Step 4 or Step 5 below.

Step 3. Move horizontally to the left to the material/temperature line for the design metal temperature. For values of B falling below the left end of the material/temperature line, see Step 5.

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

Step 5. For values of B falling below the left end of the material/temperature line for the design temperature, the value of A can be calculated using the following equation:

$$A = 2B/E$$

Step 6. If the required I_s is greater than the computed moment of inertia I for the combined-ring shell 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 the computed I for the section selected in Step 1, that section should be satisfactory.

(b) Stiffening rings may be attached to either the outside or the inside of the component by continuous welding.

NB-3133.6 Cylinders Under Axial Compression. The maximum allowable compressive stress to be used in the design of cylindrical shells and tubular products subjected to loadings that produce longitudinal compressive stresses in the shell or wall shall be the lesser of the values given in (a) or (b) below.

(a) the S_m value for the applicable material at design temperature given in Section II, Part D, Subpart 1, Tables 2A and 2B;

(b) the value of the factor B determined from the applicable chart contained in Section II, Part D, Subpart 3, using the following definitions for the symbols on the charts:

R = inside radius of the cylindrical shell or tubular product

T = minimum required thickness of the shell or tubular product, exclusive of the corrosion allowance

The value of B shall be determined from the applicable chart contained in Section II, Part D, Subpart 3 as given in Steps 1 through 5 below.

Step 1. Using the selected values of T and R, calculate the value of factor A using the following equation:

$$A = \frac{0.125}{(R/T)}$$

Step 2. Using the value of A calculated in Step 1, enter the applicable material chart in Section II, Part D, Subpart 3 for the material under consideration. Move vertically to an intersection with the material/temperature line for the design temperature. Interpolation may be made between lines for intermediate temperatures. In cases where the value at A falls to the right of the end of the material/temperature line, assume an intersection with the horizontal projection of the upper end of the material/temperature line. For values of A falling to the left of the material/temperature line, see Step 4.

Step 3. From the intersection obtained in Step 2, move horizontally to the right and read the value of factor B. This is the maximum allowable compressive stress for the values of T and R used in Step 1.

Step 4. For values of A falling to the left of the applicable material/temperature line, the value of B shall be calculated using the following equation:

$$B = \frac{AE}{2}$$

Step 5. Compare the value of B determined in Step 3 or 4 with the computed longitudinal compressive stress in the cylindrical shell or tube, using the selected values of T and R. If the value of B is smaller than the computed compressive stress, a greater value of T must be selected and the design procedure repeated until a value of B is obtained that is greater than the compressive stress computed for the loading on the cylindrical shell or tube.

NB-3134 Leak Tightness

Where a system leak tightness greater than that required or demonstrated by a hydrostatic test is required, the leak tightness requirements for each component shall be set forth in the Design Specifications.

NB-3135 Attachments

(a) Except as permitted in (d), (e), or (f) below, attachments and connecting welds within the jurisdictional boundary of the component as defined in NB-1130 shall meet the stress limits of the component or NB-3200.

(b) The design of the component shall include consideration of the localized interaction effects and loads transmitted through the attachment to and from the pressure-retaining portion of the component. Localized interaction effects include thermal stresses, stress

concentrations, and restraint of the pressure-retaining portion of the component.

(c) The first welded structural attachment within 2t of the pressure-retaining portion of the component, where t is the nominal thickness of the pressure-retaining material, shall be evaluated for cyclic loading. Evaluation shall be in accordance with the appropriate subarticle of Article NB-3000 and shall be made at the juncture of the attachment to the component.

(d) Beyond 2t the appropriate design rules of Article NF-3000 may be used as a substitute for the design rules of Article NB-3000 for cast and forged portions of attachments that are in the component support load path.

(e) Nonstructural attachments shall meet the requirements of NB-4435.

(f) Beyond 2t the appropriate design rules of Article NG-3000 may be used as a substitute for the design rules of Article NB-3000 for portions of cast or forged attachments that are core support structures.

NB-3136 Appurtenances

(a) Except as permitted in (b) below, the portions of appurtenances having a pressure-retaining function shall be designed in accordance with the rules for components.

(b) Small diameter appurtenance fabrication weld joints may be designed using weld joint details in accordance with Figure NB-4440-1, provided the following requirements are met.

(1) The appurtenance weld joint shall have an outside diameter equal to NPS 2 (DN 50) or less (see Figure NB-4440-1).

(2) The design of the welded joints shall be such that the stresses will not exceed the limits described in Section III Appendices, Mandatory Appendix XIII, Article XIII-3000 and tabulated in Section II, Part D, Subpart 1, Tables 2A and 2B.

(3) A fatigue strength reduction factor of 4 shall be used in the fatigue analysis of the joints.

(4) The requirements of NB-4440 and NB-5260 shall be satisfied.

NB-3137 Reinforcement for Openings

The requirements applicable to vessels and piping are contained in NB-3330 and NB-3643, respectively.

NB-3200 DESIGN BY ANALYSIS

NB-3210 REQUIREMENTS FOR ACCEPTABILITY

The requirements for the acceptability of a design by analysis are given in (a) through (d) below.

(a) The design shall be such that stress intensities will not exceed the limits described in Section III Appendices, Mandatory Appendix XIII and in NB-3100.

(b) The design details shall conform to the rules given in NB-3100 and those given in the subarticle applicable to the specific component.

(c) For configurations where compressive stresses occur, in addition to the requirements in (a) and (b) above, the critical buckling stress shall be taken into account. For the special case of external pressure, NB-3133 applies.

(d) Protection against nonductile fracture shall be provided by satisfying one of the following provisions:

(1) performing an evaluation of service and test conditions by methods similar to those contained in Section III Appendices, Nonmandatory Appendix G; or

(2) for piping, pump, and valve material thickness greater than $2\frac{1}{2}$ in. (64 mm) establishing a lowest service temperature[7] that is not lower than RT_{NDT} (see NB-2331) + 100°F (56°C);

(3) for piping, pump, and valve material thickness equal to or less than $2\frac{1}{2}$ in. (64 mm), the requirements of NB-2332(a) shall be met at or below the lowest service temperature as established in the design specification.

NB-3300 VESSEL DESIGN

NB-3310 GENERAL REQUIREMENTS

NB-3311 Acceptability

The requirements for acceptability of a vessel design are as follows:

(a) The design shall be such that the requirements of NB-3100 and NB-3200 shall be satisfied.

(b) The rules of this subarticle shall be met. In cases of conflict between NB-3200 and NB-3300 the requirements of NB-3300 shall govern.

NB-3320 DESIGN CONSIDERATIONS

NB-3321 Design and Service Loadings

The provisions of NB-3110 apply.

NB-3322 Special Considerations

The provisions of NB-3120 apply.

NB-3323 General Design Rules

The provisions of NB-3130 apply except when they conflict with rules of this subarticle. In case of conflict, this subarticle governs in the design of vessels.

NB-3324 Pressure Thickness (23)

The minimum vessel wall thickness shall satisfy the requirements of NB-3200. As an aid to the designer, the equations of NB-3324.1, NB-3324.2, and NB-3324.3 are provided to establish a tentative thickness, where

D = inside diameter of a head skirt or the attached cylinder. D is also equal to the length of the major axis of an ellipsoidal head
L = inside crown center radius of curvature
P = Design Pressure
R = inside radius of shell or head
r = inside knuckle radius
R_o = outside radius of shell or head
S_m = design stress intensity values (Section II, Part D, Subpart 1, Tables 2A and 2B)
t = thickness of shell or head

NB-3324.1 Cylindrical Shells.

$$t = \frac{PR}{S_m - 0.5P} \quad \text{or} \quad t = \frac{PR_o}{S_m + 0.5P}$$

NB-3324.2 Spherical Shells and Heads.

$$t = \frac{PR}{2S_m - P} \quad \text{or} \quad t = \frac{PR_o}{2S_m}$$

NB-3324.3 Ellipsoidal and Torispherical Heads. For heads where $t/L > 0.002$ and $r/D > 0.06$, use the equation in NB-3324.2 and substitute L for R. L is not permitted to be larger than D. For an ellipsoidal head, $L = (\frac{1}{2}$ major axis of the ellipse$)^2/(\frac{1}{2}$ minor axis of the ellipse). For heads outside of these limits, tentative thickness may be determined using the stress analysis methods of NB-3200 with consideration of buckling.

NB-3325 Perforated Flat Plates and Tubesheets

Guidelines for calculating stresses in perforated flat plates and tubesheets are provided in Section III Appendices, Nonmandatory Appendix A, Article A-8000.

NB-3330 OPENINGS AND REINFORCEMENT

NB-3331 General Requirements for Openings

(a) For vessels or parts thereof that meet the requirements of Section III Appendices, Mandatory Appendix XIII, XIII-3510, analysis showing satisfaction of the requirements of Section III Appendices, Mandatory Appendix XIII, XIII-3100 and XIII-3400 in the immediate vicinity of the openings is not required for pressure loading if the rules of NB-3330 are met.

(b) For vessels or parts thereof that do not meet the requirements of Section III Appendices, Mandatory Appendix XIII, XIII-3510 so that a fatigue analysis is required, the rules contained in NB-3330 ensure satisfaction of the requirements of Section III Appendices, Mandatory Appendix XIII, XIII-3100 in the vicinity of openings, and no specific analysis showing satisfaction of those stress limits is required for pressure loading. The requirements of Section III Appendices, Mandatory Appendix XIII, XIII-3400 may also be considered to be satisfied if, in the vicinity of the nozzle, the stress intensity resulting from external nozzle loads and thermal effects, including gross but not local structural discontinuities, is shown by analysis to be less than $1.5S_m$. In this case, when evaluating the requirements of Section III Appendices, Mandatory Appendix XIII, XIII-3520, the peak stress intensity resulting from pressure loadings may be obtained by application of the stress index method of NB-3338 or NB-3339.

(c) The provisions of (a) and (b) above are not intended to restrict the design to any specified section thicknesses or other design details, provided the basic stress limits are satisfied. If it is shown by analysis that all the stress requirements have been met, the rules of NB-3330 are waived.

(d) Openings shall be circular, elliptical, or of any other shape that results from the intersection of a circular or elliptical cylinder with a vessel of the shapes permitted by this Subsection. Additional restrictions given in NB-3338.2(d) are applicable if the Stress Index Method is used. If fatigue analysis is not required, the restrictions on hole spacing are applicable unless there will be essentially no pipe reactions.

(e) Openings are not limited as to size except to the extent provided in NB-3338.2(d).

(f) All references to dimensions apply to the finished dimensions excluding material added as corrosion allowance. Rules regarding metal available for reinforcement are given in NB-3335.

(g) Any type of opening permitted in these rules may be located in a welded joint.

NB-3332 Reinforcement Requirements for Openings in Shells and Formed Heads

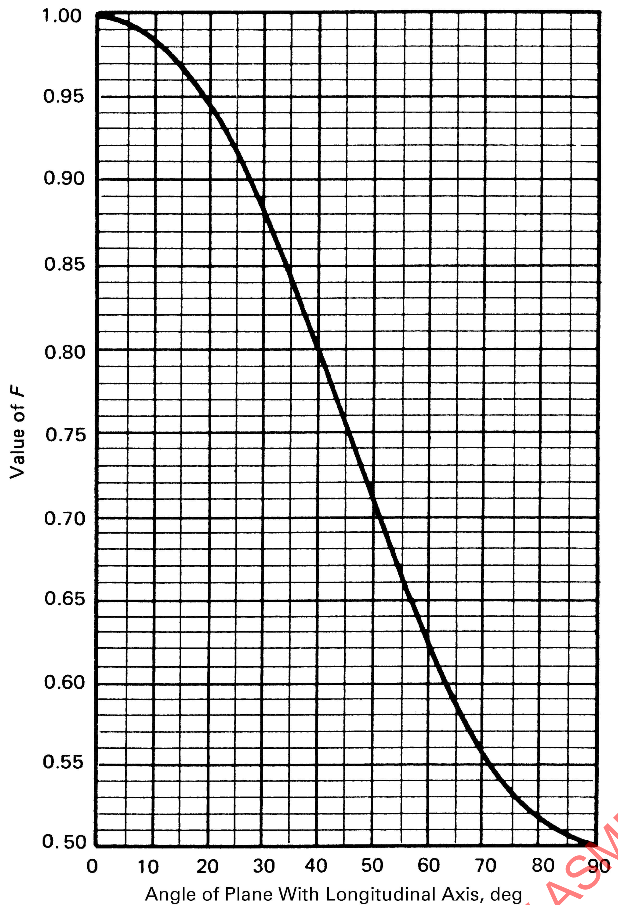
NB-3332.1 Openings Not Requiring Reinforcement. (23)
The rules for openings not requiring reinforcement are given in (a) through (c) below, where R is the mean radius and t is the nominal thickness of the vessel shell or head at the location of the opening; and *locally stressed area* means any area in the shell where the local primary membrane stress exceeds $1.1S_m$, but excluding those areas where such local primary membrane stress is due to an unreinforced opening.

(a) A single opening has a diameter not exceeding $0.2\sqrt{Rt}$, or if there are two or more openings within any circle of diameter $2.5\sqrt{Rt}$, but the sum of the diameters of such unreinforced openings shall not exceed $0.25\sqrt{Rt}$.

(b) No two unreinforced openings shall have their centers closer to each other, measured on the inside of the vessel wall, than 1.5 times the sum of their diameters.

(c) No unreinforced opening shall have its center closer than $2.5\sqrt{Rt}$ to the edge of a locally stressed area in the shell.

Figure NB-3332.2-1
Chart for Determining Value of *F*



NB-3332.2 Required Area of Reinforcement. The total cross-sectional area of reinforcement A, required in any given plane for a vessel under internal pressure, shall not be less than:

$$A = dt_rF$$

where

d = finished diameter of a circular opening or finished dimension (chord length) of an opening on the plane being considered for elliptical and obround openings in corroded condition.

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 Figure NB-3332.2-1 may be used for integrally reinforced openings in cylindrical shells and cones.)

t_r = the thickness that meets the requirements of Section III Appendices, Mandatory Appendix XIII, XIII-3110 in the absence of the opening.

Not less than half the required material shall be on each side of the center line.

NB-3333 Reinforcement Required for Openings in Flat Heads

Flat heads that have an opening with a diameter that does not exceed one-half the head diameter shall have a total cross-sectional area of reinforcement not less than that given by the equation:

$$A = 0.5dt_r$$

where d is as defined in NB-3332 and t_r is the thickness, that meets the requirements of Section III Appendices, Mandatory Appendix XIII, XIII-3110 and XIII-3130 in the absence of the opening.

NB-3334 Limits of Reinforcement

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

NB-3334.1 Limit of Reinforcement Along the Vessel Wall. The limits of reinforcement, measured along the midsurface of the nominal wall thickness, shall meet the following.

(a) One hundred percent of the required reinforcement shall be within 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 sum of the thicknesses of the vessel wall and the nozzle wall.

(b) Two-thirds of the required reinforcement shall be within a distance on each side of the axis of the opening equal to the greater of the following:

(1) $r + 0.5\sqrt{Rt}$, where R is the mean radius of shell or head, t is the nominal vessel wall thickness, and r is the radius of the finished opening in the corroded condition;

(2) the radius of the finished opening in the corroded condition plus two-thirds the sum of the thicknesses of the vessel wall and the nozzle wall.

NB-3334.2 Limit of Reinforcement Normal to the Vessel Wall. 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 following limits as shown in Figure NB-3338.2(a)-2.

(a) For Figure NB-3338.2(a)-2, sketches (a), (b), (d), and (e):

$$\text{Limit} = 0.5\sqrt{r_m t_n} + 0.5r_2$$

where

r_i = inside radius
r_m = mean radius
= $r_i + 0.5t_n$
r_2 = transition radius, between nozzle and wall
t_n = nominal nozzle thickness, as indicated

For the case of a nozzle with a tapered inside diameter, the limit shall be obtained by using r_i and t_n values at the nominal outside diameters of the vessel wall [Figure NB-3338.2(a)-2, sketch (e)].

(b) For Figure NB-3338.2(a)-2, sketches (c) and (f):

$$\text{Limit} = 0.5\sqrt{r_m t_n}$$

where

r_i = inside radius
r_m = $r_i + 0.5t_n$
t_n = $t_p + 0.667X$
t_p = nominal thickness of the attached pipe
X = slope offset distance
θ = angle between vertical and slope, 45 deg or less

For the case of a nozzle with a tapered inside diameter, the limit shall be obtained by using r_i and t_n values at the center of gravity of nozzle reinforcement area. These values must be determined by a trial and error procedure [Figure NB-3338.2(a)-2, sketch (f)].

NB-3335 Metal Available for Reinforcement

Metal may be counted as contributing to the area of reinforcing called for in NB-3332, provided it lies within the limits of reinforcement specified in NB-3334, and shall be limited to material that meets the following requirements:

(a) metal forming a part of the vessel wall that is in excess of that required on the basis of membrane stress intensity (Section III Appendices, Mandatory Appendix XIII, XIII-3110) and is exclusive of corrosion allowance;

(b) similar excess metal in the nozzle wall, provided the nozzle is integral with the vessel wall or is joined to it by a full penetration weld;

(c) weld metal that is fully continuous with the vessel wall;

(d) the mean coefficient of thermal expansion of metal to be included as reinforcement under (b) and (c) above shall be within 15% of the value of the vessel wall material;

(e) metal not fully continuous with the shell, such as that in nozzles attached by partial penetration welds, shall not be counted as reinforcement;

(f) metal available for reinforcement shall not be considered as applying to more than one opening.

NB-3336 Strength of Reinforcing Material

Material used for reinforcement shall preferably be the same as that of the vessel wall. If the material of the nozzle wall or reinforcement has a lower design stress intensity value S_m than that for the vessel material, the amount of area provided by the nozzle wall or reinforcement in satisfying the requirements of NB-3332 shall be taken as the actual area provided multiplied by the ratio of the nozzle or reinforcement design stress intensity value to the vessel material design stress intensity value. No reduction in the reinforcing required may be taken for the increased strength of reinforcing material and weld metal having higher design stress intensity values than that of the material of the vessel wall. The strength of the material at the point under consideration shall be used in fatigue analyses.

NB-3337 Attachment of Nozzles and Other Connections

NB-3337.1 General Requirements. Nozzles and other Category D connections (see NB-3351) shall be attached to the shell or head of the vessel by one of the methods provided in NB-3352.

NB-3337.2 Full Penetration Welded Nozzles. Full penetration welds, as shown in Figures NB-4244(a)-1, NB-4244(b)-1, NB-4244(c)-1, and NB-4244(e)-1 may be used (except as otherwise provided in NB-3337.3) for the purpose of achieving continuity of metal and facilitating the required radiographic examination. When all or part of the required reinforcement is attributable to the nozzle, the nozzle shall be attached by full penetration welds through either the vessel or the nozzle thickness, or both.

NB-3337.3 Partial Penetration Welded Nozzles.

(a) Partial penetration welds, as shown in Figures NB-4244(d)-1 and NB-4244(d)-2, are allowed only for nozzles on which there are substantially no piping reactions, such as control rod housings, pressurizer heater wells, and openings for instrumentation. Earthquake loadings need not be considered in determining whether piping reactions are substantial. For such nozzles, all reinforcement shall be integral with the portion of the vessel penetrated. Partial penetration welds shall be of sufficient size to develop the full strength of the nozzles. Nozzles attached by partial penetration welds shall have an interference fit or a maximum diametral clearance between the nozzle and the vessel penetration of:

(1) 0.010 in. (0.25 mm) for $d \leq 1$ in. (25 mm)

(2) 0.020 in. (0.50 mm) for 1 in. (25 mm) $< d \leq 4$ in. (100 mm)

(3) 0.030 in. (0.75 mm) for $d > 4$ in. (100 mm)

where d is the outside diameter of the nozzle, except that the above limits on maximum clearance need not be met for the full length of the opening, provided there is a region at the weld preparation and a region near the end of the opening opposite the weld that does meet the above limits on maximum clearance and the latter region is extensive enough (not necessarily continuous) to provide a positive stop for nozzle deflection.

(b) In satisfying the limit of Section III Appendices, Mandatory Appendix XIII, XIII-3400, the stress intensities resulting from pressure-induced strains (dilation of hole) may be treated as secondary in the penetrating part of partial penetration welded construction, provided the requirements of NB-3352.4(d) and Figure NB-4244(d)-1 are fulfilled.

NB-3338 Fatigue Evaluation of Stresses in Openings

NB-3338.1 General. For the purpose of determining peak stresses around the opening, three acceptable methods are listed below.

(a) Analytical Method. This method uses suitable analytical techniques such as finite element computer analyses, which provide detailed stress distributions around openings. In addition to peak stresses due to pressure, the effects of other loadings shall be included. The total peak stress at any given point shall be determined by combining stresses due to pressure, thermal, and external loadings in accordance with the rules of Section III Appendices, Mandatory Appendix XIII.

(b) Experimental Stress Analysis. This is based on data from experiments (Section III Appendices, Mandatory Appendix II).

(c) Stress Index Method. This uses various equations together with available data obtained from an extensive series of tests covering a range of variation of applicable dimensional ratios and configurations (see NB-3338.2). This method covers only single, isolated openings. Stress indices may also be determined by theoretical or experimental stress analysis.

NB-3338.2 Stress Index Method.

(a) The term *stress index*, as used herein, is defined as the numerical ratio of the stress components σ_t, σ_n, and σ_r [Figure NB-3338.2(a)-1] under consideration to the computed membrane hoop stress in the unpenetrated vessel material; however, the material that increases the thickness of a vessel wall locally at the nozzle shall not be included in the calculations of these stress components. When the thickness of the vessel wall is increased over that required to the extent provided hereinafter, the values of r_1 and r_2 in Figure NB-3338.2(a)-2 shall be referred to the thickened section.

(b) The nomenclature used in NB-3338 is defined as follows.

R = inside radius, in corroded condition, of cylindrical vessel, spherical vessel, or spherical head

S = stress intensity (combined stress) at the point under consideration

t = nominal wall thickness, less corrosion allowance, of vessel or head

σ_n = stress component normal to the plane of the section (ordinarily the circumferential stress around the hole in the shell)

σ_r = stress component normal to the boundary of the section

σ_t = stress component in the plane of the section under consideration and parallel to the boundary of the section

(c) When the conditions of (d) below are satisfied, the stress indices of Table NB-3338.2(c)-1 may be used for nozzles designed in accordance with the applicable rules of NB-3330. These stress indices deal only with the maximum stresses, at certain general locations, due to internal pressure. In the evaluation of stresses in or adjacent to vessel openings and connections, it is often necessary to consider the effect of stresses due to external loadings or thermal stresses. In such cases, the total stress at a given point may be determined by superposition. In the case of combined stresses due to internal pressure and nozzle loading, the maximum stresses for a given location shall be considered as acting at the same point and added algebraically unless positive evidence is available to the contrary.

Figure NB-3338.2(a)-1
Direction of Stress Components

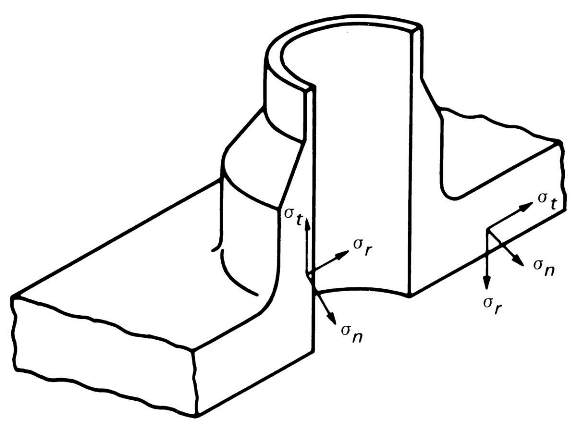


Figure NB-3338.2(a)-2
Nozzle Dimensions

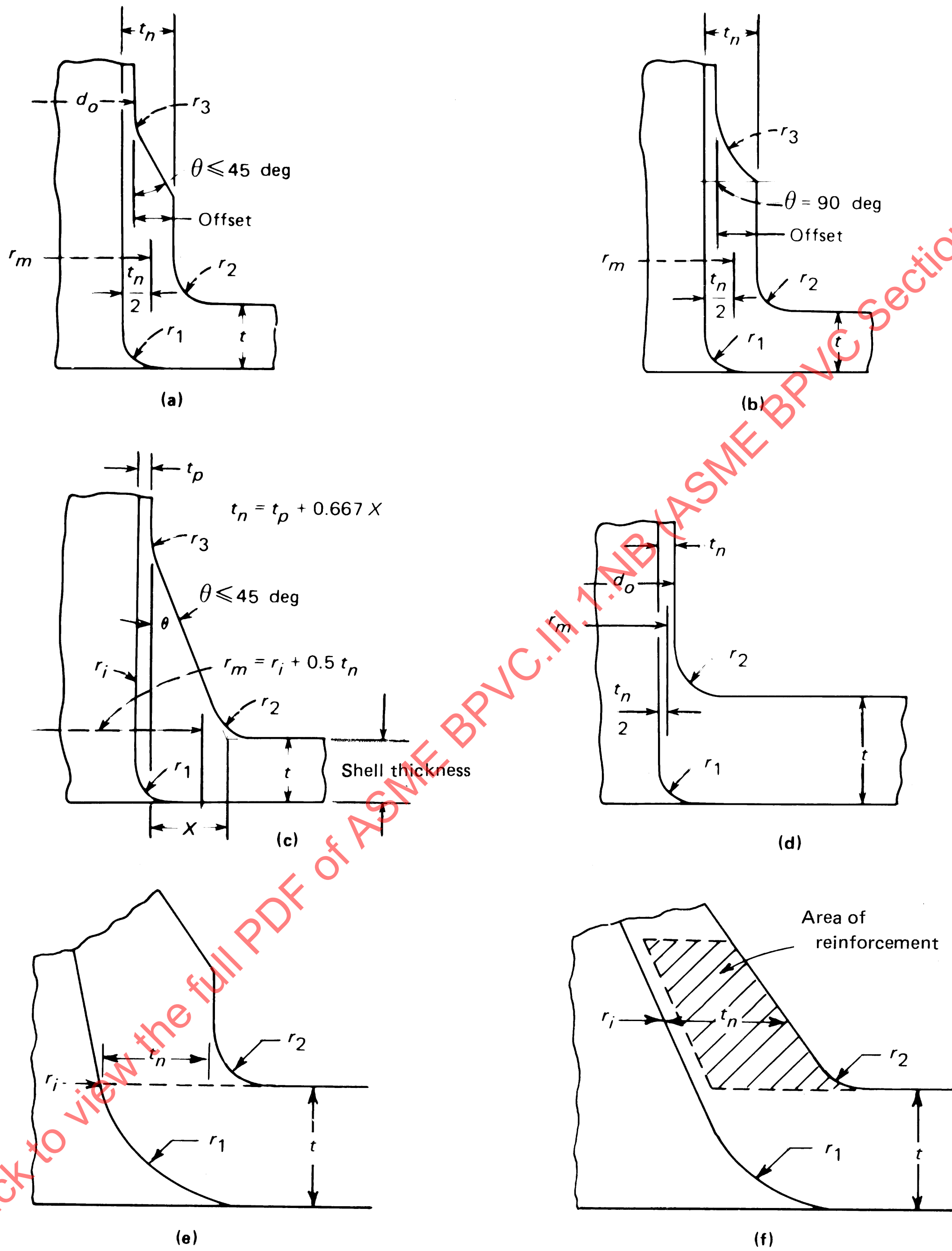


Table NB-3338.2(c)-1
Stress Indices for Nozzles

Nozzles in Spherical Shells and Formed Heads		
Stress	Inside Corner	Outside Corner
σ_n	2.0	2.0
σ_t	−0.2	2.0
σ_r	$-2t/R$	0
S	2.2	2.0

Nozzles in Cylindrical Shells				
	Longitudinal Plane		Transverse Plane	
Stress	Inside	Outside	Inside	Outside
σ_n	3.1	1.2	1.0	2.1
σ_t	−0.2	1.0	−0.2	2.6
σ_r	$-t/R$	0	$-t/R$	0
S	3.3	1.2	1.2	2.6

(d) The indices of Table NB-3338.2(c)-1 apply when the conditions stipulated in (1) through (7) below exist.

(1) The opening is for a circular nozzle whose axis is normal to the vessel wall. If the axis of the nozzle makes an angle ϕ with the normal to the vessel wall and if $d/D \le 0.15$, an estimate of the σ_n index on the inside may be obtained from one of the following equations.

For hillside connections in spheres or cylinders:

$$K_2 = K_1 \left(1 + 2 \sin^2 \phi\right)$$

For lateral connections in cylinders:

$$K_2 = K_1 \left[1 + (\tan \phi)^{4/3}\right]$$

where

K_1 = the σ_n inside stress index of Table NB-3338.2(c)-1 for a radial connection

K_2 = the estimated σ_n inside stress index for the nonradial connection

(2) The arc distance measured between the center lines of adjacent nozzles along the inside surface of the shell is not less than three times the sum of their inside radii for openings in a head or along the longitudinal axis of a shell and is not less than two times the sum of their radii for openings along the circumference of a cylindrical shell. When two nozzles in a cylindrical shell are neither in a longitudinal line nor in a circumferential arc, their center line distance along the inside surface of the shell shall be such that $\left[(L_c + 2)^2 + (L_l + 3)^2\right]^{1/2}$ is not less than the sum of their inside radii, where L_c is the component of the center line distance in the circumferential direction and L_l is the component of the center line distance in the longitudinal direction.

(3) The following dimensional ratios are met:

Ratio	Cylinder	Sphere
D/t	10 to 100	10 to 100
d/D	0.5 max.	0.5 max.
$d/\sqrt{Dt}$	...	0.8 max.
$d/\sqrt{Dt_n r_2/t}$	1.5 max.	...

where D is the inside shell diameter, t is the shell thickness, and d is the inside nozzle diameter. In the case of cylindrical shells, the total nozzle reinforcement area on the transverse axis of the connections, including any outside of the reinforcement limits, shall not exceed 200% of that required for the longitudinal axis (compared to 50% permitted by Figure NB-3332.2-1) unless a tapered transition section is incorporated into the reinforcement and the shell, meeting the requirements of NB-3361.

(4) In the case of spherical shells and formed heads, at least 40% of the total nozzle reinforcement area shall be located beyond the outside surface of the minimum required vessel wall thickness.

(5) The inside corner radius r_1 [Figure NB-3338.2(a)-2] is between 10% and 100% of the shell thickness t.

(6) The outer corner radius r_2 [Figure NB-3338.2(a)-2] is large enough to provide a smooth transition between the nozzles and the shell. In addition, for opening diameters greater than 1½ times the shell thickness in cylindrical shells and 2:1 ellipsoidal heads and greater than three shell thicknesses in spherical shells, the value of r_2 shall be not less than one-half the thickness of the shell or nozzle wall, whichever is greater.

(7) The radius r_3 [Figure NB-3338.2(a)-2] is not less than the greater of the following:

(-a) $0.002\theta d_o$, where d_o is the outside diameter of the nozzle and is as shown in Figure NB-3338.2(a)-2, and the angle θ is expressed in degrees;

(-b) $2(\sin \theta)^3$ times offset for the configuration shown in Figure NB-3338.2(a)-2, sketches (a) and (b).

NB-3339 Alternative Rules for Nozzle Design

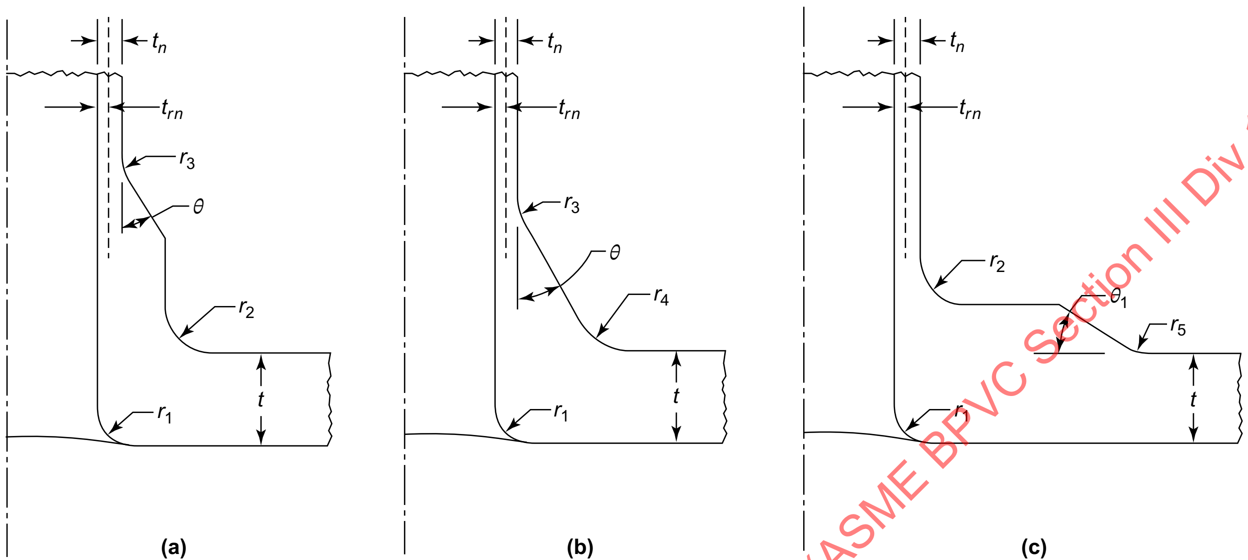
Subject to the limitations stipulated in NB-3339.1, the requirements of this paragraph constitute an acceptable alternative to the rules of NB-3332 through NB-3336 and NB-3338.

NB-3339.1 Limitations. These alternative rules are applicable only to nozzles in vessels within the limitations stipulated in (a) through (f) below.

(a) The nozzle is circular in cross-section and its axis is normal to the vessel or head surface.

(b) The nozzle and reinforcing (if required) are welded integrally into the vessel with full penetration welds. Details such as those shown in Figures NB-4244(a)-1, NB-4244(b)-1, and NB-4244(c)-1 are acceptable.

Figure NB-3339.1(b)-1
Examples of Acceptable Transition Details (23)



$r_1 = 0.1t$ to $0.5t$

$r_2 \geq$ larger of $\sqrt{dt_{rn}}$ or $t/2$

$r_3 \geq$ larger of $\left[\sqrt{(\theta/90)\,(dt_{rn})}\,\right]$ or $\left[(\theta/90)t_n\right]$

$r_4 \geq$ larger of $\left(1 - \sqrt{(\theta/90}\,\right)\sqrt{dt_{rn}}$ or $\left(1 - \theta/90\right)\left(t/2\right)$

$r_5 = (\theta\sqrt{90})t$

θ and θ_1 are in degrees

However, fillet welds shall be finished to a radius in accordance with Figure NB-3339.1(b)-1.

(c) In the case of spherical shells and formed heads, at least 40% of the total nozzle reinforcement area shall be located beyond the outside surface of the minimum required vessel wall thickness.

(d) The spacing between the edge of the opening and the nearest edge of any other opening is not less than the smaller of $1.25(d_1 + d_2)$ or $2.5\sqrt{Rt}$, but in any case not less than $d_1 + d_2$, where d_1 and d_2 are the inside diameters of the openings.

(e) The material used in the nozzle, reinforcing, and vessel adjacent to the nozzle shall have a ratio of UTS/YS of not less than 1.5, where

UTS = specified minimum ultimate tensile strength
YS = specified minimum yield strength

(f) The following dimensional limitations are met:

	Nozzles in Cylindrical Vessels	Nozzles in Spherical Vessels or Hemispherical Heads
D/t	10 to 100	10 to 100
d/D	0.5 max.	0.5 max.
$d/\sqrt{Dt}$	...	0.8 max.
$d/\sqrt{Dt_n r_2/t}$	1.5 max.	...

NB-3339.2 Nomenclature. The nomenclature used in NB-3339 is defined as follows:

A_a = available reinforcing area
A_r = required minimum reinforcing area
D = inside diameter, in corroded condition, of cylindrical vessel, spherical vessel, or spherical head
d = inside diameter, in corroded condition, of the nozzle
R = inside radius, in corroded condition, of cylindrical vessel, spherical vessel, or spherical head
t = nominal wall thickness, less corrosion allowance, of vessel or head
t_n = nominal wall thickness, less corrosion allowance, of nozzle
t_r = wall thickness of vessel or head, computed by the equations given in NB-3324.1 for cylindrical vessels and in NB-3324.2 for spherical vessels or spherical heads
t_{rn} = wall thickness of nozzle, computed by the equation given in NB-3324.1, in. (mm)

For the definitions of r_1, r_2, r_3, r_4, θ, and θ_1, see Figure NB-3339.1(b)-1; for L_c and L_n, see Figure NB-3339.4-1; for S, σ_t, σ_n, and σ_r, see NB-3338.2 and Figure NB-3338.2(a)-1.

Table NB-3339.3-1
Required Minimum Reinforcing Area, A_r

$d/\sqrt{Rt_r}$	A_r, in.^{2} (mm^2) Nozzles in Cylinders	A_r, in.^{2} (mm^2) Nozzles in Spherical Vessels or Heads
< 0.20	None [Note (1)]	None [Note (1)]
> 0.20 and < 0.40	$[4.05(d/\sqrt{Rt_r})^{1/2} - 1.81]dt_r$	$\left[5.40(d/\sqrt{Rt_r})^{1/2} - 2.41\right]dt_r$
> 0.40	$0.75dt_r$	$dt_r \cos\phi$ $\phi = \sin^{-1}(d/D)$

NOTE: (1) The transition radius r_2, shown in Figure NB-3339.1(b)-1, or the equivalent thereof is required.

NB-3339.3 Required Reinforcement Area. The required minimum reinforcing area is related to the value of $d/\sqrt{Rt_r}$ as tabulated in Table NB-3339.3-1. The required minimum reinforcing area shall be provided in all planes containing the nozzle axis.

NB-3339.4 Limits of Reinforcing Zone. Reinforcing metal included in meeting the minimum required reinforcing area specified in Table NB-3339.3-1 must be located within the reinforcing zone boundary shown in Figure NB-3339.4-1.

NB-3339.5 Strength of Reinforcing Material Requirements. Material in the nozzle wall used for reinforcing shall preferably be the same as that of the vessel wall. If material with a lower design stress intensity value S_m is used, the area provided by such material shall be increased in proportion to the inverse ratio of the stress values of the nozzle and the vessel wall material. No reduction in the reinforcing area requirement shall be taken for the increased strength of nozzle material or weld metal that has a higher design stress intensity value than that of the material of the vessel wall. The strength of the material at the point under consideration shall be used in fatigue analyses. The mean coefficient of thermal expansion of metal to be included as reinforcement shall be within 15% of the value for the metal of the vessel wall.

NB-3339.6 Transition Details. Examples of acceptable transition tapers and radii are shown in Figure NB-3339.1(b)-1. Other configurations that meet the reinforcing area requirements of NB-3339.3 and with equivalent or less severe transitions are also acceptable; e.g., larger radius–thickness ratios.

NB-3339.7 Stress Indices.

(a) The term *stress index*, as used herein, is defined as the numerical ratio of the stress components σ_t, σ_n, and σ_r, under consideration, to the computed stress σ.

(b) The nomenclature for the stress components is shown in Figure NB-3338.2(a)-1 and is defined as follows:

P = service pressure
S = stress intensity (combined stress) at the point under consideration
σ = $P(D+t)/4t$ for nozzles in spherical vessels or heads
 = $P(D+t)/2t$ for nozzles in cylindrical vessels
σ_n = stress component normal to the plane of the section (ordinarily the circumferential stress around the hole in the shell)
σ_r = stress component normal to the boundary of the section
σ_t = stress component in the plane of the section under consideration and parallel to the boundary of the section

(c) When the conditions of NB-3339.1 through NB-3339.6 are satisfied, the stress indices given in Table NB-3339.7(c)-1 may be used. These stress indices deal only with the maximum stresses, at certain general locations, due to internal pressure. In the evaluation of stresses in or adjacent to vessel openings and connections, it is often necessary to consider the effect of stresses due to external loadings or thermal stresses. In such cases, the total stress at a given point may be determined by superposition. In the case of combined stresses due to internal pressure and nozzle loading, the maximum stresses shall be considered as acting at the same point and added algebraically. If the stresses are otherwise determined by more accurate analytical techniques or by the experimental stress analysis procedure of Section III Appendices, Mandatory Appendix II, the stresses are also to be added algebraically.

NB-3340 ANALYSIS OF VESSELS

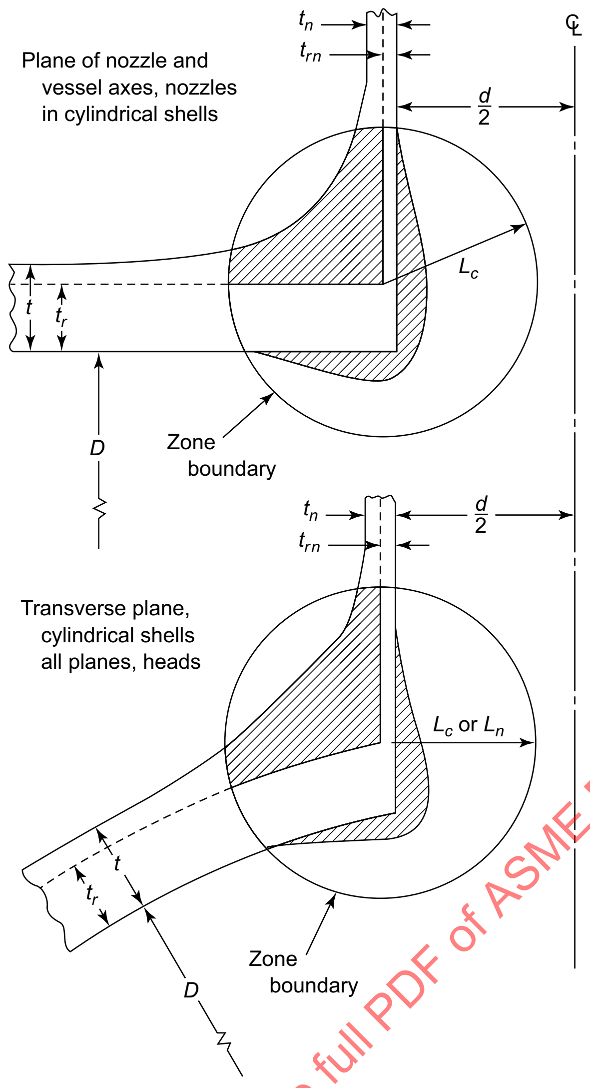
The provisions of Section III Appendices, Mandatory Appendix XIII, XIII-2100(a) apply.

NB-3350 DESIGN OF WELDED CONSTRUCTION

NB-3351 Welded Joint Category

The term *Category* defines the location of a joint in a vessel, but not the type of joint. The categories established are for use in specifying special requirements regarding

(23) **Figure NB-3339.4-1**
Limits of Reinforcing Zone



GENERAL NOTES:

(a) *Reinforcing Zone Limit*

(1) For nozzles in cylindrical shells: $L_c = 0.75\,(t/D)^{2/3}D$

(2) For nozzles in heads: $L_n = (t/D)^{2/3}\left(d/D + 0.5\right)D$

(3) The center of L_c or L_n is at the juncture of the outside surfaces of the shell and nozzles of thickness t_r and t_{rn}.

(4) In constructions where the zone boundary passes through a uniform thickness wall segment, the zone boundary may be considered as L_c or L_n through the thickness.

(b) *Reinforcing Area*

(1) Hatched areas represent available reinforcement area A_a.

(2) Metal area within the zone boundary, in excess of the area formed by the intersection of the basic shells, shall be considered as contributing to the required area A_r. The basic shells are defined as having inside diameter D, thickness t_r, inside diameter of the nozzle d, and thickness t_{rn}.

(3) The available reinforcement area A_a shall be at least equal to $A_r/2$ on each side of the nozzle center line and in every plane containing the nozzle axis.

Table NB-3339.7(c)-1
Stress Indices for Internal Pressure Loading

Nozzles in Spherical Shells and Spherical Heads		
Stress	Inside	Outside
σ_n	$2.0 - d/D$	$2.0 - d/D$
σ_t	-0.2	$2.0 - d/D$
σ_r	$-4t/(D + t)$	0
S	Larger of: $2.2 - d/D$ or $2.0 + [4t/(D + t)] - d/D$	$2.0 - d/D$

Nozzles in Cylindrical Shells				
	Longitudinal Plane		Transverse Plane	
Stress	Inside	Outside	Inside	Outside
σ_n	3.1	1.2	1.0	2.1
σ_t	-0.2	1.0	-0.2	2.6
σ_r	$-2t/(D + t)$	0	$-2t/(D + t)$	0
S	3.3	1.2	1.2	2.6

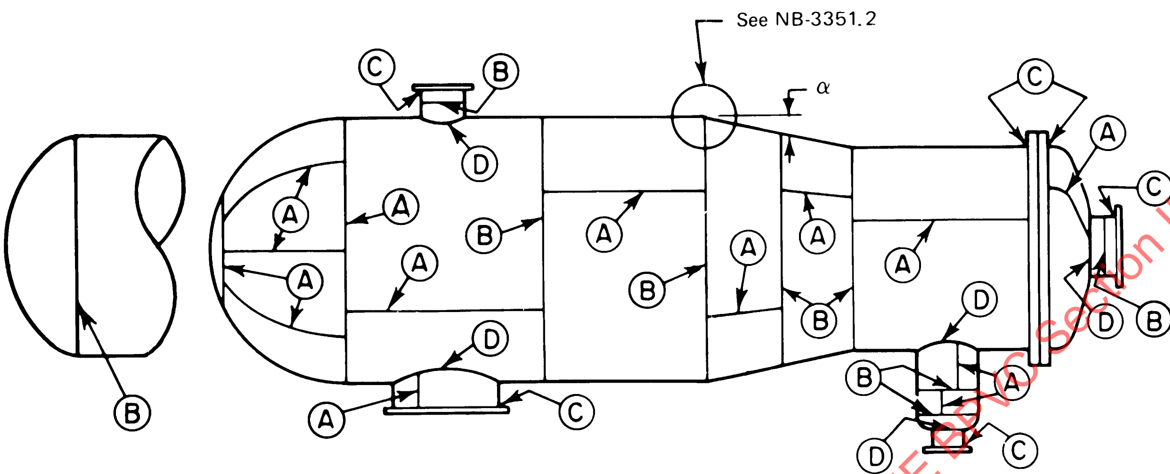
joint type and degree of examination for certain welded joints. Since these special requirements, which are based on service, material, and thickness, do not apply to every welded joint, only those joints to which special requirements apply are included in the categories. The special requirements apply to joints of a given category only when specifically stated. The joints included in each category are designated as joints of Categories A, B, C, and D. Figure NB-3351-1 illustrates typical joint locations included in each category.

NB-3351.1 Category A. Category A comprises longitudinal welded joints within the main shell, communicating chambers,[8] transitions in diameter, or nozzles; any welded joint within a sphere, within a formed or flat head, or within the side plates[9] of a flat sided vessel; and circumferential welded joints connecting hemispherical heads to main shells, to transitions in diameters, to nozzles, or to communicating chambers.

NB-3351.2 Category B. Category B comprises circumferential welded joints within the main shell, communicating chambers, nozzles, or transitions in diameter, including joints between the transition and a cylinder at either the large or small end; and circumferential welded joints connecting formed heads other than hemispherical to main shells, to transitions in diameter, to nozzles, or to communicating chambers.

NB-3351.3 Category C. Category C comprises welded joints connecting flanges, Van Stone laps, tubesheets, or flat heads to main shell, to formed heads, to transitions in diameter, to nozzles, or to communicating chambers[8] any welded joint connecting one side plate[9] to another side plate of a flat sided vessel.

Figure NB-3351-1
Welded Joint Locations Typical of Categories A, B, C, and D



NB-3351.4 Category D. Category D comprises welded joints connecting communicating chambers 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. For nozzles at the small end of a transition in diameter, see Category B.

NB-3352 Permissible Types of Welded Joints

The design of the vessel shall meet the requirements for each category of joint. Butt joints are full penetration joints between plates or other elements that lie approximately in the same plane. Category B angle joints between plates or other elements that have an offset angle α not exceeding 30 deg are considered as meeting the requirements for butt joints. Figure NB-3352-1 shows typical butt welds for each category joint.

NB-3352.1 Joints of Category A. All welded joints of Category A as defined in NB-3351 shall meet the fabrication requirements of NB-4241 and shall be capable of being examined in accordance with NB-5210.

NB-3352.2 Joints of Category B. All welded joints of Category B as defined in NB-3351 shall meet the fabrication requirements of NB-4242 and shall be capable of being examined in accordance with NB-5220. When joints with opposing lips to form an integral backing strip or joints with backing strips not later removed are used, the suitability for cyclic service shall be analyzed by the method of Section III Appendices, Mandatory Appendix XIII, XIII-3500 using a fatigue strength reduction factor of not less than 2.

NB-3352.3 Joints of Category C. All welded joints of Category C as defined in NB-3351 shall meet the fabrication requirements of NB-4243 and shall be capable of being examined in accordance with NB-5230. Minimum dimensions of the welds and throat thickness shall be as shown in Figure NB-4243-1, where:

(a) for forged tubesheets, forged flat heads, and forged flanges with the weld preparation bevel angle not greater than 45 deg measured from the face:

t, t_n = nominal thicknesses of welded parts
t_c = $0.7t_n$ or $\frac{1}{4}$ in. (6 mm), whichever is less
t_w = $t_n/2$ or $t/4$, whichever is less

(b) for all other material forms and for forged tubesheets, forged flat heads, and forged flanges with the weld preparation bevel angle greater than 45 deg measured from the face:

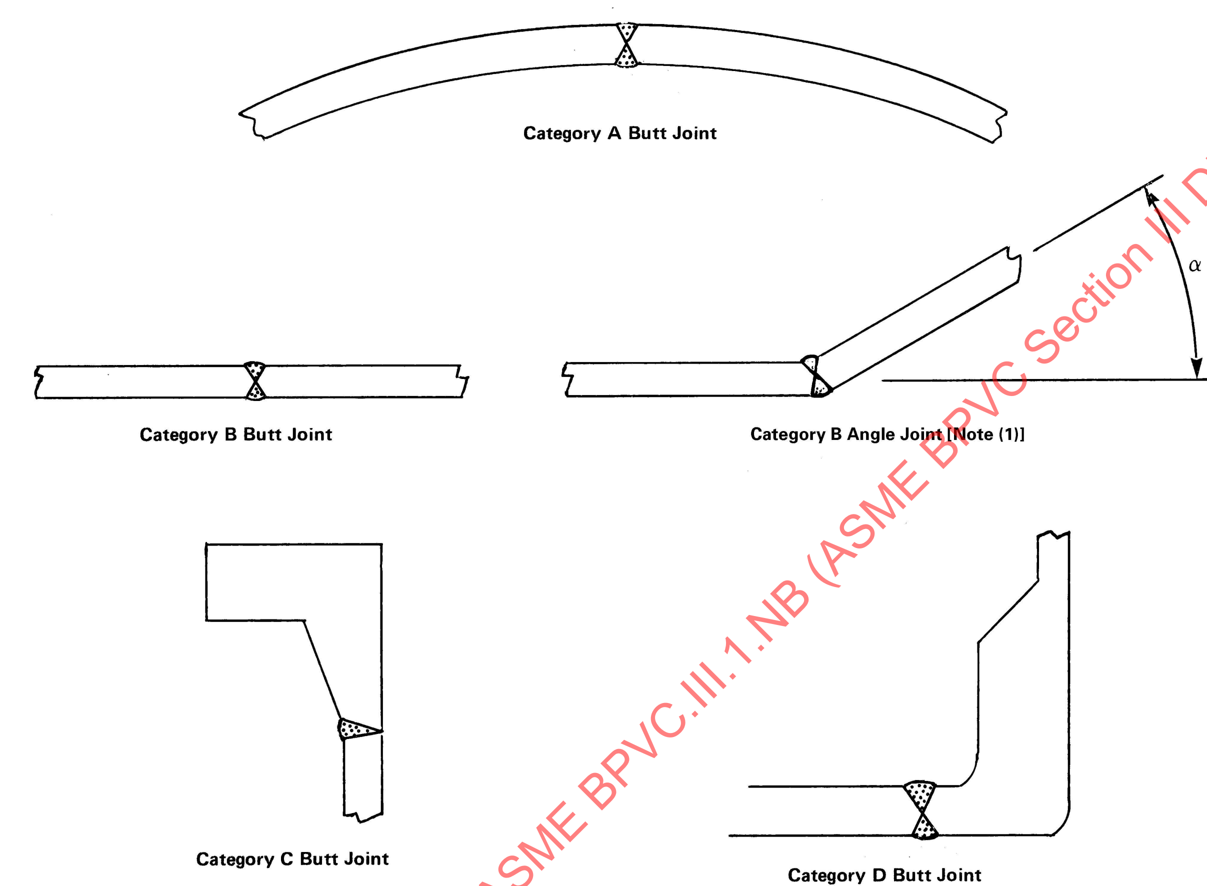
t, t_n = nominal thicknesses of welded parts
t_c = $0.7t_n$ or $\frac{1}{4}$ in. (6 mm), whichever is less
t_w = t_n or $t/2$, whichever is less

NB-3352.4 Joints of Category D. All welded joints of Category D as defined in NB-3351 shall be in accordance with the requirements of one of (a) through (e) below.

(a) Butt-Welded Nozzles. Nozzles shall meet the fabrication requirements of NB-4244(a) and shall be capable of being examined in accordance with NB-5242. The minimum dimensions and geometrical requirements of Figure NB-4244(a)-1 shall be met, where

r_1 = $\frac{1}{4}t$ or $\frac{3}{4}$ in. (19 mm), whichever is less
r_2 = $\frac{1}{4}$ in. (6 mm) minimum
t = nominal thickness of part penetrated
t_n = nominal thickness of penetrating part

Figure NB-3352-1
Typical Butt Joints



NOTE: (1) When α does not exceed 30 deg, joint meets requirements for butt joints.

(b) Full Penetration Corner-Welded Nozzles. Nozzles shall meet the fabrication requirements of NB-4244(b) and shall be capable of being examined as required in NB-5243. The minimum dimensions of Figure NB-4244(b)-1 shall be met, where

r_1 = $\frac{1}{4}t$ or $\frac{3}{4}$ in. (19 mm), whichever is less
r_2 = $\frac{1}{4}$ in. (6 mm) minimum
t = nominal thickness of part penetrated
t_c = $0.7t_n$ or $\frac{1}{4}$ in. (6 mm), whichever is less
t_n = nominal thickness of penetrating part

(c) Use of Deposited Weld Metal for Openings and Nozzles

(1) Nozzles shall meet the fabrication requirements of NB-4244(c) and shall be capable of being examined in accordance with NB-5244.

(2) When the deposited weld metal is used as reinforcement, the coefficients of thermal expansion of the base metal, the weld metal, and the nozzle shall not differ by more than 15% of the lowest coefficient involved.

(3) The minimum dimensions of Figure NB-4244(c)-1 shall be met, where

r_1 = $\frac{1}{4}t$ or $\frac{3}{4}$ in. (19 mm), whichever is less
t = nominal thickness of part penetrated
t_c = $0.7t_n$ or $\frac{1}{4}$ in. (6 mm), whichever is less
t_n = nominal thickness of penetrating part

(4) The corners of the end of each nozzle neck extending less than $\sqrt{dt_n}$ beyond the inner surface of the part penetrated shall be rounded to a radius of one-half the thickness t_n of the nozzle neck or $\frac{3}{4}$ in. (19 mm), whichever is smaller.

(d) Attachment of Nozzles Using Partial Penetration Welds

(1) Partial penetration welds used to connect nozzles as permitted in NB-3337.3 shall meet the fabrication requirements of NB-4244(d) and shall be capable of being examined in accordance with the requirements of NB-5245.

(2) The minimum dimensions of Figures NB-4244(d)-1 and NB-4244(d)-2 shall be met, where

d = outside diameter of nozzle or of the inner cylinder as shown in Figure NB-4244(d)-2
r_1 = $^1/_4 t_n$ or $^3/_4$ in. (19 mm), whichever is less
r_2 = $^1/_{16}$ in. (1.5 mm) minimum
r_3 = r_2 or equivalent chamfer minimum
r_4 = $^1/_2 t_n$ or $^3/_4$ in. (19 mm), whichever is less
t = nominal thickness of part penetrated
t_c = $0.7t_n$ or $^1/_4$ in. (6 mm), whichever is less
t_n = nominal thickness of penetrating part or the lesser of t_{n1} or t_{n2} in Figure NB-4244(d)-2
λ = $^1/_{16}$ in. (1.5 mm) minimum
λ = t_n maximum

(3) The corners of the end of each nozzle neck, extending less than $\sqrt{dt_n}$ beyond the inner surface of the part penetrated, shall be rounded to a radius of one-half of the thickness t_n of the penetrating part or $^3/_4$ in. (19 mm), whichever is smaller.

(4) Weld groove design for partial penetration joints attaching nozzles may require special consideration to achieve the minimum depth of weld and adequate access for welding examination. The welds shown in the sketches of Figures NB-4244(d)-1 and NB-4244(d)-2 may be on either the inside or the outside of the vessel shell. Weld preparation may be J-groove as shown in the figures or straight bevel.

(5) A fatigue strength reduction factor of not less than four shall be used when fatigue analysis is required.

(e) Oblique Full Penetration Nozzles. Internal or external nozzles shall meet the fabrication requirements of NB-4244(e) and shall be capable of being examined in accordance with NB-5246.

NB-3353 Tube-to-Tubesheet Welds

All tube-to-tubesheet welds shall meet the fabrication requirements of NB-4350 and shall be examined as required by NB-5274. Pressure boundary tube-to-tubesheet welds shall satisfy the applicable requirements of Section III Appendices, Mandatory Appendix XIII, Article XIII-3000 considering the loadings of NB-3110.

NB-3354 Structural Attachment Welds

Welds for structural attachments shall meet the requirements of NB-4430.

NB-3355 Welding Grooves

The dimensions and shape of the edges to be joined shall be such as to permit complete fusion and complete joint penetration, except as otherwise permitted in NB-3352.4.

NB-3357 Thermal Treatment

All vessels and vessel parts shall be given the appropriate postweld heat treatment prescribed in NB-4620.

NB-3360 SPECIAL VESSEL REQUIREMENTS

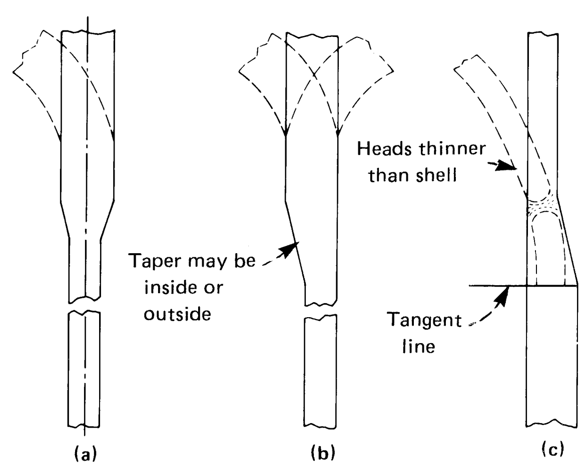
NB-3361 Category A and B Joints Between Sections of Unequal Thickness

In general, a tapered transition section as shown in Figure NB-3361-1, which is a type of gross structural discontinuity [Section III Appendices, Mandatory Appendix XIII, XIII-1300(i)], shall be provided at joints of Categories A and B between sections that differ in thickness by more than one-fourth the thickness of the thinner section. The transition section may be formed by any process that will provide a uniform taper. An ellipsoidal or hemispherical head that has a greater thickness than a cylinder of the same inside diameter may be machined to the outside diameter of the cylinder provided the remaining thickness is at least as great as that required for a shell of the same diameter. A uniform taper is not required for flanged hubs. The adequacy of the transition shall be evaluated by stress analysis. Stress intensity limitations are given in Section III Appendices, Mandatory Appendix XIII, Article XIII-3000. The requirements of this paragraph do not apply to flange hubs.

NB-3362 Bolted Flange Connections

It is recommended that the dimensional requirements of bolted flange connections to external piping conform to ASME B16.5, Steel Pipe Flanges and Flanged Fittings.

Figure NB-3361-1
Category A and B Joints Between Sections of Unequal Thickness



GENERAL NOTE: Length of taper may include the width of the weld.

NB-3363 Access Openings

Access openings, where provided, shall consist of handhole or manhole openings having removable covers. These may be located on either the inside or outside of the shell or head openings and may be attached by studs or bolts in combination with gaskets or welded membrane seals or strength welds. Plugs using pipe threads are not permitted.

NB-3364 Attachments

Attachments used to transmit support loads shall meet the requirements of NB-3135.

NB-3365 Supports

All vessels shall be so supported and the supporting members shall be arranged and attached to the vessel wall in such a way as to provide for the maximum imposed loadings. The stresses produced in the vessel by such loadings and by steady state and transient thermal conditions shall be subjected to the stress limits of this Subsection. Additional requirements are given in NCA-3211.18 and Subsection NF.

NB-3400 PUMP DESIGN

NB-3410 GENERAL REQUIREMENTS FOR CENTRIFUGAL PUMPS

NB-3411 Scope

(23) **NB-3411.1 Applicability.** The rules of NB-3400 apply to (a) through (n) below.

(a) pump casings
(b) pump inlets and outlets
(c) pump covers
(d) clamping rings
(e) seal housing and seal glands
(f) related bolting
(g) pump internal heat exchanger piping
(h) pump auxiliary nozzle connections up to the face of the first flange or circumferential joint in welded connections, excluding the connecting weld
(i) piping identified with the pump and external to and forming part of the pressure-retaining boundary and supplied with the pump
(j) mounting feet or pedestal supports when integrally attached to the pump pressure-retaining boundary and supplied with the pump
(k) driver casings (Type M pumps only)
(l) driver covers (Type M pumps only)
(m) pressure-retaining parts of the electrical and instrument penetrations (Type M pumps only)
(n) pressure-retaining boundaries of the driver heat exchangers (Type M pumps only)

NB-3411.2 Exemptions. The rules of NB-3400 do not apply to (a) through (c) below.

(a) pump shafts and impellers; shafts may be designed in accordance with Section III Appendices, Nonmandatory Appendix S
(b) nonstructural internals
(c) seal packages

NB-3412 Acceptability

NB-3412.1 Acceptability of Large Pumps. The requirements for the design acceptability of pumps having an inlet connection greater than NPS 4 (DN 100) diameter are given in (a), (b), and (c) below.

(a) The design shall be such that the requirements of NB-3100 and of NB-3200 or Section III Appendices, Mandatory Appendix II (provided the requirements of NB-3414 and the minimum wall thicknesses of NB-3430 are met) are satisfied.

(b) The rules of this subarticle shall be met. In cases of conflict between NB-3100 and NB-3200 or Section III Appendices, Mandatory Appendix II and NB-3400, the requirements of NB-3400 apply.

(c) The requirements for prevention of nonductile fracture as set forth in NB-3210(d) shall be met.

NB-3412.2 Acceptability of Small Pumps. The requirements for the design acceptability of pumps having an inlet connection 4 in. nominal pipe size (DN 100) diameter or smaller are given in (a) and (b) below.

(a) The design shall be such that the requirements of NB-3100 or Section III Appendices, Mandatory Appendix II are satisfied.

(b) The rules of this subarticle shall be met. In cases of conflict between NB-3100 or Section III Appendices, Mandatory Appendix II and NB-3400, the requirements of this subarticle shall apply.

NB-3414 Design and Service Conditions

The general design considerations, including definitions of NB-3100 plus the requirements of NB-3320, NB-3330, NB-3361, and NB-3362 are applicable to pumps.

NB-3415 Loads From Connected Piping

(a) Loads imposed on pump inlets and outlets by connected piping shall be considered in the pump casing design. The forces and moments produced by the connected piping on each pump inlet and outlet shall be provided by the Owner in the Design Specifications.

(b) Stresses generated in the pump casing by the connected piping shall be combined with the pressure stresses in accordance with the requirements of NB-3200.

NB-3417 Earthquake Loadings

(a) The effects of earthquake shall be considered in the design of pumps, pump supports, and restraints. The stresses resulting from these earthquake effects shall be included with the stresses resulting from pressure or other applied loads.

(b) Where pumps are provided with drivers on extended supporting structures and these structures are essential to maintaining pressure integrity, an analysis shall be performed when required by the Design Specifications.

NB-3418 Corrosion

The requirements of NB-3121 apply.

NB-3419 Cladding

Cladding dimensions used in the design of pumps shall be required as in NB-3122.

NB-3420 DEFINITIONS

NB-3421 Radially Split Casing

A radially split casing shall be interpreted as one in which the primary sealing joint is radially disposed around the shaft.

NB-3422 Axially Split Casing

An axially split casing shall be interpreted as one in which the primary sealing joint is axially disposed with respect to the shaft.

NB-3423 Single and Double Volute Casings

Figures NB-3423-1 and NB-3423-2 show typical single and double volute casings, respectively.

NB-3424 Seal Housing

Seal housing is defined as that portion of the pump cover or casing assembly that contains the seal and forms a part of the primary pressure boundary.

NB-3425 Typical Examples of Pump Types

Figures NB-3441.1-1 through NB-3441.6(a)-1 are typical examples to aid in the determination of pump type and are not to be considered as limiting.

NB-3430 DESIGN REQUIREMENTS FOR CENTRIFUGAL PUMPS

NB-3431 Design of Welding

(a) The design of welded construction shall be in accordance with NB-3350.

(b) Partial penetration welds are permitted for piping connections NPS 2 (DN 50) and less when the requirements of NB-3337.3 and NB-3352.4(d) are met.

NB-3432 Cutwater Tip Stresses

(a) It is recognized that localized high stresses may occur at the cutwater tips of volute casings (Figure NB-3441.3-2). Adequacy of the design in this area shall be demonstrated either by an investigation through experimental stress analysis in accordance with Section III Appendices, Mandatory Appendix II or by detailing satisfactory service performance of other pumps under similar operating conditions.

(b) Where experimental stress analysis is used, stress intensity at this point shall meet the requirements of Section III Appendices, Mandatory Appendix XIII, XIII-3400, XIII-3500, XIII-3700, and XIII-3800.

NB-3433 Reinforcement of Pump Casing Inlets and Outlets

NB-3433.1 Axially Oriented Inlets and Outlets.

(a) An axially oriented pump casing inlet or outlet shall be considered similar to an opening in a vessel and shall be reinforced. It shall be treated as required in NB-3331 through NB-3336.

(b) To avoid stress concentrations, the outside radius r_2 in Figure NB-3441.3-2 shall not be less than one-half the thickness of the inlets and outlets as reinforced.

NB-3433.2 Radially Oriented Inlets and Outlets. Reinforcement of radially oriented inlets and outlets in accordance with the rules of NB-3331 through NB-3336 is required.

Figure NB-3423-1
Typical Single Volute Casing

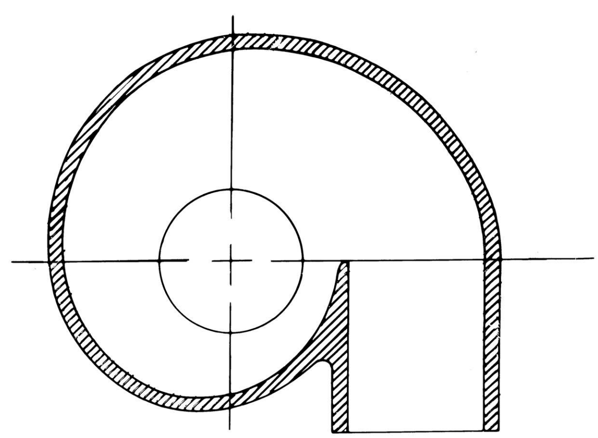


Figure NB-3423-2
Typical Double Volute Casing

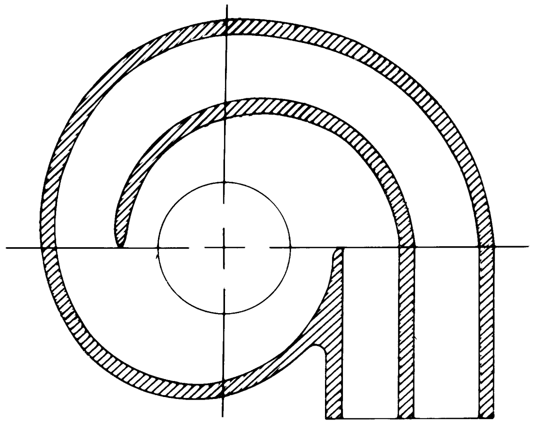
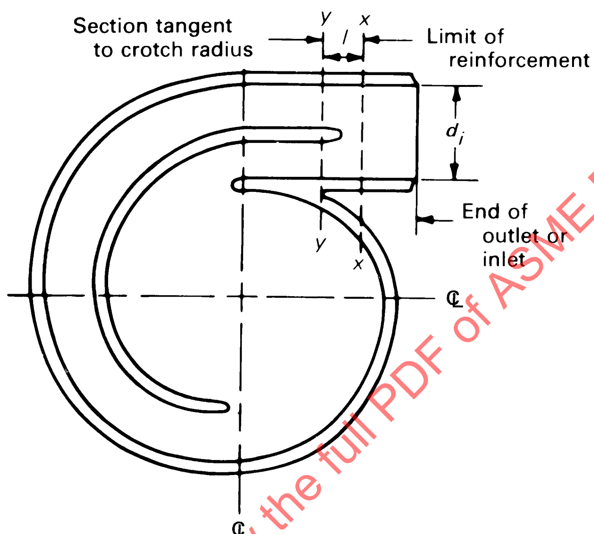


Figure NB-3433.4-1
Minimum Tangential Inlet and Outlet Wall Thickness



NB-3433.3 Tangential Inlets and Outlets. Except as modified in NB-3433.4, any design that has been demonstrated to be satisfactory for the specified Design Loadings may be used.

NB-3433.4 Minimum Inlet and Outlet Wall Thicknesses. The wall thickness of the inlet or outlet shall not be less than the minimum wall thickness of the casing for a distance l as shown in Figure NB-3433.4-1. The wall thickness beyond the distance l may be reduced to the minimum wall thickness of the connected piping. The change in wall thickness shall be gradual and have a maximum slope as indicated in Figure NB-4250-1. The distance l in Figure NB-3433.4-1 is the limit of reinforcement. The value of l, in. (mm), shall be determined from the relationship:

$$l = 0.5\sqrt{r_m t_m}$$

where

r_i = inlet or outlet inside radius, in. (mm)
= $d_i/2$
r_m = $r_i + 0.5t_m$, in. (mm)
t_m = mean inlet or outlet wall thickness, in. (mm), taken between section x–x and a parallel section y–y

NB-3434 Bolting

Bolting in axisymmetric arrangements involving the pressure boundary shall be designed in accordance with Section III Appendices, Mandatory Appendix XIII, Article XIII-4000.

NB-3435 Piping

NB-3435.1 Piping Under External Pressure. Piping located within the pressure-retaining boundary of the pump shall be designed in accordance with NB-3133.

NB-3435.2 Piping Under Internal Pressure. Piping identified with the pump and external to or forming a part of the pressure-retaining boundary, such as auxiliary water connections, shall be designed in accordance with NB-3600.

NB-3436 Attachments

(a) External and internal attachments to pumps shall be designed so as not to cause excessive localized bending stresses or harmful thermal gradients in the pump as determined by the rules of NB-3200. Such attachments shall be designed to minimize stress concentrations in applications where the number of stress cycles, due either to pressure or thermal effect, is relatively large for the expected life of the equipment.

(b) Attachments shall meet the requirements of NB-3135.

NB-3437 Pump Covers

Pump covers shall be designed in accordance with NB-3200.

NB-3438 Supports

Pump supports shall be designed in accordance with the requirements of Subsection NF unless included under the rules of NB-3411.1(j).

NB-3440 DESIGN OF SPECIFIC PUMP TYPES

NB-3441 Standard Pump Types

NB-3441.1 Design of Type A Pumps. Type A pumps are those having single volutes and radially split casings with single suction, as illustrated in Figures NB-3441.1-1 and NB-3441.1-2. Their design shall be in accordance with the requirements of this subarticle.

NB-3441.2 Design of Type B Pumps. Type B pumps are those having single volutes and radially split casings with double suction, as illustrated in Figure NB-3441.2-1. Their design shall be in accordance with the requirements of this subarticle.

NB-3441.3 Design of Type C Pumps. Type C pumps are those having double volutes and radially split casings with single suction, as illustrated in Figures NB-3441.3-1 and NB-3441.3-2. The splitter is considered a structural part of the casing. Casing design shall be in accordance with the requirements of this subarticle and with those given in (a) through (d) below.

(a) Casing Wall Thickness. Except where specifically indicated in these rules, no portion of the casing wall shall be thinner than the value of t determined as follows:

$$t = (0.63 \times P \times A)/S_m$$

where

A = scroll dimension inside casing as shown in Figure NB-3441.3-2, in. (mm)
P = Design Pressure, psig (MPa gage)
S_m = allowable stress intensity for casing material at Design Temperature, psi (MPa)
t = minimum allowable wall thickness, in. (mm)

(b) Splitter Wall Thickness

(1) The splitter shall have a minimum wall thickness of t as determined above for the casing wall and shall extend from point B in Figure NB-3441.3-2 through a minimum angle of 135 deg to point C. Beyond point C, the splitter wall may be reduced in thickness and tapered to blend with the cutwater tip radius.

(2) Cutwater tip and splitter tip radii shall not be less than $0.05t$.

(3) All cutwater and splitter fillets, including the tips, where they meet the casing wall, shall have a minimum radius of $0.10t$ or 0.25 in. (6 mm), whichever is greater.

(c) Crotch Radius (Figure NB-3441.3-2). The crotch radius shall not be less than $0.3t$.

(d) Bottom of Casing

(1) That section of the pump casing within the diameter defined by dimension A in Figure NB-3441.3-2 on the inlet side of the casing, normally referred to as the bottom of the casing (see Figure NB-3441.3-1), shall have a wall thickness no less than the value of t determined in (a) above.

(2) The casing surface shall be analyzed in accordance with an acceptable procedure, such as that shown for flat heads in Section III Appendices, Nonmandatory Appendix A, Article A-5000, or by an experimental stress technique, such as described in Section III Appendices, Mandatory Appendix II.

(3) The minimum permissible thickness of the bottom of the casing shall be the lesser of the value determined by the analysis in (2) above and the value obtained from the calculation shown in (a) above.

NB-3441.4 Design of Type D Pumps.

(a) Type D pumps are those having double volutes and radially split casings with double suction as illustrated in Figure NB-3441.4(a)-1. The design shall be in accordance with this subarticle.

(b) The requirements of NB-3441.3(a), NB-3441.3(b), and NB-3441.3(c), governing casing wall thickness, splitter wall thickness, and crotch radius, apply.

(c) In the casing portion between the cover and the casing wall, a wall thickness in excess of t may be required.

NB-3441.5 Design of Type E Pumps. Type E pumps are those having volute type radially split casings and multivane diffusers that form structural parts of the casing as illustrated in Figure NB-3441.5-1. The design shall be in accordance with this subarticle.

NB-3441.6 Design of Type F Pumps.

(a) Type F pumps are those having radially split, axisymmetric casings with either tangential or radial outlets as illustrated in Figure NB-3441.6(a)-1. The basic configuration of a Type F pump casing is a shell with a dished head attached at one end and a bolting flange at the other. The inlet enters through the dished head, and the outlet may be either tangent to the side or normal to the center line of the casing. Variations of these inlet and outlet locations are permitted.

(b) The design of Type F pumps shall be in accordance with this subarticle.

Figure NB-3441.1-1
Type A Pump

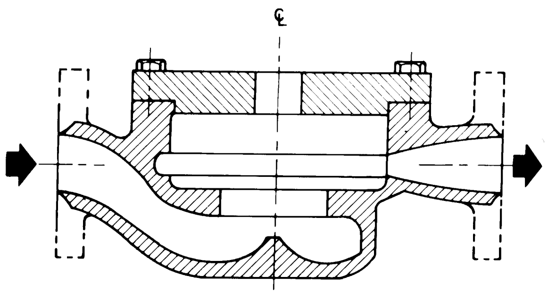


Figure NB-3441.3-1
Type C Pump

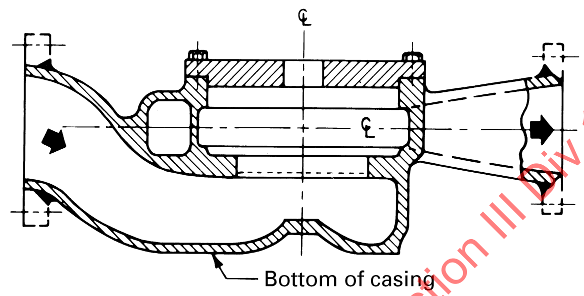


Figure NB-3441.1-2
Type A Pump

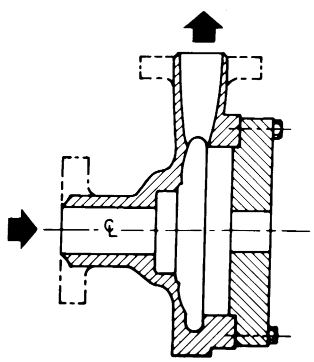


Figure NB-3441.2-1
Type B Pump

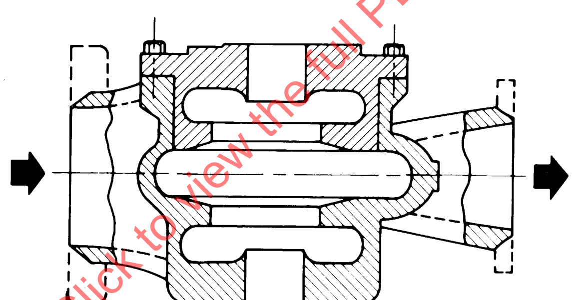


Figure NB-3441.3-2
Type C Pump

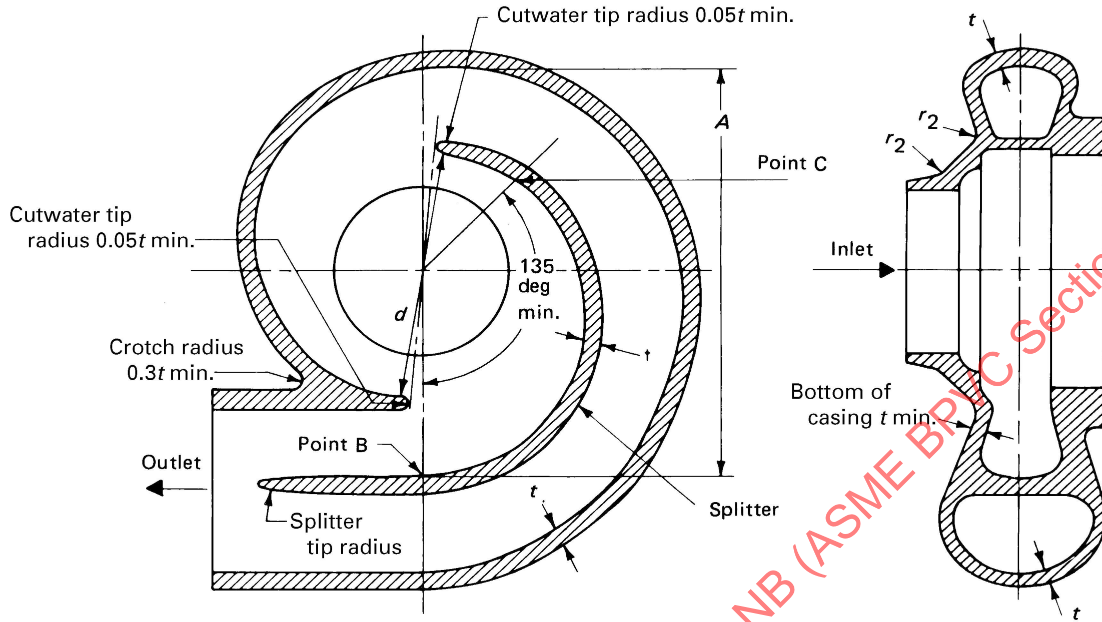


Figure NB-3441.4(a)-1
Type D Pump

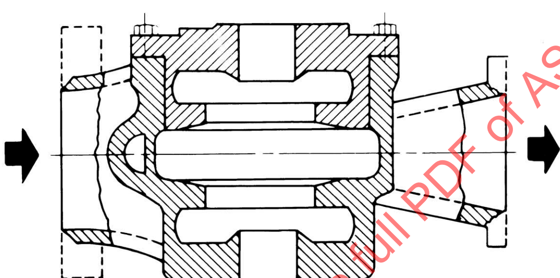


Figure NB-3441.5-1
Type E Pump

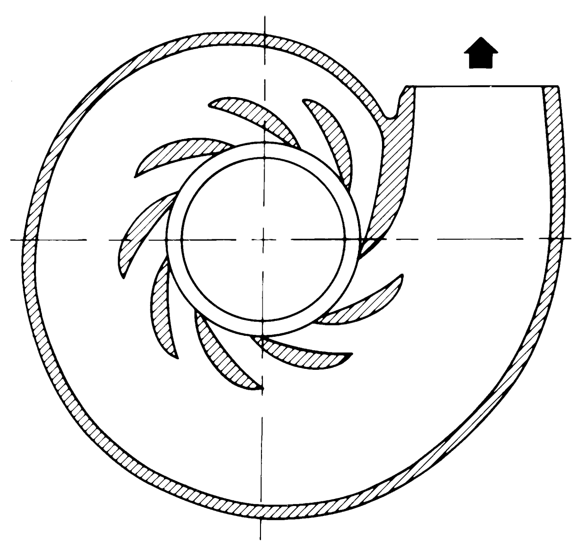
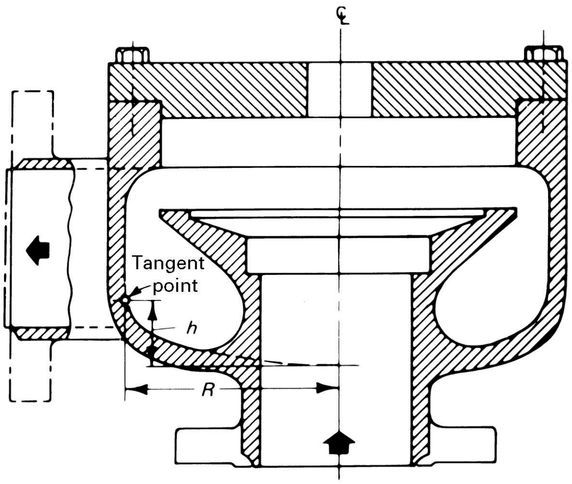


Figure NB-3441.6(a)-1
Type F Pump



(23) **NB-3441.7 Design of Type M Pumps.**

(a) Type M pumps typify glandless type of pumps. With glandless pumps the enclosure of the driver (motors or turbines) are integral or bolted to the pump casing (see Figure NB-3441.7-1) or welded to a vessel that contains the pump impeller and diffuser (see Figure NB-3441.7-2). In both cases the driver enclosure is at the same pressure as the pump enclosure and is to be designed as a pressure boundary item. In installations shown in Figure NB-3441.7-2, the pumps do not have a separate and distinct pump casing with inlet/outlet nozzles, volute casing, or barrel. The pump impeller and diffuser may be located within the larger pressure vessel, which supports the driver enclosure. The pump shaft exits an opening in the pump casing or the pressure vessel and couples the impeller to the driver. In installations shown in Figure NB-3441.7-1, there is a regular pump casing that is to be designed to the rules of this Article (see NB-3400). In addition to the driver casing, a heat exchanger may be required to cool the driver. The heat exchanger is connected to the driver casing by piping. The driver casing, piping, and heat exchanger are exposed to the same pressure as the pump casing or the vessel that contains the impeller.

(b) Examples of typical Type M pump configurations are illustrated in Figures NB-3441.7-1 and NB-3441.7-2. The common pump pressure boundary shown in both figures includes the driver casing, driver covers, pressure-retaining parts of the electrical and instrument penetrations, piping, and the driver heat exchanger. In Figure NB-3441.7-1, the pump pressure boundary also includes the pump casing while in Figure NB-3441.7-2, the pump pressure boundary begins at the attachment point of the driver casing to the main vessel (such as reactor pressure vessel or steam generator). The design of the functional part of the pump and motor such as the impeller, shaft, coupling, rotor, stator, and instruments are not governed by ASME Code rules.

(c) The Class 1, Type M pump pressure boundaries shall be designed and constructed in accordance with the requirements of this subarticle with the following additional requirements:

(1) Driver casings shall be designed in accordance with NB-3200.

(2) Driver covers shall be designed in accordance with NB-3200.

(3) Pressure-retaining parts of the electrical and instrument penetrations shall be designed in accordance with NB-3200 or NB-3300.

(4) Pressure-retaining parts of the driver heat exchanger shall be designed in accordance with NB-3200 or NB-3300.

NB-3442 Special Pump Types — Type J Pumps

(a) Type J pumps are those that cannot logically be classified with any of the preceding types.

(b) Any design method that has been demonstrated to be satisfactory for the specified Design Conditions may be used.

NB-3500 VALVE DESIGN

NB-3510 ACCEPTABILITY

NB-3511 General Requirements[10]

The requirements for design acceptability for valves, except for direct spring-loaded pressure relief valves, shall be those given in this subarticle. Refer to NB-3590 for the design rules for direct spring-loaded pressure relief valves. These requirements for the acceptability of a valve design are not intended to ensure the functional adequacy of the valve. In all cases, pressure–temperature rating shall be as given in NB-3530 and, except for NB-3512.2(d) and in local regions (Section III Appendices, Mandatory Appendix XIII, XIII-3120), the wall thickness of the valve body shall not be less than that given by NB-3541. The requirements for prevention of nonductile fracture as set forth in NB-3210(d) shall be met. The requirements of NCA-3211.19(c)(1)(-a) for specifying the location of valve boundary jurisdiction may be considered to have been met by employing the minimum limits of NB-1131, unless the Design Specification extends the boundary of jurisdiction beyond these minimum limits. The requirements of NCA-3211.19(c)(1)(-b) for

(23)

Figure NB-3441.7-1
Typical Type M Pump With Volute Case

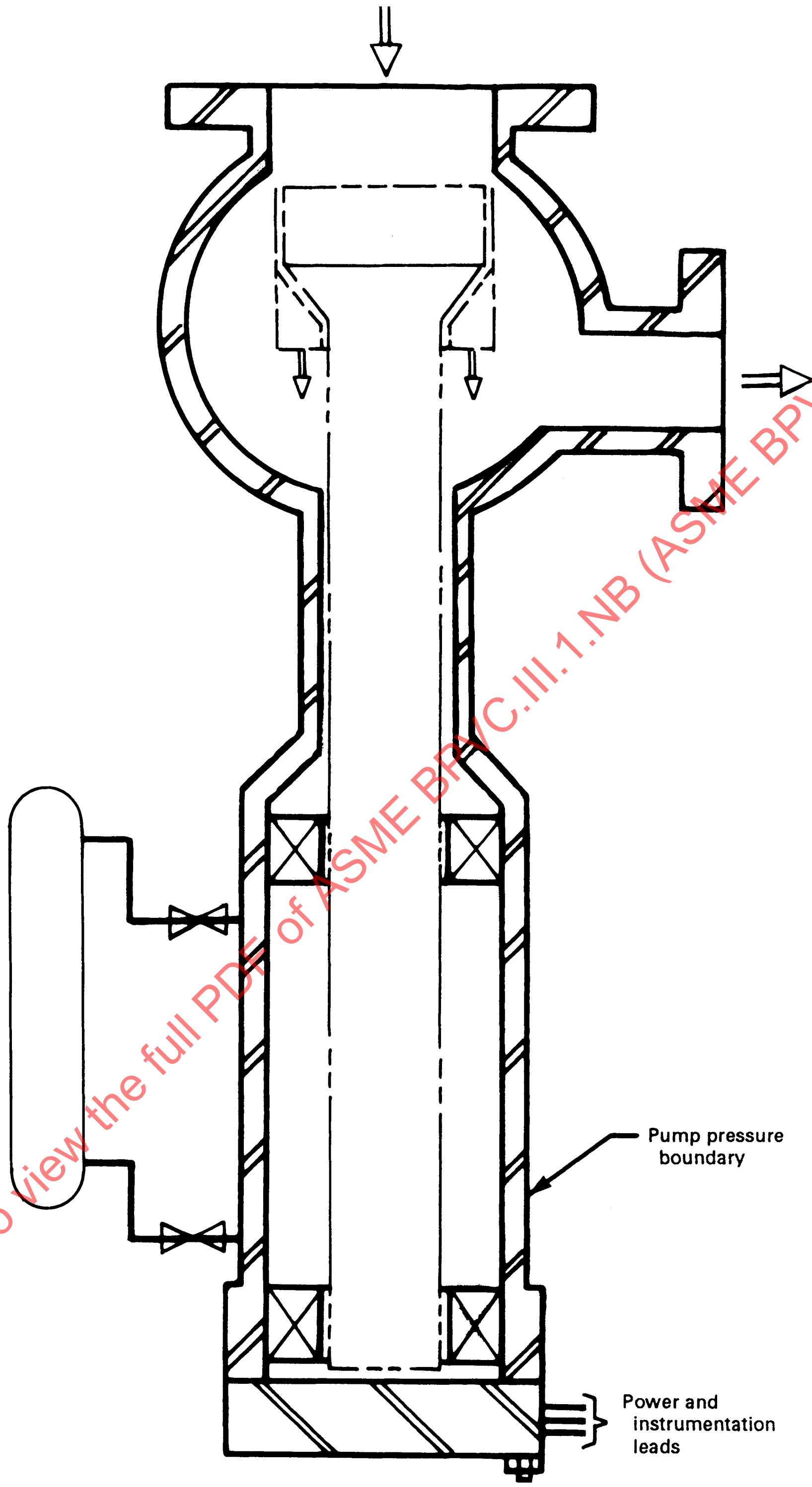
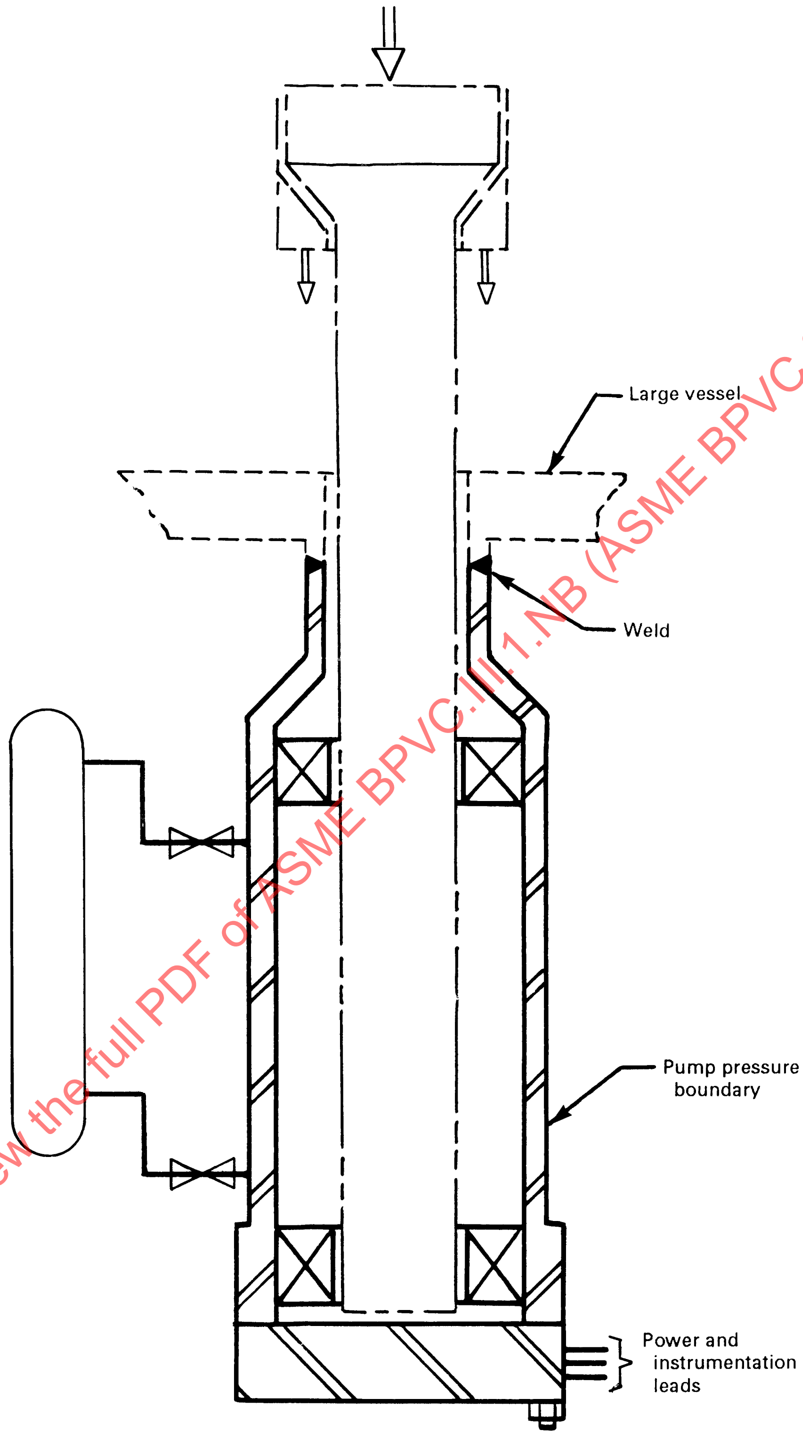


Figure NB-3441.7-2
Typical Type M Pump, Integral to Vessel (23)



specifying the boundary conditions are not applicable to valve end connections.

CAUTION: Certain types of double-seated valves have the capability of trapping liquid in the body or bonnet cavity in the closed position. If such a cavity accumulates liquid and is in the closed position at a time when adjacent system piping is increasing in temperature, a substantial and uncontrolled increase in pressure in the body or bonnet cavity may result. Where such a condition is possible, it is the responsibility of the Owner or the Owner's designee to provide, or require to be provided, protection against harmful overpressure in such valves.

NB-3512 Acceptability of Large Valves

Valve designs having an inlet piping connection larger than NPS 4 (DN 100) are acceptable when they satisfy either the standard design rules or one of the alternative design rules.

NB-3512.1 Standard Design Rules. The design shall be such that requirements of this subarticle are met. The requirements of NB-3530 through NB-3550 apply to valves of conventional shape having generally cylindrical or spherical bodies with a single neck of a diameter commensurate with that of the main body portion, such as having a neck inside diameter less than twice the main run inside diameter in the neck region.

NB-3512.2 Alternative Design Rules. A valve design may not satisfy all of the requirements of NB-3512.1. A design may be accepted provided it meets one of the alternatives listed in (a), (b), (c), or (d) below.

(a) When the valve design satisfies the rules of NB-3530 through NB-3546.2 with thermal stresses neglected, the rules of Section III Appendices, Mandatory Appendix XIII relative to accounting for thermal secondary stresses and fatigue analysis (Section III Appendices, Mandatory Appendix XIII, XIII-3410, XIII-3420, and XIII-3500) shall also be satisfied.

(b) When a valve is exempted from fatigue analysis by the rules of Section III Appendices, Mandatory Appendix XIII, XIII-3510, the design is acceptable, provided that the requirements of (1) or (2) below are met.

(1) The rules of NB-3530 through NB-3546 shall be met. The rules of Section III Appendices, Mandatory Appendix XIII may be substituted for those of NB-3545.2 for evaluating secondary stresses, and NB-3545.3 need not be considered.

(2) The rules of NB-3530 and NB-3541 shall be met. An experimental stress analysis is performed in accordance with Section III Appendices, Mandatory Appendix II, and the rules of Section III Appendices, Mandatory Appendix XIII with respect to primary and secondary stresses resulting from pressure and mechanical loads shall be met. Unless otherwise specified in the Design Specifications, the pipe reactions shall be taken as those loads that produce a stress [see NB-3545.2(b)] of 0.5 times the yield strength of the piping in tension for the direct or axial load and a stress of 1.0 times the yield strength of the piping in bending and torsion. Thermal secondary stresses shall be accounted for by either the rules of Section III Appendices, Mandatory Appendix XIII or NB-3545.

(c) When a valve design satisfies the rules of NB-3530 and NB-3541, and when an experimental stress analysis has been performed upon a similar valve in accordance with Section III Appendices, Mandatory Appendix II, and an acceptable analytic method has been established, the results may be used in conjunction with the requirements of Section III Appendices, Mandatory Appendix XIII for pressure and mechanical loads to establish design acceptability. Accommodation of thermal secondary stresses and pipe reactions shall be as given in (b)(2). Requirements for fatigue analysis of either Section III Appendices, Mandatory Appendix XIII or NB-3550 shall be met.

(d) When permitted by the Design Specification, a weld end valve that does not meet all of the requirements of NB-3540 may be designed so that it meets the requirements of NB-3200 for all pressure-retaining parts and those parts defined by NB-3546.3(a), and shall also meet all of the following requirements.

(1) Pressure, thermal, and mechanical effects, such as those resulting from earthquake, maximum stem force, closure force, assembly forces, and others that may be defined in the Design Specification, shall be included in the design analysis. For Level A Service Limits, the pipe reaction effects are to be determined by considering that the maximum fiber stress in the connected pipe is at one-half of its yield strength in direct tension and at its yield strength in torsion and in bending in the plane of the neck and run, and also in the plane of the run perpendicular to the neck, each considered separately. The individual pipe reaction effects that result in the maximum stress intensity at all points, including all other effects, shall be used for the analysis to satisfy the rules of NB-3200. The valve Design Specification shall provide the loadings and operating requirements to be considered under Level B, C, and D Service Limits [NCA-3211.19(b)(1)(-f)] for which a design analysis is to be included in the Design Report.

(2) In place of using the values of S_m to satisfy the rules of Section III Appendices, Mandatory Appendix XIII, the allowable stress intensity values for ferritic valve body and bonnet materials shall be those allowable stress values given in Section II, Part D, Subpart 1, Table 1A. For materials in Section II, Part D, Subpart 1, Tables 2A and 2B, a reduced allowable stress intensity based on applying a factor of 0.67 to the yield strengths listed in Section II, Part D, Subpart 1, Table Y-1 shall be used.

(3) The adequacy of the stress analysis of the body and bonnet shall be verified by experimental stress analysis conducted in accordance with the requirements of Section III Appendices, Mandatory Appendix II, II-1100

through II-1400. Individual tests shall be made to verify the adequacy of the stress analysis of internal pressure effects and pipe reaction effects. Tests shall be made on at least one valve model of a given configuration, but a verified analytical procedure may then be applied to other valves of the same configuration, although they may be of different size or pressure rating. The geometrical differences shall be accounted for in the extrapolation stress analysis. The analytical procedure shall have verified capability of providing this extrapolation.

(4) A Design Report shall be prepared in sufficient detail to show that the valve satisfies all applicable requirements.

(5) Prior to installation, the valve shall be hydrostatically tested in accordance with NB-3531.2. For this purpose, the primary pressure rating shall be determined by interpolation in accordance with NB-3543(c).

NB-3513 Acceptability of Small Valves

Valve designs having an inlet piping connection NPS 4 (DN 100) or less are acceptable when they satisfy either the standard design rules or the alternative design rules.

NB-3513.1 Standard Design Rules. The design shall be such that the requirements of NB-3530 and NB-3541 shall be met for wall thicknesses corresponding to the applicable pressure–temperature rating. When the Special Class Ratings of ASME B16.34 apply, the NDE exemptions of NB-2510 shall not be used.

NB-3513.2 Alternative Design Rules. A valve design shall satisfy the requirements of NB-3512.2.

NB-3515 Acceptability of Metal Bellows and Metal Diaphragm Stem Sealed Valves

Valves using metal bellows or metal diaphragm stem seals shall be constructed in accordance with the rules of this subarticle, based on the assumption that the bellows or diaphragms do not retain pressure, and Design Pressure is imposed on a required backup stem seal such as packing. The bellows or diaphragms need not be constructed in accordance with the requirements of this Section.

NB-3520 DESIGN CONSIDERATIONS

NB-3521 Design and Service Loadings

The general design considerations of NB-3100 are applicable to valves. In case of conflict between NB-3100 and NB-3500, the requirements of NB-3500 shall apply.

NB-3524 Earthquake

The rules of this subarticle consider that under earthquake loadings the piping system, not the valve, will be limiting and that the integrity of the valve pressure-retaining body is adequately considered under the piping requirements of NB-3600. Where valves are provided with operators having extended structures and these structures are essential to maintaining pressure integrity, an analysis, when required by the Design Specifications, may be performed based on static forces resulting from equivalent earthquake accelerations acting at the centers of gravity of the extended masses.

NB-3525 Level A and B Service Limits

The design rules of NB-3512 and NB-3513 apply to loadings for which Level A or B Limits are designated except that when evaluating Level B Limits during operation of relief or safety valves (a) and (b) below shall be met.

(a) The service pressure may exceed the Design Pressures defined by the pressure–temperature ratings of ASME B16.34 by no more than 10%.

(b) The rules of NB-3540 apply using allowable stress intensity values of 110% of those listed in Section II, Part D, Subpart 1, Tables 2A and 2B.

NB-3526 Level C Service Limits

If the Design Specifications specify any loadings for which Level C Limits are designated, the rules used in evaluating these loadings shall be those of NB-3512 and NB-3513, except as modified by the following subparagraphs.

NB-3526.1 Pressure–Temperature Ratings. The pressure permissible for loadings for which Level C Limits are designated shall not exceed 120% of that permitted for Level A Limits.

NB-3526.2 Pipe Reaction Stress. Pipe reaction stresses shall be computed in accordance with the equations of NB-3545.2(b)(1), and the allowable value considered individually is $1.8S_m$ for the valve body material at 500°F (260°C). In performing these calculations, the value of S shall be taken as 1.2 times the yield strength at 500°F (260°C) of the material of the connected pipe, or 36.0 ksi (248 MPa) when the pipe material is not defined in the Design Specifications.

NB-3526.3 Primary Stress and Secondary Stress. The equation of NB-3545.2 shall be satisfied using C_p equal to 1.5, P_{eb} computed in accordance with NB-3526.2, and Q_{T3} equal to 0, and the calculated value shall be limited to $2.25S_m$.

NB-3526.4 Secondary and Peak Stresses. The requirements of NB-3545 and NB-3550 need not be met.

NB-3527 Level D Service Limits

If the Design Specifications specify any loadings for which Level D limits are designated, the following requirements shall apply:

(a) The rules of Section III Appendices, Mandatory Appendix XXVII may be used in evaluating those loadings.

(b) As an alternative to (a), it is acceptable to demonstrate that both (1) and (2) below are satisfied.

(1) The maximum internal pressure shall not exceed the lesser of 2.0 times the Design Pressure and the rated pressure at the temperature for which Service Level D Limits are specified.

(2) Calculate the valve crotch [Figure NB-3545.2(a)-1, Section A-A] stress intensity S_n due to all applicable loads

$$S_n = 0.5Q_P + P_{es}$$

where

P_{es} = primary stress in crotch region of valve body caused by piping loads for which Level D Service Limits are specified; includes combined axial, bending, and torsion

Q_P = as defined in NB-3545.2

The allowable value of this stress intensity is the lesser of $3.6S_m$ and $1.05S_u$ for austenitic steel, high-nickel alloy, and copper-nickel alloy materials in Section II, Part D, Subpart 1, Table 2A and all materials in Table 2B, or $1.05S_u$ for ferritic materials in Section II, Part D, Subpart 1, Table 2A.

NB-3530 GENERAL RULES

NB-3531 Pressure–Temperature Ratings and Hydrostatic Tests

NB-3531.1 Pressure–Temperature Ratings. A valve designed in accordance with NB-3541 may be used in accordance with the pressure–temperature ratings in ASME B16.34, Tables 2-1.1A through 2-3.19A (Standard Class) for flanged end or welding end (including socket welding end) valves, and ASME B16.34, Tables 2-1.1B through 2-2.7B (Special Class) for welding end (including socket welding end) valves, provided the Design Pressure and Design Temperature are used. When a single valve has a flanged and a welding end, the flanged end requirements shall be used. The materials[11] listed in ASME B16.34, Table 1, may be used if listed in Section II, Part D, Subpart 1, Tables 2A and 2B, subject to the temperature limitations therein, and as defined in NCA-1220.

NB-3531.2 Hydrostatic Tests.

(a) Except for pilot-operated pressure relief valves and power-actuated pressure relief valves, valves designed in accordance with NB-3541 shall be subjected to the shell hydrostatic test pressures required by ASME B16.34 and in accordance with other appropriate rules of Article NB-6000. Valves with a primary pressure rating less than Class 150 shall be subjected to the required test pressure for Class 150 rated valves. For pilot-operated pressure relief valves and power-actuated pressure relief valves, the hydrostatic tests shall be performed in accordance with (f) and in accordance with other appropriate rules of Article NB-6000.

(b) The shell hydrostatic test shall be made with the valve in the partially open position. Stem leakage during this test is permissible. End closure seals for retaining fluid at test pressure in welding end valves may be positioned in the welding end transitions, as defined in NB-3544.8(b), in reasonable proximity to the end plane of the valve so as to ensure safe application of the test pressure.

(c) After the shell hydrostatic test, a valve closure test shall also be performed with the valve in the fully closed position with a test pressure across the valve disk no less than 110% of the 100°F (38°C) pressure rating. For valves that are designed for Service Conditions that have the pressure differential across the closure member limited to values less than the 100°F (38°C) pressure rating, and have closure members or actuating devices (direct, mechanical, fluid, or electrical), or both, that would be subject to damage at high differential pressures, the test pressure may be reduced to 110% of the maximum specified differential pressure in the closed position. This exception shall be identified in the Design Specification, and this maximum specified differential pressure shall be noted on the valve nameplate and N Certificate Holder's Data Report Form. During this test, seat leakage is permitted unless a limiting leakage value is defined by the Design Specifications. The duration of this test shall be 1 min/in. (2.5 s/mm) of minimum wall thickness t_m with a minimum duration of 1 min unless otherwise defined in the Design Specifications.

(d) For valves designed for nonisolation service, whose primary function is to modulate flow, and by their design are prevented from providing full closure, the valve closure test defined in (c) above is not required. This exception shall be identified in the Design Specification and noted on the valve nameplate and the N Certificate Holder's Data Report Form.

(e) Hydrostatic tests for metal bellows or metal diaphragm stem sealed valves shall include hydrostatic testing of the valve body, bonnet, body-to-bonnet joint, and either the bellows or diaphragm or the required backup stem seal.

(f) The primary side pressure-containing portion, including the closure disk in a forced closed position, of each pressure relief valve (regardless of device type) shall be hydrostatically tested at a pressure of 1.5 times the primary side Design Pressure of the valve, but in no case lower than 1.5 times the set pressure marked on the valve. Except as allowed in NB-6115, these tests shall be conducted after all machining and welding operations on the parts have been completed. The minimum test durations shall be in accordance with NB-6223. For closed system application, the outlet

portion of the pressure relief valves shall be hydrostatically tested to 1.5 times the secondary side Design Pressure (see NB-7111). During these tests, closure seat leakage is permitted.

NB-3531.3 Allowance for Variation From Design Loadings. Under the conditions of relief or safety valve operation for valves designed in accordance with NB-3541, the service pressure may exceed the Design Pressure as defined by the pressure–temperature ratings of ASME B16.34 by no more than 10%.

NB-3532 Design Stress Intensity Values

Design stress intensity values to be used in the design of valves are given in Section II, Part D, Subpart 1, Tables 2A and 2B.[11]

NB-3533 Marking

Each valve shall be marked as required by ASME B16.34 and NCA-8220.

(23) NB-3534 Nomenclature

A_f = effective fluid pressure area based on fully corroded interior contour for calculating crotch primary membrane stress [see NB-3545.1(a)]

A_m = metal area based on fully corroded interior contour effective in resisting fluid force acting on A_f [see NB-3545.1(a)]

C_a = stress index for oblique bonnets [see NB-3545.2(a)]

C_b = stress index for body bending secondary stress resulting from moment in connected pipe [see NB-3545.2(b)]

C_p = stress index for body primary plus secondary stress, inside surface, resulting from internal pressure [see NB-3545.2(a)]

C_1 = discontinuity temperature gradient index, °F/in.^{2} (°C/mm^2) [see NB-3545.2]

C_2 = stress index for thermal secondary membrane stress resulting from structural discontinuity [see Figure NB-3545.2(c)-3 and NB-3554]

C_3 = stress index for maximum secondary membrane plus bending stress resulting from structural discontinuity [see NB-3545.2, Figure NB-3545.2(c)-4, and NB-3554]

C_4 = maximum magnitude of the difference in average wall temperatures for wall thicknesses T_{e1} and t_e (resulting from a step change in fluid temperature ΔT_f) divided by ΔT_f [see Figure NB-3545.2(c)-5 and NB-3554]

C_5 = stress index for thermal fatigue stress component resulting from through-wall temperature gradient caused by step change in fluid temperature [see Figure NB-3545.2(c)-6 and NB-3554]

C_6 = $E\alpha$ = product of Young's modulus and the coefficient of linear thermal expansion at 500°F (260°C), psi/°F (MPa/°C) (see NB-3545.2 and NB-3554)

C_7 = stress index for thermal stress resulting from through-wall temperature gradient associated with 100°F/hr (56°C/h) fluid temperature change rate, psi/in. (MPa/mm) (see NB-3545.2)

d = inside diameter used as a basis for crotch reinforcement [see NB-3545.1(a)]

d_e = inside diameter of the larger end of the valve body [see NB-3545.2(b)(3)]

d_m = inside diameter used as basis for determining body minimum wall thickness (see NB-3541)

F_b = bending modulus of standard connected pipe

G_b = valve body section bending modulus at crotch region [see NB-3545.2(b)], in.^{3} (mm^3)

I = moment of inertia, used in calculating G_b [see NB-3545.2(b)(5)]

I_t = fatigue usage factor for step changes in fluid temperature

K_e = strain distribution factor used in elastic–plastic fatigue calculation (see NB-3550)

L_A, L_N = effective distances used to determine A_f, A_m [see NB-3545.1(a)(3)]

m, n = material parameters for determining K_e [see NB-3554]

N_a = permissible number of complete startup/shutdown cycles at 100°F/hr (56°C/h) fluid temperature change rate (see NB-3545.3)

N_i = permissible number of step changes in fluid temperature from Section III Appendices, Mandatory Appendix I

N_{ri} = required number of fluid step temperature changes ΔT_{fi} (see NB-3553)

P_{eb} = secondary stress due to pipe reaction [see NB-3545.2(b)], psi (MPa)

P_m = general primary membrane stress intensity at crotch region, calculated according to NB-3545.1(a), psi (MPa)

p_d = Design Pressure, psi (MPa)

p_r = Pressure Rating Class Index, psi (MPa)

p_s = standard calculation pressure from NB-3545.1, psi (MPa)

p_1, p_2 = rated pressures from tables of ASME B16.34 corresponding to Pressure Rating Class Indices p_{r1} and p_{r2}, psi (MPa)

Q_p = sum of primary plus secondary stresses at crotch resulting from internal pressure [see NB-3545.2(a)], psi (MPa)

Q_{T1} = maximum thermal stress component caused by through-wall temperature gradient associated with 100°F/hr (56°C/h) fluid temperature change rate [see NB-3545.2(c)], psi (MPa)

Q_{T3} = maximum thermal secondary membrane plus bending stress resulting from structural discontinuity and 100°F/hr (56°C/h) fluid temperature change rate, psi (MPa)

r = mean radius of body wall at crotch region [see Figure NB-3545.2(c)-1], in. (mm)

r_i = inside radius of body at crotch region for calculating Q_p [see NB-3545.2(a)], in. (mm)

r_2 = fillet radius of external surface at crotch [see NB-3545.1(a)], in. (mm)

S = assumed maximum stress in connected pipe for calculating the secondary stress due to pipe reaction [see NB-3545.2(b)], psi (MPa)

S_i = fatigue stress intensity range at crotch region resulting from step change in fluid temperature ΔT_{fi} and pressure ΔP_{fi} (see NB-3550), psi (MPa)

S_m = design stress intensity (see NB-3532), psi (MPa)

S_n = sum of primary plus secondary stress intensities at crotch region resulting from 100°F/hr (56°C/h) temperature change rate (see NB-3545.2), psi (MPa)

$S_{n(\max)}$ = maximum range of sum of primary plus secondary stress, psi (MPa)

S_{p1} = fatigue stress intensity at inside surface in crotch region resulting from 100°F/hr (56°C/h) fluid temperature change rate (see NB-3545.3), psi (MPa)

S_{p2} = fatigue stress intensity at outside surface in crotch region resulting from 100°F/hr (56°C/h) fluid temperature change rate (see NB-3545.3), psi (MPa)

T_b = thickness of valve wall adjacent to crotch region for calculating L_A and L_N [see Figure NB-3545.1(a)-1], in. (mm)

T_e = maximum effective metal thickness in crotch region for calculating thermal stresses [see Figure NB-3545.2(c)-1], in. (mm)

T_r = thickness of body (run) wall adjacent to crotch for calculating L_A and L_N [see Figure NB-3545.1(a)-1], in. (mm)

t_e = minimum body wall thickness adjacent to crotch for calculating thermal stresses [see Figure NB-3545.2(c)-1], in. (mm)

t_m = minimum body wall thickness as determined by NB-3541, in. (mm)

t_1, t_2 = minimum wall thicknesses from ASME B16.34 corresponding to Listed Pressure Rating Class Indices p_{r1} and p_{r2} and inside diameter d_m, in. (mm)

ΔP_{fi} = full range of pressure fluctuation associated with ΔT_{fi}, psi (MPa)

ΔP_i = specified range of pressure fluctuation associated with ΔT_i, psi (MPa)

ΔT_{fi} = a specified step change in fluid temperature, °F (°C), where i = 1, 2, 3, ..., n; used to determine the fatigue acceptability of a valve body (see NB-3554)

ΔT_i = specified range of fluid temperature, °F (°C), where i = 1, 2, 3, ..., n; used to evaluate normal valve usage (see NB-3553)

$\Delta T'$ = maximum magnitude of the difference in average wall temperatures for walls of thicknesses t_e and T_e, resulting from 100°F/hr (56°C/h) fluid temperature change rate, °F (°C)

NB-3540 DESIGN OF PRESSURE-RETAINING PARTS

NB-3541 General Requirements for Body Wall Thickness

The minimum wall thickness of a valve body is to be determined by the rules of NB-3542 or NB-3543.

NB-3542 Minimum Wall Thickness of Listed Pressure-Rated Valves

The wall thickness requirements for listed pressure-rated valves apply also to integral body venturi valves. For a valve designed to a listed pressure rating of ASME B16.34, the minimum thickness of its body wall, including the neck, is to be determined from ASME B16.34. Highly localized variations of inside diameter associated with weld preparation [see NB-3544.8(a) and NB-3544.8(b)] need not be considered for establishing minimum wall thickness t_m. In all such cases, however, the requirements of NB-3545.2(b)(6) shall be satisfied.

NB-3543 Minimum Wall Thickness of Valves of Nonlisted Pressure Rating

To design a valve for Design Pressure and Design Temperature corresponding to other than one of the pressure ratings listed in the tables of ASME B16.34, the procedure is the same as that of NB-3542 except that interpolation is required as follows.

(a) Based on the Design Temperature, linear interpolation between the tabulated temperature intervals shall be used to determine the listed pressure rating p_1, next below, and p_2, next above, the Design Pressure p_d

corresponding to listed Pressure Rating Class Indices, p_{r1} and p_{r2}, respectively.

NOTE: For all listed pressure ratings except Class 150, the Pressure Rating Class Index is the same as the pressure rating class designation. For Class 150, use 115 for the Pressure Rating Class Index.

(b) Determine the minimum wall thickness t_m corresponding to Design Loadings by:

$$t_m = t_1 + \left(\frac{p_d - p_1}{p_2 - p_1}\right) \times (t_2 - t_1)$$

(c) Determine the interpolated Pressure Rating Class Index p_r, corresponding to Design Loadings, by:

$$p_r = p_{r_1} + \left(\frac{p_d - p_1}{p_2 - p_1}\right) \times \left(p_{r_2} - p_{r_1}\right)$$

NB-3544 Body Shape Rules

The rules of this paragraph constitute minimum requirements intended to limit the fatigue strength reduction factor, associated with local structural discontinuities in critical regions, to 2.0 or less. When smaller values of the fatigue strength reduction factor can be justified, it is permissible to use them.

NB-3544.1 Fillets for External and Internal Intersections and Surfaces.

(a) Intersections of the surfaces of the pressure-retaining boundary at the neck to body junction shall be provided with fillets of radius $r_2 \geq 0.3t_m$. Figure NB-3544.1(a)-1 illustrates such fillets.

(b) Corner radii on internal surfaces with $r_4 < r_2$ are permissible.

(c) Sharp fillets shall be avoided. When sharp discontinuities are convenient for ring grooves and similar configuration details, they shall be isolated from the major body primary and secondary stresses or modified as illustrated by Figure NB-3544.1(c)-1.

Figure NB-3544.1(a)-1
Fillets and Corners

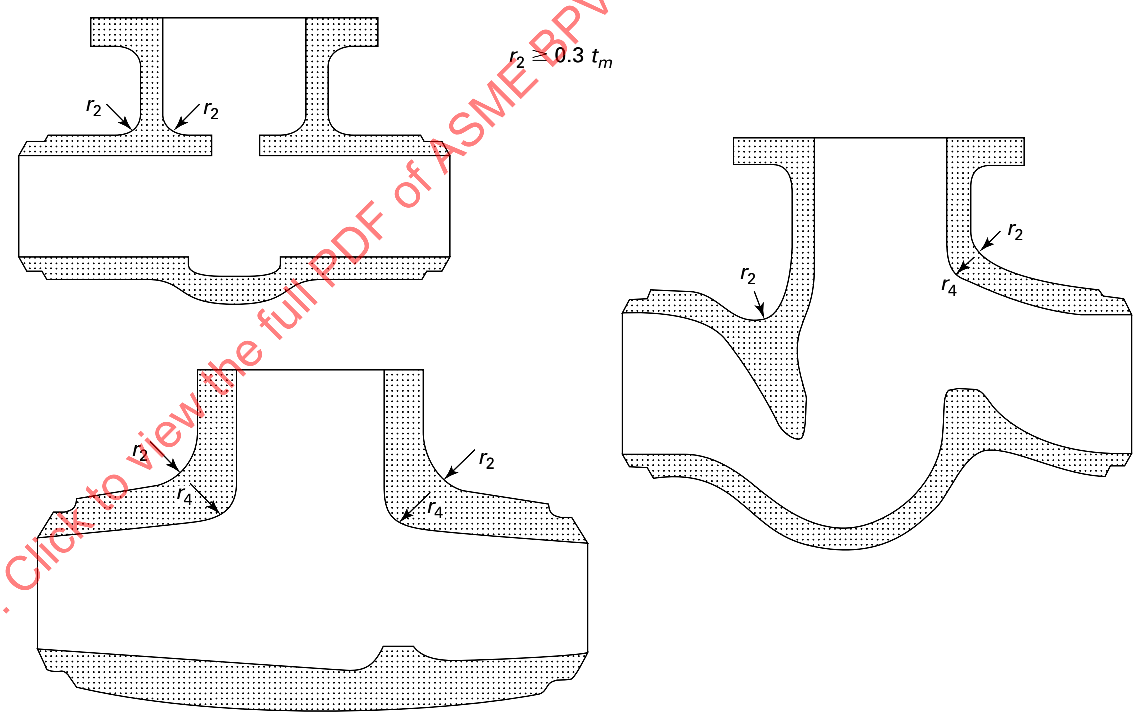
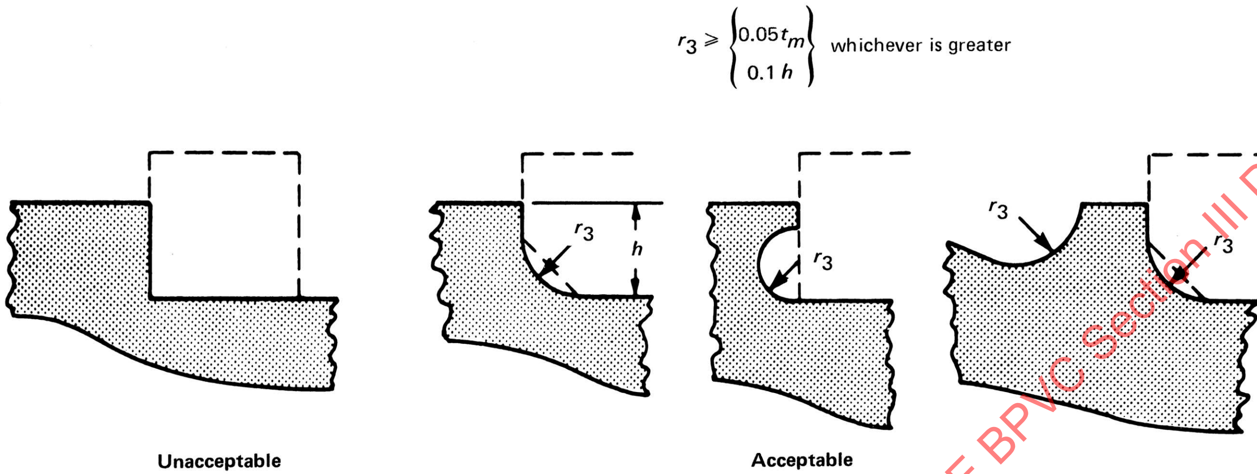


Figure NB-3544.1(c)-1
Ring Grooves



NB-3544.2 Penetrations of Pressure-Retaining Boundary. Penetrations of the pressure-retaining boundary, other than the neck intersection, such as holes required for check valve shafts and drain or sensing lines, shall be located to minimize the compounding of normal body stresses.

NB-3544.3 Attachments. Attachments, such as lugs and similar protuberances, on the pressure-retaining boundary shall be tapered to minimize discontinuity stresses (see Figure NB-3544.3-1). Reentrant angles shall be avoided. Attachments shall meet the requirements of NB-3135.

NB-3544.4 Body Internal Contours. Body internal contours in sections normal to the run or neck center lines shall be generally smooth in curvature, or so proportioned that the removal of unavoidable discontinuities, such as the valve seat, will leave generally smooth curvature.

NB-3544.5 Out-of-Roundness. Out-of-roundness in excess of 5% for sections of essentially uniform thickness shall be such that:

$$\frac{b}{t_b} + \frac{3}{4}\left(\frac{3b^2 - 2ab - a^2}{t_b{}^2}\right) + 1 \leq 1.5\left(\frac{S_m}{p_s}\right)$$

where

$2a$ = minor inside diameter, in. (mm)
$2b$ = major inside diameter, in. (mm)
t_b = thickness, in. (mm)

The ovality criterion can be satisfied by increasing the thickness locally, provided that the thickness variation is smoothly distributed. Out-of-roundness in excess of this limitation must be compensated for by providing reinforcement.

NB-3544.6 Doubly Curved Sections. Sections curved longitudinally with radius r_{Long}, as well as laterally with radius r_{Lat}, must be such that:

$$\frac{1}{r_{\text{Long}}} + \frac{1}{r_{\text{Lat}}} \geq \frac{4}{3d_m}$$

where d_m is the diameter used to establish the local wall thickness by NB-3541.

NB-3544.7 Flat Sections. Flat sections shall be sufficiently limited in extent so that arcuate sections having the same radius–thickness ratio as required by NB-3542 may be inscribed (Figure NB-3544.7-1). The inscribed section may be less thick than the minimum thickness required by NB-3542, provided that its radius is proportionally smaller than the value used to determine the minimum required thickness. The method of NB-3544.6 above may be used to show additive support, but the denominator of the right side term must be reduced in the ratio of the thickness of the inscribed arcuate section to the minimum required thickness (see NB-3542). If adequacy cannot be shown by the above

Figure NB-3544.3-1
Lugs and Protuberances

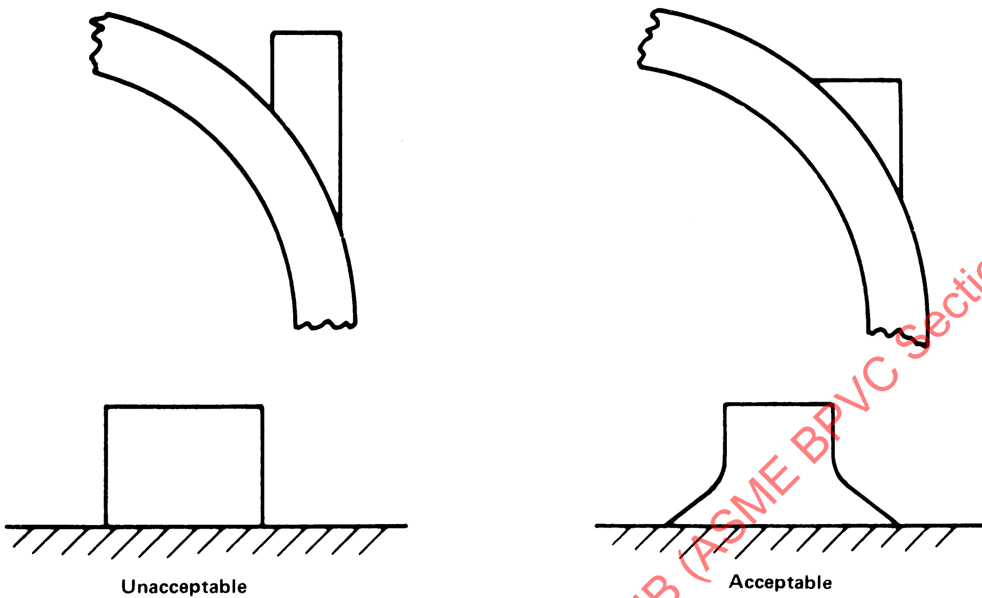
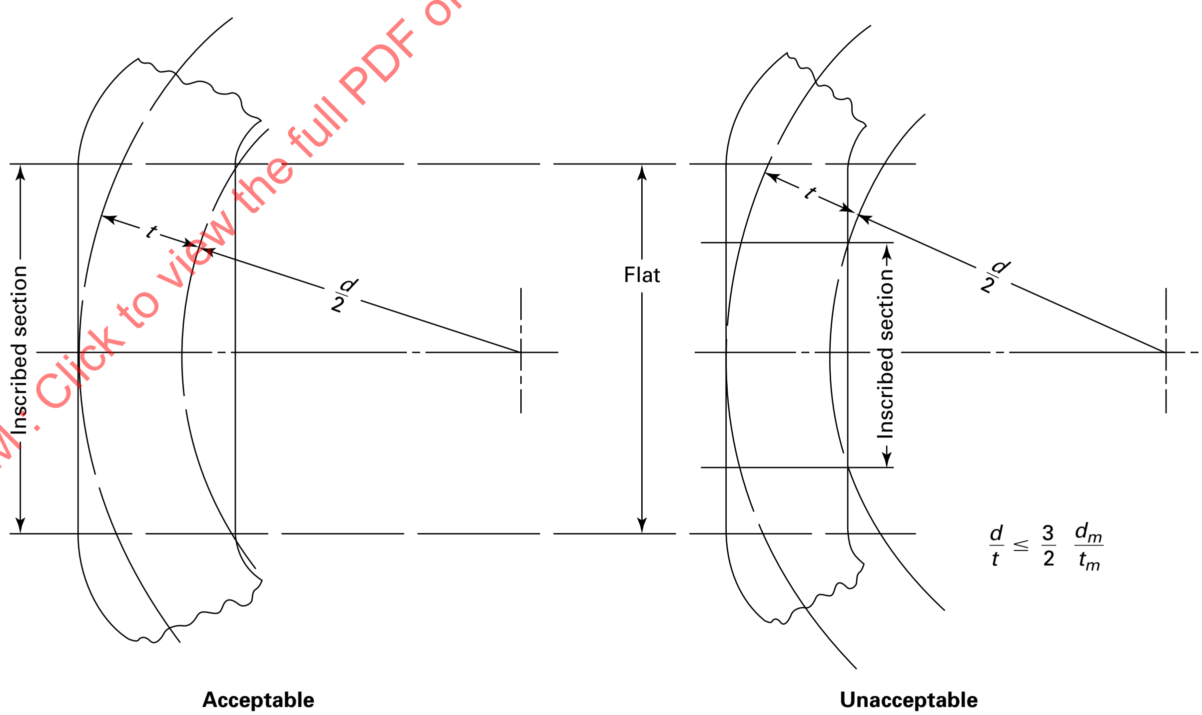


Figure NB-3544.7-1
Flat Wall Limitation



rules, it is necessary to determine the stresses in the flat region experimentally to demonstrate adequacy for pressure-induced stresses only, with internal pressure equal to the standard calculation pressure p_s.

NB-3544.8 Body End Dimensions.

(a) Valve body contours at valve weld ends shall be in accordance with Figure NB-4250-1, and, unless otherwise stated in the Design Specifications, with ASME B16.34.

(b) Valve body transitions leading to valve weld ends shall be in accordance with ASME B16.34.

(c) Flanged ends shall be in accordance with ASME B16.34.

(d) Alignment tolerances given in Figure NB-4233(a)-1 shall apply to all auxiliary piping, such as drain lines, which begin or terminate at the valve.

(e) For socket welding ends, valves NPS 2 (DN 50) and smaller for which the body cavity consists of cylindrically bored sections shall meet all of the following:

(1) d_m shall be the port drill diameter;

(2) the requirements of NB-3542 shall be satisfied; and

(3) socket welding end valves greater than NPS 2 (DN 50) shall not be used.

NB-3544.9 Openings for Auxiliary Connections. Openings for auxiliary connections, such as for drains, bypasses, and vents, shall meet the requirements of ASME B16.34 and the applicable reinforcement requirements of NB-3330.

NB-3545 Body Primary and Secondary Stress Limits

The limits of primary and secondary stresses are established in the following subparagraphs.

NB-3545.1 Primary Membrane Stress Due to Internal Pressure. For valves meeting all requirements of this subarticle, the most highly stressed portion of the body under internal pressure is at the neck to flow passage junction and is characterized by circumferential tension normal to the plane of center lines, with the maximum value at the inside surface. The rules of this paragraph are intended to control the general primary membrane stress in this crotch region. The Standard Calculation Pressure p_s to be used for satisfying the requirements of NB-3545 is found either directly or by interpolation from the tables in ASME B16.34 as the pressure at 500°F (260°C) for the given Pressure Rating Class Index p_r.

(a) In the crotch region, the maximum primary membrane stress is to be determined by the pressure area method in accordance with the rules of (1) through (6) below using Figure NB-3545.1(a)-1.

(1) From an accurately drawn layout of the valve body, depicting the finished section of the crotch region in the mutual plane of the bonnet and flow passage center lines, determine the fluid area A_f and metal area A_m. A_f and A_m are to be based on the internal surface after complete loss of metal assigned to corrosion allowance.

(2) Calculate the crotch general primary membrane stress intensity:

$$P_m = \left(\frac{A_f}{A_m} + 0.5\right)p_s$$

The allowable value of this stress intensity is S_m for the valve body material at 500°F (260°C) as given in Section II, Part D, Subpart 1, Tables 2A and 2B.

(3) The distances L_A and L_N , which provide bounds on the fluid and metal areas, are determined as follows. Use the larger value of:

$$L_A = 0.5d - T_b$$

or

$$L_A = T_r$$

and use

$$L_N = 0.5r_2 + 0.354\sqrt{T_b(d + T_b)}$$

where the dimensions are as shown in Figure NB-3545.1(a)-1.

In establishing appropriate values for the above parameters, some judgment may be required if the valve body is irregular as it is for globe valves and others with nonsymmetric shapes. In such cases, the internal boundaries of A_f shall be the lines that trace the greatest width of internal wetted surfaces perpendicular to the plane of the stem and pipe ends [see Figure NB-3545.1(a)-1, sketches (b), (d), and (e)].

(4) If the calculated boundaries for A_f and A_m, as defined by L_A and L_N, fall beyond the valve body [see Figure NB-3545.1(a)-1, sketch (b)], the body surface becomes the proper boundary for establishing A_f and A_m. No credit is to be taken for any area of connected piping that may be included within the limits of L_A and L_N. If the flange is included with A_m, the area of one bolt hole is to be subtracted for determining the net value of A_m.

(5) Except as modified below, web or fin-like extensions of the valve body are to be credited to A_m only to an effective length from the wall equal to the average thickness of the credited portion. The remaining web area is to be added to A_f [see Figure NB-3545.1(a)-1, sketch (b)]. However, to the extent that additional area will pass the following test, it may also be included in A_m. A line perpendicular to the plane of the stem and pipe ends from any points in A_m does not break out of the wetted surface but passes through a continuum of metal until it breaks through the outer surface of the body.

(6) In most cases, it is expected that the portions defined by A_m in the several illustrations of Figure NB-3545.1(a)-1 will be most highly stressed.

Figure NB-3545.1(a)-1
Pressure Area Method

(23)

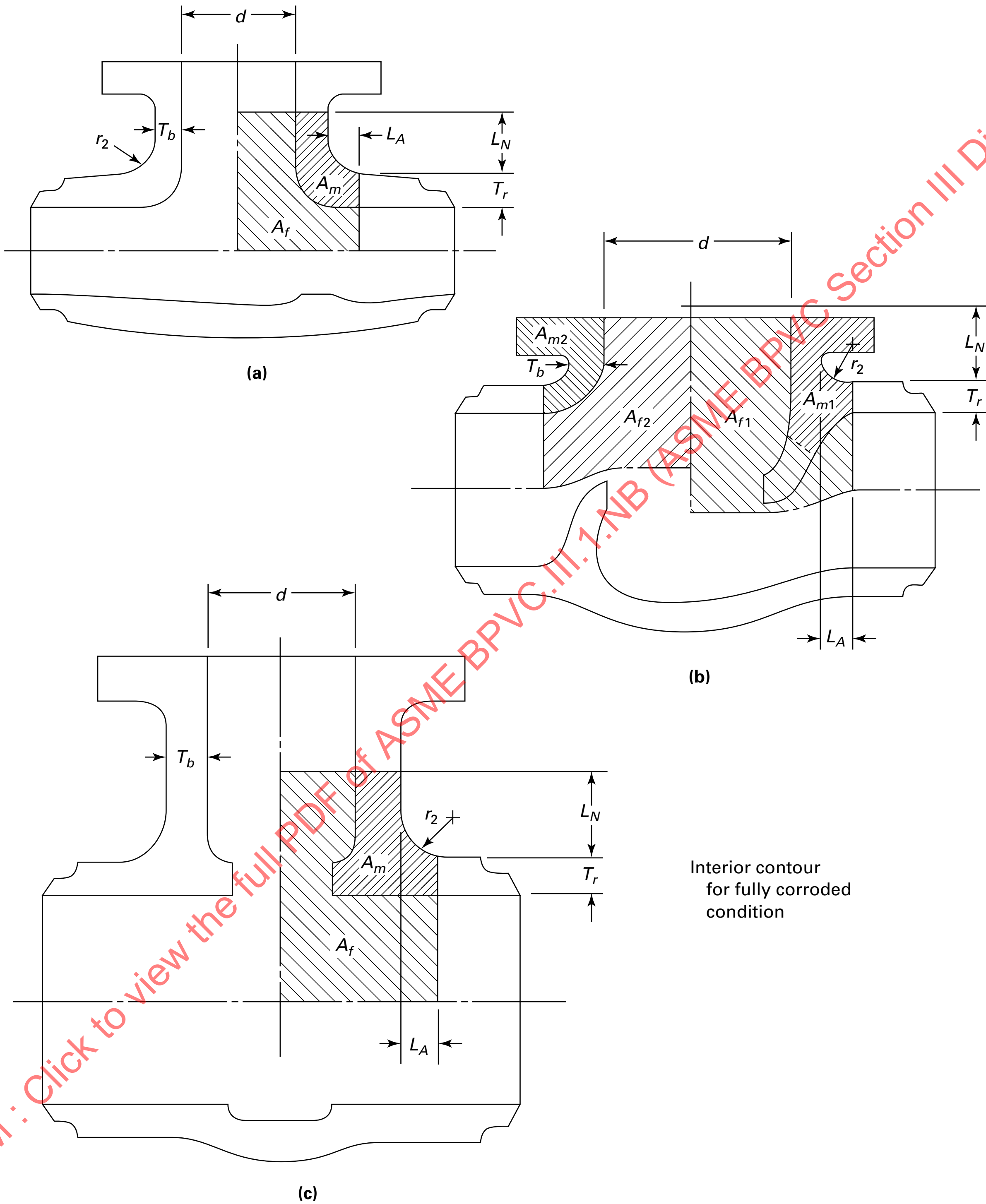
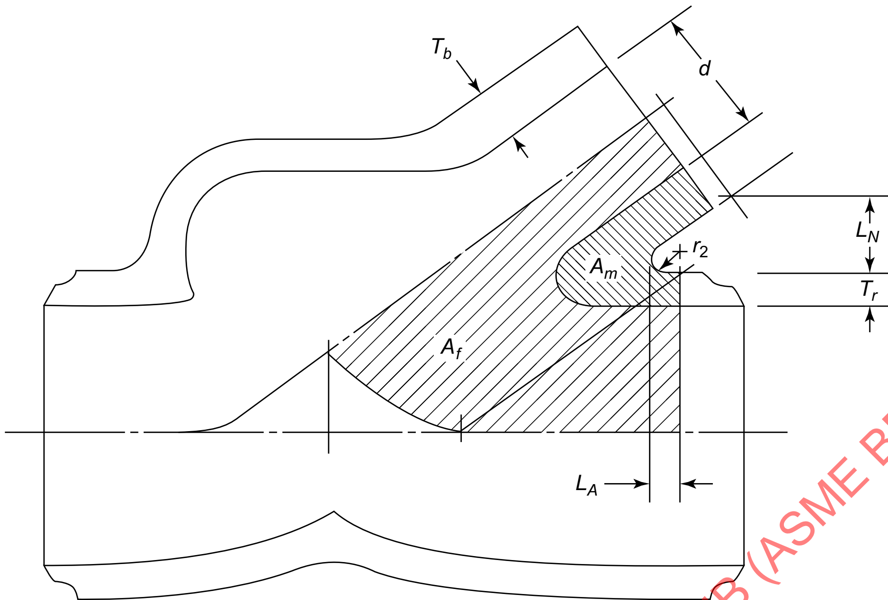
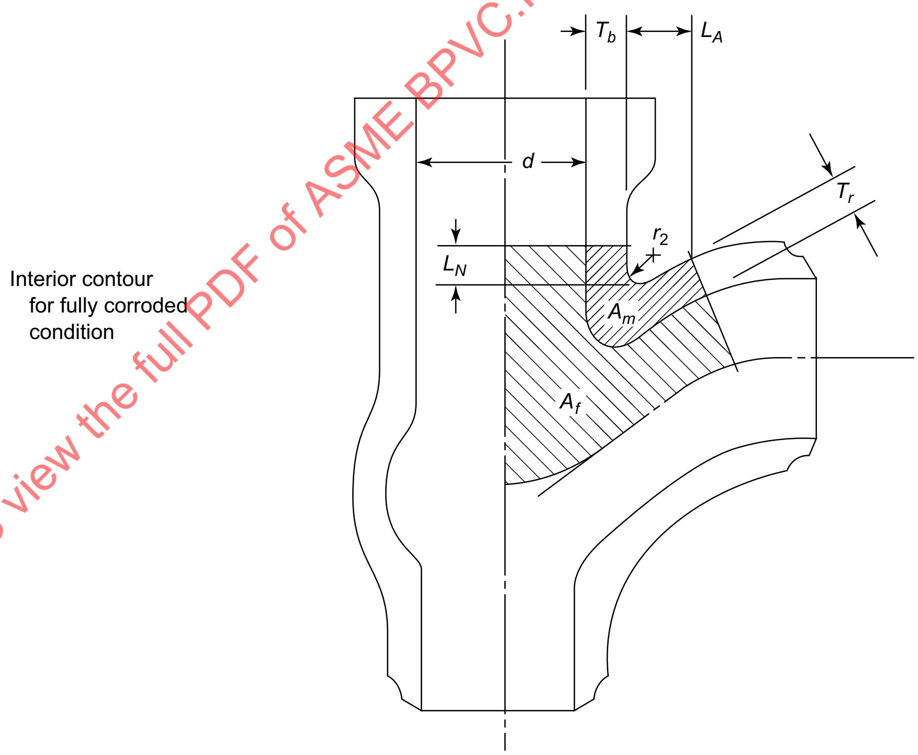


Figure NB-3545.1(a)-1
Pressure Area Method (Cont'd)



(d)



(e)

However, in the case of highly irregular valve bodies, it is recommended that all sections of the crotch be checked to ensure that the largest value of P_m has been established considering both open and fully closed conditions.

(b) In regions other than the crotch, while the value of P_m calculated by (a) will be the highest value of body general primary membrane stress for all normal valve types with typical wall proportioning, the designer is cautioned to review unusual body configurations for possible higher stress regions. Suspected regions are to be checked by the pressure area method applied to the particular local body contours. The allowable value of this stress intensity is S_m for the valve body material at 500°F (260°C) as given in Section II, Part D, Subpart 1, Tables 2A and 2B.

NB-3545.2 Secondary Stresses. In addition to satisfying the criteria of NB-3541 through NB-3545.1, a valve body shall also satisfy the criterion that the range of primary plus secondary stresses S_n due to internal pressure, pipe reaction, and thermal effects shall not exceed $3S_m$ for the body material at 500°F (260°C), where Q_p, P_{eb}, and Q_{T3} are determined by the rules of this paragraph. That is:

$$S_n = Q_p + P_{eb} + 2Q_{T_3} \leq 3S_m$$

(a) See below.

(1) The body primary plus secondary stress Q_p due to internal pressure is to be determined by:

$$Q_p = C_p\left(\frac{r_i}{t_e} + 0.5\right)p_s$$

where the primary plus secondary pressure stress index C_p is equal to 3 and

p_s = Standard Calculation Pressure defined by NB-3545.1, psi (MPa)
r_i = radius of a circle that circumscribes the inside wall contour in the crotch region, in. (mm)
t_e = an effective wall thickness at that location, in. (mm) (typically $t_e = T_r$) [see Figure NB-3545.1(a)-1]

In choosing an appropriate value for t_e, credit may be taken for general reinforcement material at the critical section but not for local fillets. Protuberances or ribs are not to be considered in determining r_i and t_e. Guidance is provided by Figure NB-3545.2(a)-1 in which the illustrations correspond to the critical sections of the valve bodies of Figure NB-3545.1(a)-1. The parameters r_i and t_e are intended to be representative of a tee, reinforced or unreinforced, with the general configuration of the valve body for which minor shape details associated with the valve function are ignored.

(2) For valve bodies with bonnet center lines other than perpendicular to the flow passage, the body stress Q_p due to internal pressure defined above must be multiplied by the factor C_a:

$$C_a = 0.2 + \frac{0.8}{\sin \alpha}$$

where

α = acute angle between the bonnet and flow passage center lines, deg

(b) The secondary stress due to pipe reaction shall meet the criteria of (1) through (6) below to ensure the adequacy of the valve body for safely transmitting forces and moments imposed by the connected piping system.

(1) Based on the critical section A–A at the crotch, as illustrated by Figure NB-3545.2(a)-1, calculate the value of P_{eb} where
(Bending load effect)

$$P_{eb} = \frac{C_b F_b S}{G_b}$$

The allowable value of P_{eb} is $1.5S_m$ for the valve body material at 500°F (260°C). Determination of S, F_b, C_b, and G_b required to calculate P_{eb} is to be in accordance with the requirements of (2) through (5) below.

(2) When the valve designer knows the material of the connected pipe, S may be calculated as the yield strength for the pipe material at 500°F (260°C). When the designer does not know the piping material or is designing a valve independently of a particular application, the value of S shall be taken as 30,000 psi (200 MPa).

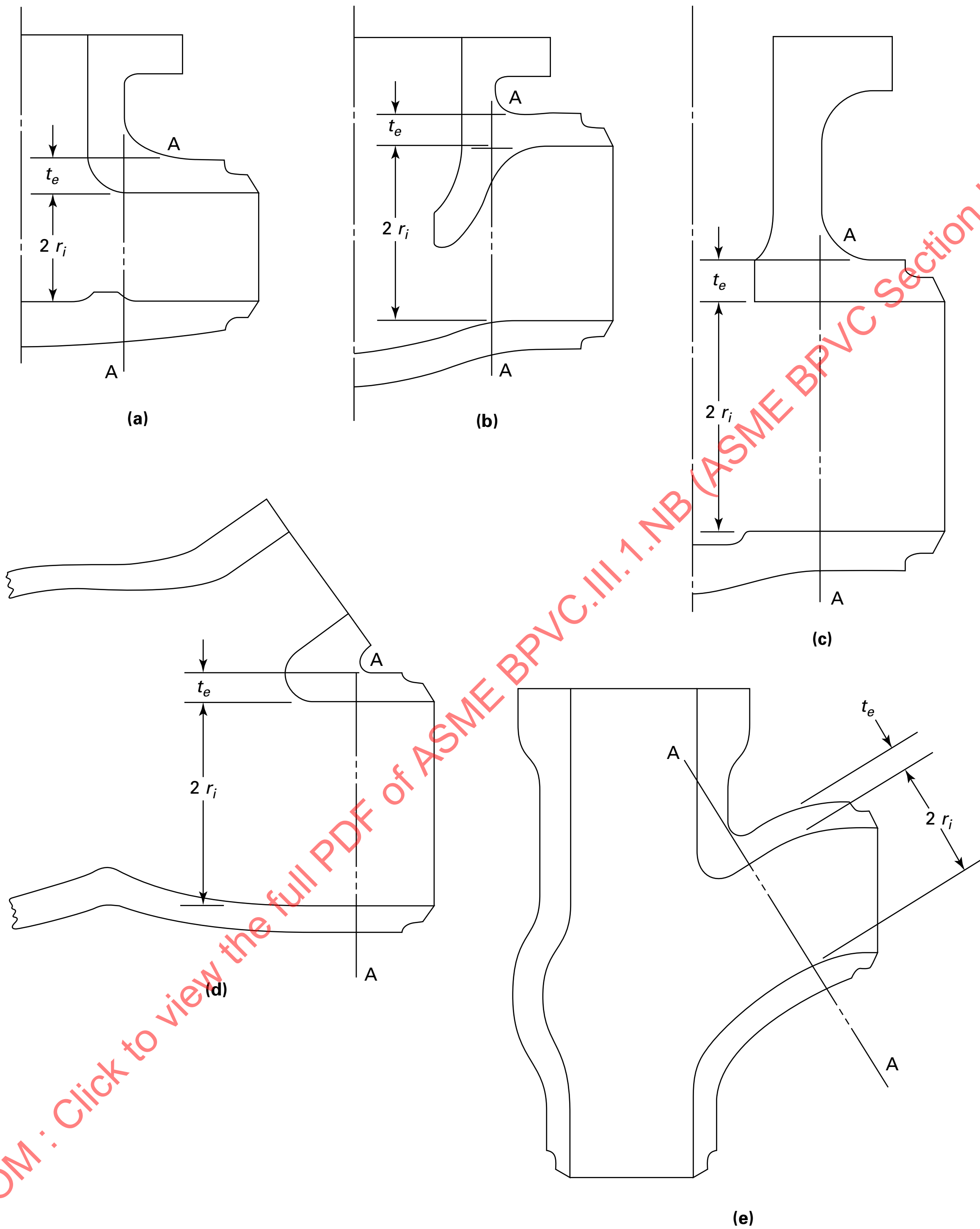
(3) Calculate F_b as follows:

$$F_b = \frac{0.393\, d_e^3 p_s}{f_o - p_s}$$

where

d_e = the inside diameter of the larger end of the valve body
f_o = 20,000 when p_s is in psi units
f_o = 137.9 when p_s is in MPa units

Figure NB-3545.2(a)-1
Critical Sections of Valve Bodies



The value F_b to be applied shall be the greater of the calculated value, or

(-a) for $d_e \le 10.02$ in. (254.5 mm), the section modulus of Schedule 40 pipe with the next larger inside diameter than d_e, or

(-b) for $d_e > 10.02$ in. (254.5 mm), the quantity:

(-1) $0.295 d_e^2$ when d_e is in inch units

(-2) $7.493 d_e^2$ when d_e is in mm units

(4) Calculate the factor C_b:

$$C_b = 0.335\left(\frac{r}{t_e}\right)^{\frac{2}{3}}$$

When the results are less than 1.0, use $C_b = 1.0$.

(5) The factor G_b is the section modulus $I/(r_i + t_e)$, in.^{3} (mm^3), for bending at the plane through A–A about the axis perpendicular to the mutual plane of bonnet and body center lines, such as that axis that produces maximum bending stress at the corner of the crotch. The fiber stress at the outside surface is to be considered as governing in calculating G_b.

(6) When valves are to be applied in a venturi arrangement such that the connected pipe may be larger than that corresponding to the nominal size of the valve, it is necessary to base P_{eb} on the actual larger connected pipe. Such cases must be treated individually to ensure compliance with the secondary and fatigue stress criteria of this subarticle. When the venturi arrangement is not fabricated by the N Certificate Holder, the Design Specifications shall include sufficient information to permit the N Certificate Holder to make this check.

(c) Thermal secondary stresses in the valve crotch region, resulting from through-wall temperature gradient and thickness variation (average temperature difference), are to be calculated on the basis of a continuous ramp change in fluid temperature at 100°F/hr (56°C/h) using the model of Figure NB-3545.2(c)-1 sketch (a). Figure NB-3545.2(c)-1 sketch (b) illustrates how r, T_{e1}, T_{e2}, and t_e are to be determined for the typically irregular crotch shape of valves. The thermal secondary stress components are to be determined in accordance with the following:

(1) Stress component Q_{T1}, which is the result of a through-wall temperature gradient, is defined as:

$$Q_{T_1} = C_7\left(T_{e_1}\right)^2$$

where

C_7 = 110 psi/in.^{2} (0.001 MPa/mm^2) for ferritic steels, or

C_7 = 380 psi/in.^{2} (0.004 MPa/mm^2) for austenitic steels

T_{e1} is illustrated in Figure NB-3545.2(c)-1.

(2) Stress component Q_{T3} that is the membrane plus bending stress as a result of wall thickness variation is defined as: (23)

$$Q_{T_3} = C_6 C_3 \Delta T'$$

where C_3 is found from Figure NB-3545.2(c)-4 and C_6 is defined in NB-3534:

$$\Delta T' = C_1\left(T_{e_1}^2 - t_e^2\right)$$

where

C_1 = 0.53 °F/in.^{2} (4.6 × 10^{-4}°C/mm^2) for ferritic steels, or

C_1 = 1.4 °F/in.^{2} (1.2 × 10^{-3}°C/mm^2) for austenitic steels

t_e is illustrated in Figure NB-3545.2(c)-1.

NB-3545.3 Fatigue Requirements. The fatigue analysis requirements are satisfied provided the rules of this subparagraph and the rules of NB-3550 are met.

The calculated allowable number of cycles is $N_a \ge 2{,}000$ cycles, where N_a is determined from Section III Appendices, Mandatory Appendix I by entering the appropriate curve with S_a, with S_a defined as the larger value of S_{p1} and S_{p2} defined as follows:

$$S_{p_1} = \frac{2}{3}Q_p + \frac{P_{eb}}{2} + Q_{T_3} + 1.3Q_{T_1}$$

$$S_{p_2} = 0.4Q_p + \frac{K}{2}\left(P_{eb} + 2Q_{T_3}\right)$$

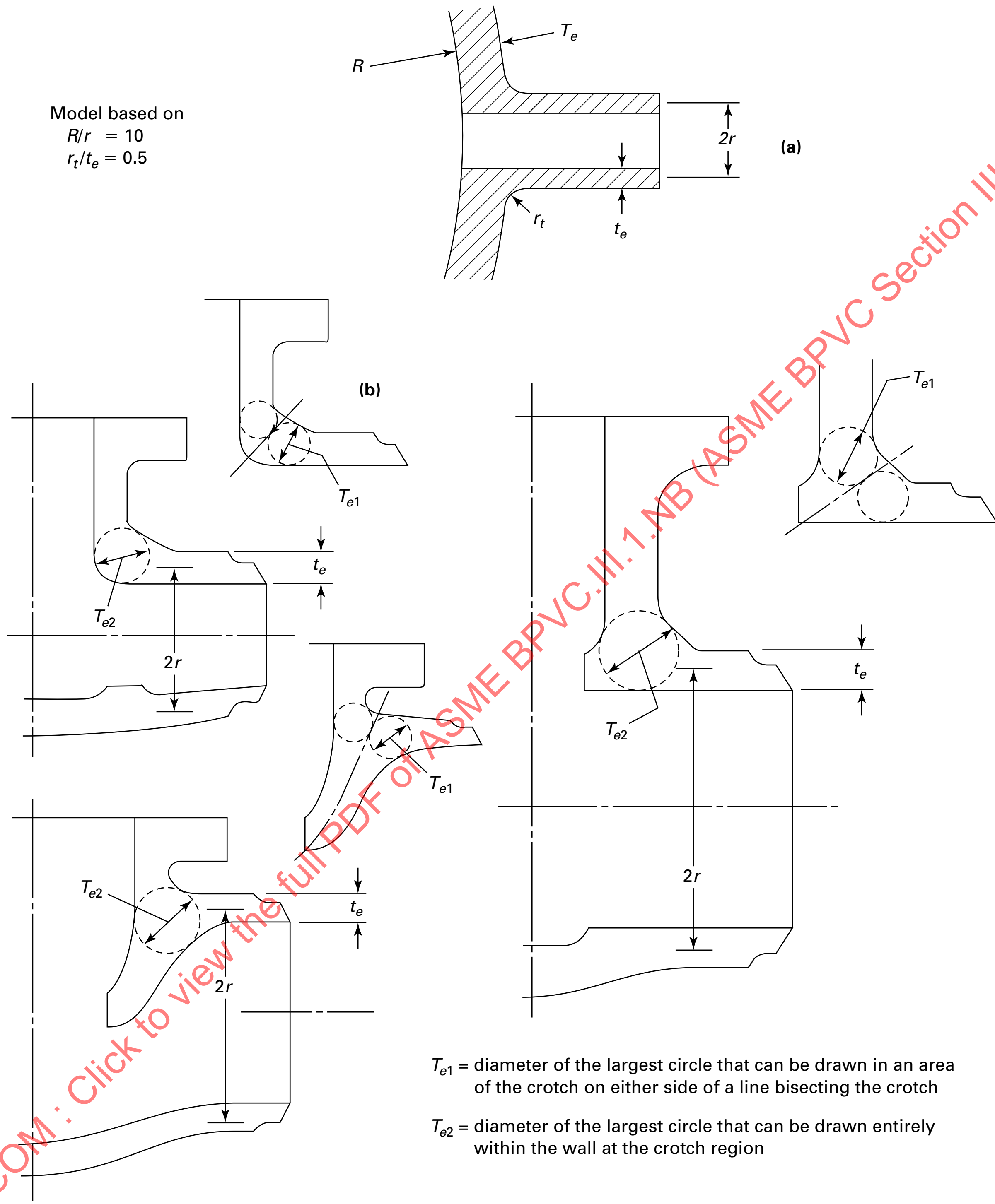
The values of S_{p1} and S_{p2} are based on the values for Q_p, P_{eb}, Q_{T1}, and Q_{T3} found in accordance with the rules of NB-3545.2. K is the fatigue strength reduction factor associated with the external fillet at the crotch and is to be considered as 2.0 unless the designer can justify use of a smaller value.

NB-3546 Design Requirements for Valve Parts Other Than Bodies

NB-3546.1 Body-to-Bonnet Joints.

(a) Bolted body-to-bonnet joints shall be designed in accordance with the pressure design rules of Section III Appendices, Mandatory Appendix XI, Article XI-3000, including the use of the appropriate allowable stress given in Section II, Part D, Subpart 1, Tables 1A and 1B, or by the procedures of Section III Appendices, Mandatory Appendix XIII, except fatigue analysis of bolts is not required.

Figure NB-3545.2(c)-1
Model for Determining Secondary Stress in Valve Crotch Region



T_{e1} = diameter of the largest circle that can be drawn in an area of the crotch on either side of a line bisecting the crotch

T_{e2} = diameter of the largest circle that can be drawn entirely within the wall at the crotch region

For $T_{e1} < t_e$ as determined above, use $T_{e1} = t_e$

Figure NB-3545.2(c)-3
Thermal Stress Index Versus Thickness Continuity Run or Branch

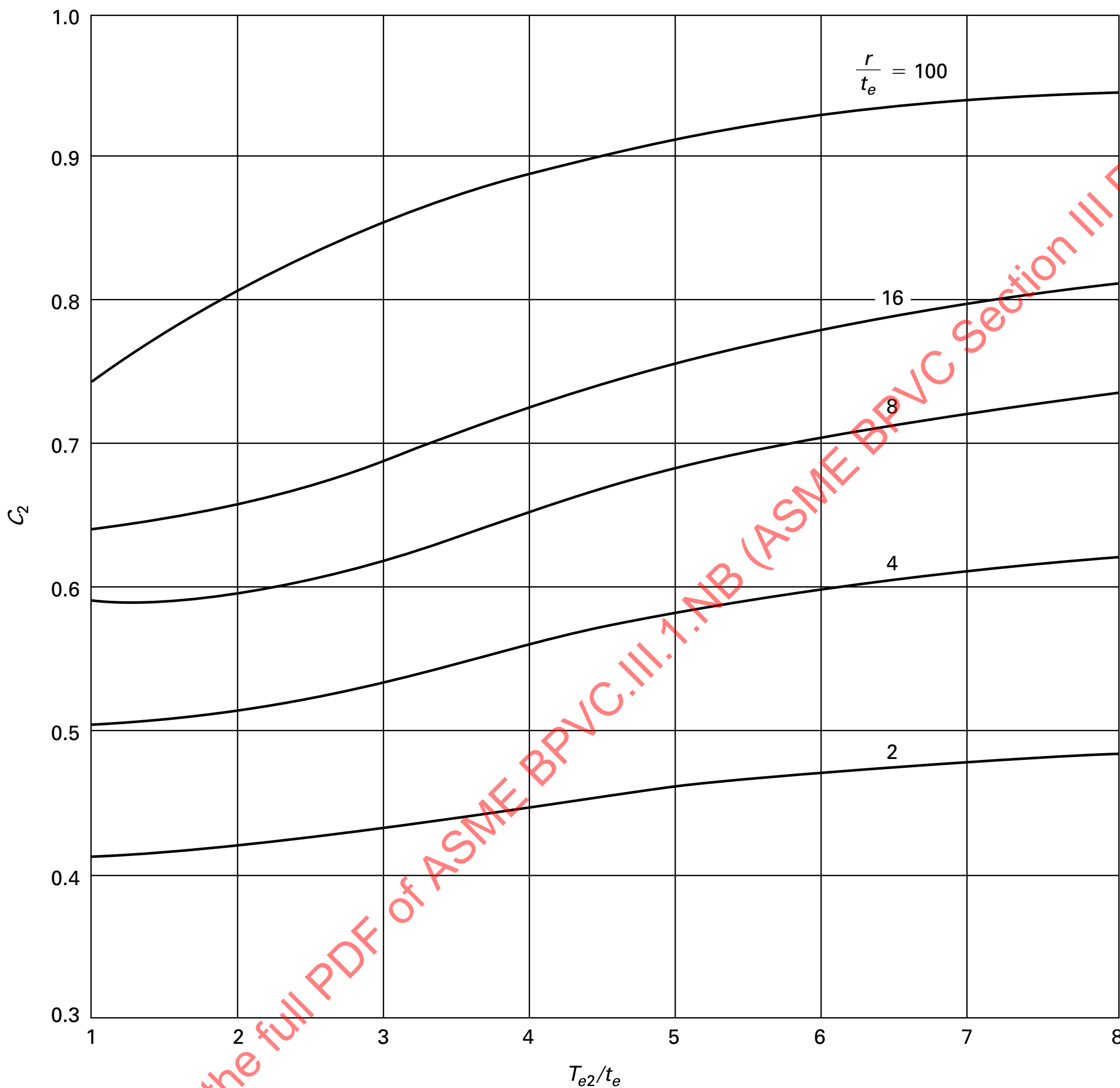


Figure NB-3545.2(c)-4
Secondary Stress Index Versus Thickness Discontinuity Run or Branch

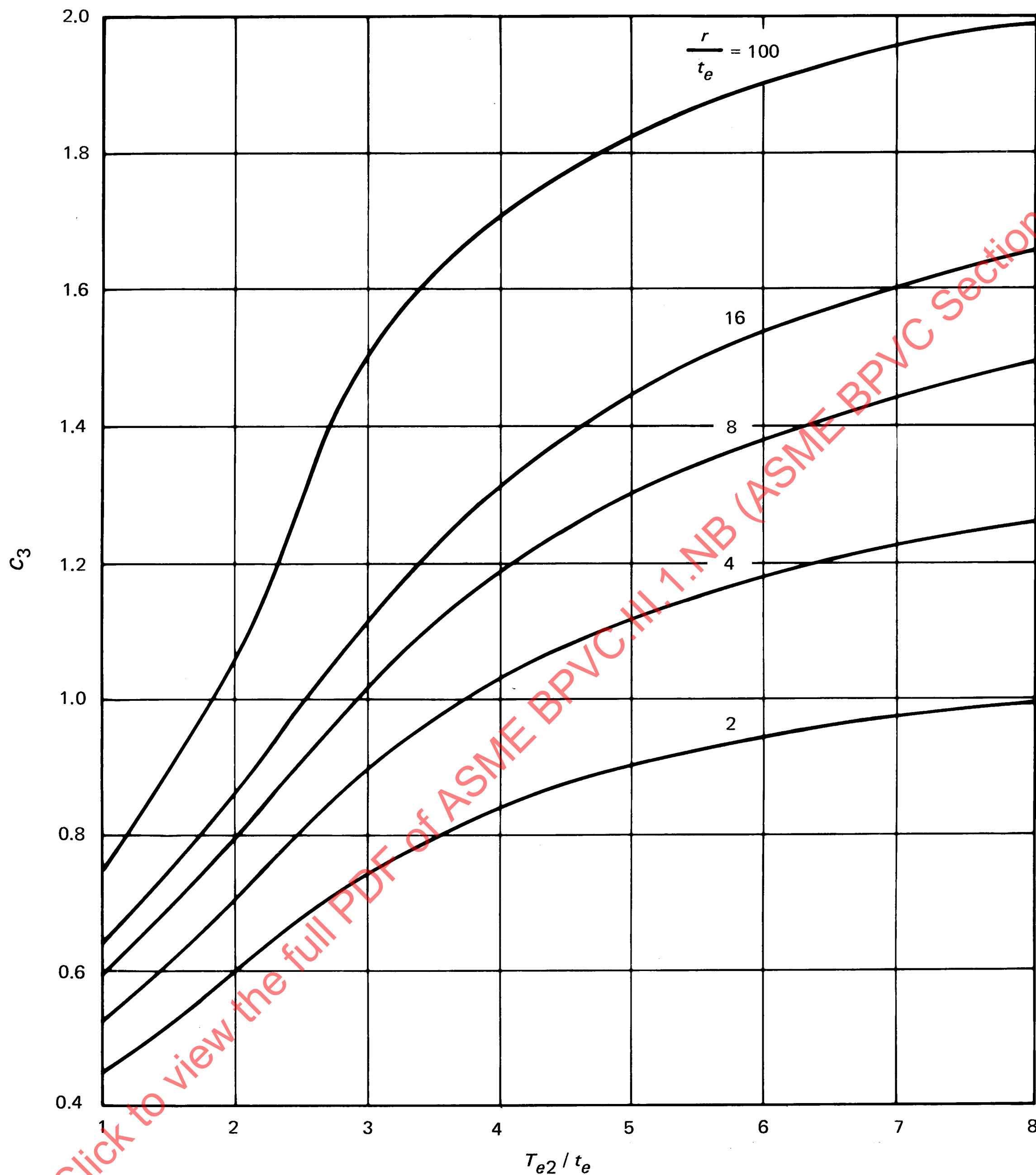


Figure NB-3545.2(c)-5
C_4 Versus T_{e1}/t_e

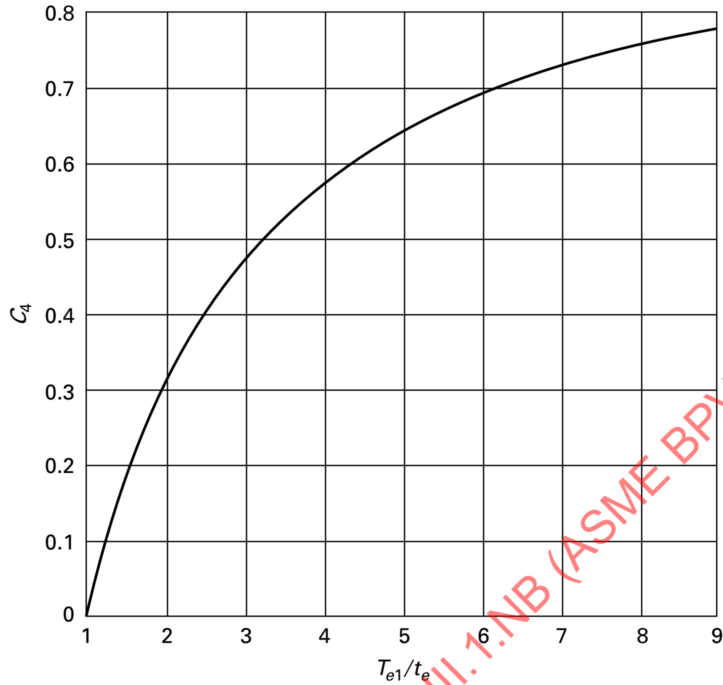
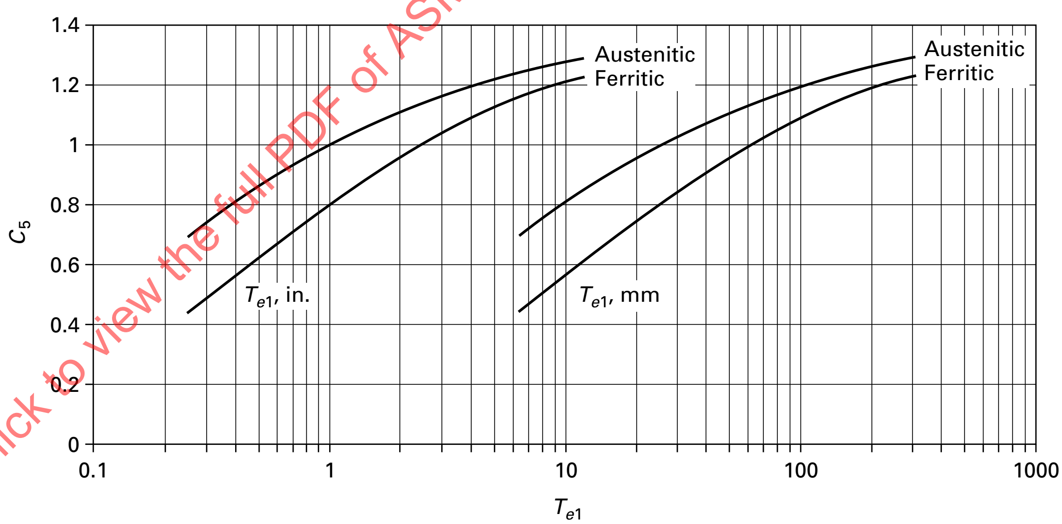


Figure NB-3545.2(c)-6
Stress Index for Thermal Fatigue



(b) Body-to-bonnet joints other than bolted connections including joints of special or patented types for which specific standards do not exist may be used provided that the N Certificate Holder shall use methods of design and construction that will be as safe as otherwise required by the rules of this subarticle for the following design conditions:

(1) Design Pressure equal to Standard Calculation Pressure p_s (see NB-3545.1);

(2) calculation temperature of 500°F (260°C);

(3) thermal stresses based on most severe conditions resulting from continuous fluid temperature ramp increase or decrease at 100°F/hr (56°C/h);

(4) fatigue life at least 2,000 cycles of startup/shutdown based on the above conditions with simultaneous increase or decrease of pressure and temperature.

NB-3546.2 Valve Disk. The valve disk shall be considered a part of the pressure-retaining boundary. The primary membrane stress intensity shall not exceed S_m, and the primary bending stress intensity shall not exceed $1.5S_m$.

NB-3546.3 Other Valve Parts.

(a) Valve stems, stem retaining structures, and other significantly stressed valve parts whose failure can lead to gross violation of the pressure-retaining boundary shall be designed so that their primary stresses, based on pressure equal to the 100°F (38°C) pressure rating and conservatively estimated or calculated additional loadings, where applicable, do not exceed S_m as tabulated in Section II, Part D, Subpart 1, Tables 2A and 2B, or for materials not listed in these Tables, do not exceed two-thirds of the minimum specified yield strength or one-fourth of the minimum specified tensile strength, whichever is lower.

(b) Bypass piping shall be designed in accordance with the requirements of NB-3600. Unless otherwise stated in the valve Design Specifications, bypass piping design shall be the responsibility of the piping system designer.

(c) Valve designs, requiring solenoid plunger core tubes or electromagnetic position indicator core tubes, may substitute the rules of NB-3641.1 for the requirements of NB-3541, NB-3542, or NB-3543 for minimum wall thickness of the extension, provided that detailed calculations are prepared in accordance with NB-3200 at the 100°F (38°C) valve pressure-rating conditions, and covering all discontinuities in the core tube, including the cap end and attachment end, and all welds, including any dissimilar metal welds. These calculations shall be included in the Design Report (see NB-3560). The calculations shall include the design loadings given in NB-3546.1(b)(1) through NB-3546.1(b)(4) along with any additional requirements given in the Design Specifications.

NB-3546.4 Fatigue Evaluation. When the Design Specifications include such service loadings that the valve is not exempted from fatigue analysis by the rules of Section III Appendices, Mandatory Appendix XIII, XIII-3510, it is recommended that consideration be given to the cyclic stress duty of the portions considered by NB-3546.

NB-3550 CYCLIC LOADING REQUIREMENTS

NB-3551 Verification of Adequacy for Cyclic Conditions

The adequacy of a valve for cyclic loading shall be verified in accordance with this subsubarticle. Nonintegral seat rings attached to the valve body by partial penetration or fillet welds (see NB-4433) are exempt from the fatigue analysis requirements of NB-3123.2, provided the seat rings are shouldered against the valve body; see Figure NB-3544.1(c)-1.

NB-3552 Excluded Cycles

In satisfying the cyclic loading requirements, the following variations need not be considered:

(a) pressure variations less than $p_d/3$ for carbon and low alloy steels and less than $p_d/2$ for austenitic stainless steels;

(b) temperature variations less than 30°F (17°C);

(c) accident or maloperation cycles expected to occur less than five times (total) during the expected valve life;

(d) startup, shutdown cycles with temperature change rates of 100°F/hr (56°C/h) or less, not in excess of 2,000.

NB-3553 Fatigue Usage

The application of a valve conforming to NB-3512.1 is acceptable for cyclic loading conditions provided its fatigue usage I_t is not greater than 1.0 as evaluated in (a), (b), and (c) below.

(a) Consider fluid temperature changes not excluded by NB-3552 to occur instantaneously. Provided that these changes occur in one direction and recovery is at temperature change rates not in excess of 100°F/hr (56°C/h), the fatigue usage factor may be found by:

$$I_t = \sum \frac{N_{ri}}{N_i}$$

where N_{ri} is the required or estimated number of fluid temperature step changes ΔT_{fi} and N_i is found from Section III Appendices, Mandatory Appendix I, Figures I-9.1 and I-9.2.

(b) If both heating and cooling effects are expected at change rates exceeding 100°F/hr (56°C/h), the number of cycles are to be associated by temperature ranges ΔT_i. For example, assuming the following variations are specified:

20 variations: $\Delta T_1 = 250°F\ (140°C)$ heating
10 variations: $\Delta T_2 = 150°F\ (80°C)$ cooling
100 variations: $\Delta T_3 = 100°F\ (56°C)$ cooling

Lump the ranges of variation so as to produce the greatest effects as follows:

$$\begin{aligned} 10 \text{ cycles } \Delta T_{f1} &= 250 + 150 = 400°F \\ &\quad (140 + 80 = 220°C) \\ 10 \text{ cycles } \Delta T_{f2} &= 250 + 100 = 350°F \\ &\quad (140 + 56 = 196°C) \\ 90 \text{ cycles } \Delta T_{f3} &= 100°F (56°C) \end{aligned}$$

(c) Pressure fluctuations not excluded by NB-3552 are to be included in the cyclic load calculations. The full range of pressure fluctuation from the normal condition to the condition under consideration shall be represented by Δp_i in NB-3554.

(23) ## NB-3554 Cyclic Stress Calculations

A valve conforming to NB-3512.1 shall be qualified by the procedure of (a) through (d) below, where C_2, C_3, C_4, and C_5 are from Figure NB-3545.2(c)-3, Figure NB-3545.2(c)-4, Figure NB-3545.2(c)-5, or Figure NB-3545.2(c)-6. C_6 is defined in NB-3534.

(a) The following criterion shall be met by the greatest temperature range:

$$Q_p\left[\Delta p_{f(\max)}/p_s\right] + C_6 C_2 C_4 \Delta T_{f(\max)} < 3S_m$$

where $\Delta T_{f(\max)}$ is the largest lumped temperature range obtained using the methods of NB-3553(b), and $\Delta p_{f(\max)}$ is the largest range of pressure fluctuation associated with $\Delta T_{f(\max)}$.

(b) Calculate:

$$S_{n(\max)} = Q_p\left[\Delta p_{f(\max)}/p_s\right] + C_6 C_3 C_4 \Delta T_{f(\max)}$$

Provided that $S_{n(\max)} \le 3S_m$, calculate the fatigue stresses for each cyclic loading condition as follows:

$$S_i = \frac{4}{3} Q_p\left(\Delta p_{fi}/p_s\right) + C_6\left(C_3 C_4 + C_5\right)\Delta T_{fi}$$

Determine the allowable number of cycles N_i for each loading condition by entering Section III Appendices, Mandatory Appendix I, Figures I-9.1 and I-9.2 with $S_i/2$, and determine the fatigue usage by NB-3553(a).

(c) If $S_{n(\max)}$ is greater than $3S_m$ but less than $3mS_m$, the value of $S_i/2$ to be used for entering the design fatigue curve is to be found by multiplying S_i by K_e, where:

$$K_e = 1.0 + \frac{(1 - n)}{n(m - 1)}\left(\frac{S_n}{3S_m} - 1\right)$$

and where the values of the material parameters m and n are as given in Section III Appendices, Mandatory Appendix XIII, Table XIII-3450-1.

(d) If $S_{n(\max)}$ is greater than $3mS_m$, use $K_e = 1/n$.

NB-3560 DESIGN REPORTS

NB-3561 General Requirements

The certified Design Reports listed in this paragraph meet the requirements of NCA-3211.40 for the Design Report.

NB-3562 Design Report for Valves Larger Than NPS 4 (DN 100)

A Design Report shall be prepared in sufficient detail to show that the valve satisfies the requirements of NB-3512. For a valve designed in accordance with NB-3512.1, the Design Report shall show that the applicable requirements of NB-3530, NB-3541 through NB-3546.2, and NB-3550 have been met. It is not necessary to write a special Design Report based on specified Design Pressure and Design Temperature when they are within the pressure–temperature rating and when supplementary information or calculations are also provided, as necessary, to complete the report for a specific application, such as the thermal cyclic duty evaluation of NB-3550. A report submitted demonstrating a design for loadings more severe than the specified loadings is also acceptable.

NB-3563 Design Report Requirements for NPS 4 and Smaller (≤DN 100) Valves

For valves whose inlet piping connection is nominally NPS 4 (DN 100) or smaller, the Design Report shall include details to show that the requirements of NB-3513 have been met.

NB-3590 PRESSURE RELIEF VALVE DESIGN

NB-3591 Acceptability

NB-3591.1 General. The rules of this subsubarticle constitute the requirements for the design acceptability of direct spring-loaded pressure relief valves. The design rules for pilot-operated and power-actuated pressure relief valves are covered by NB-3510 through NB-3563. The requirements of Article NB-7000 relative to set pressure, lift, blowdown, and closure shall be met.

NB-3591.2 Applicable Items. The rules of this subsubarticle cover the pressure-retaining integrity of the valve inlet and outlet connections, nozzle, disk, body structure, bonnet (yoke), and body-to-bonnet (yoke) bolting. The rules of this subsubarticle also cover other items such as the spring, spindle (stem), spring washers, and set pressure-adjusting screw. The rules of this subsubarticle do not apply to guides, control ring, bearings, set screws, and other non-pressure-retaining items. Figures

NB-3591.2-1 and NB-3591.2-2 are illustrations of typical direct spring-loaded pressure relief valves.

NB-3591.3 Definitions. The definitions for pressure relief valve terms used in this subsubarticle are given in ASME PTC 25, and in Article NB-7000. Pressure relief valves characteristically have multipressure zones within the valve, that is, a primary pressure zone and a secondary pressure zone as illustrated by Figures NB-3591.2-1 and NB-3591.2-2.

NB-3591.4 Acceptability of Small Liquid Relief Valves. Liquid pressure relief valves meeting the requirements of Article NB-7000 and having an inlet piping connection NPS 2 (DN 50) and under shall comply with the minimum wall thickness requirements of NB-3542 or NB-3543 for the applicable pressure zone. Flange end ratings of NB-3531.1 shall be used regardless of end connection. The applicable design requirements of this subsubarticle covering the nozzle, disk, and bonnet shall apply. The analyses of NB-3544, NB-3545, and NB-3550 do not apply.

NB-3591.5 Acceptability of Safety and Safety Relief Valves. The design shall be such that the requirements of this subsubarticle are met.

NB-3592 Design Considerations

NB-3592.1 Design Conditions. The general design requirements of NB-3100 are applicable, with consideration for the design conditions of the primary and secondary pressure zones. The design pressure of the Design Specification shall be used for the applicable zones.

In case of conflict between NB-3100 and NB-3590, the requirements of NB-3590 shall apply. Mechanical loads for both the closed and the open (full discharge) positions shall be considered in conjunction with the service conditions. In addition, the requirements of Article NB-7000 shall be met.

NB-3592.2 Stress Limits for Specified Service Loadings.

(a) Stress limits for Level A and B Service Loadings shall be as follows:

(1) the primary membrane stress intensity shall not exceed S_m;

(2) the primary membrane stress intensity plus primary bending stress intensity shall not exceed $1.5S_m$;

(3) substantiation by analysis of localized stresses associated with contact loading of bearing or seating surfaces is not required;

(4) the values of S_m shall be in accordance with Section II, Part D, Subpart 1, Tables 2A, 2B, and 4.

(b) Stress limits for Level C Service Loadings shall be as follows:

(1) the primary membrane stress intensity shall not exceed $1.5S_m$;

(2) the primary membrane stress intensity plus primary bending stress intensity shall not exceed $1.8S_m$ (see NB-3526.2);

(3) the rules of NB-3526.3 must be satisfied.

(c) Stress limits in NB-3527 for Level D Service Loadings shall be used.

(d) These requirements for the acceptability of valve design are not intended to ensure the functional adequacy of the valve. However, the Designer is cautioned that the requirements of Article NB-7000 relative to set pressure, lift, blowdown, and closure shall be met.

NB-3592.3 Earthquake. The rules of this subsubarticle consider that under earthquake loadings the piping system or vessel nozzle, rather than the valve body, will be limiting. Pressure relief valves have extended structures and these structures are essential to maintaining pressure integrity. An analysis, when required by the Design Specification, shall be performed based on static forces resulting from equivalent earthquake acceleration acting at the centers of gravity of the extended masses. Classical bending and direct stress equations, where free body diagrams determine a simple stress distribution that is in equilibrium with the applied loads, may be used.

NB-3593 Special Design Rules

NB-3593.1 Hydrostatic Test. Hydrostatic testing shall be performed in accordance with NB-3531.2(f).

NB-3593.2 Marking. In addition to the marking required by NCA-8220 and Article NB-7000, the secondary Design Pressure shall be marked on the valve or valve nameplate.

NB-3594 Design of Pressure Relief Valve Parts

NB-3594.1 Body. The valve body shall be analyzed with consideration for the specific configuration of the body and the applicable pressure zone and loadings. The design shall take into consideration the adequacy of the inlet flange connection, the outer flange connection, and the body structural configuration. In valve designs where the outlet flange is an extension of the bonnet, the bonnet design shall conform to all rules of body design. The body shall be designed in accordance with the rules of NB-3540 through NB-3550. The design adequacy of the inlet and outlet flanges shall be determined using the rules of NB-3658. Flanges shall conform to the applicable pressure–temperature ratings of NB-3531.1 and shall meet the interface dimensions of ASME B16.5.

NB-3594.2 Bonnet (Yoke). The bonnet (yoke) may be analyzed using classic bending and direct stress equations, with appropriate free body diagrams. The general primary membrane stress intensity and the general primary membrane plus primary bending stress intensity shall

Figure NB-3591.2-1
Typical Pressure Relief Devices

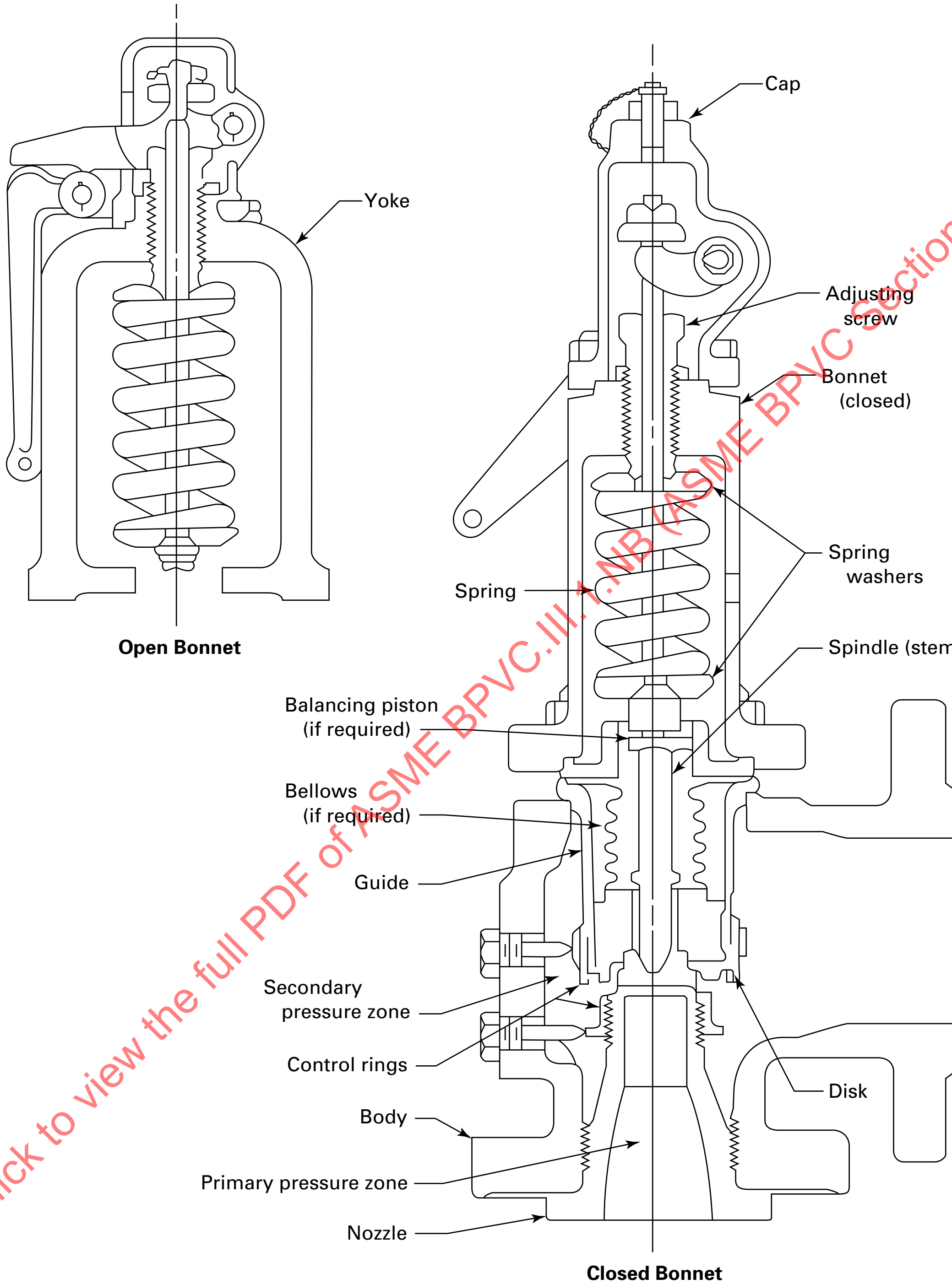


Figure NB-3591.2-2
Typical Pressure Relief and Safety Relief Devices

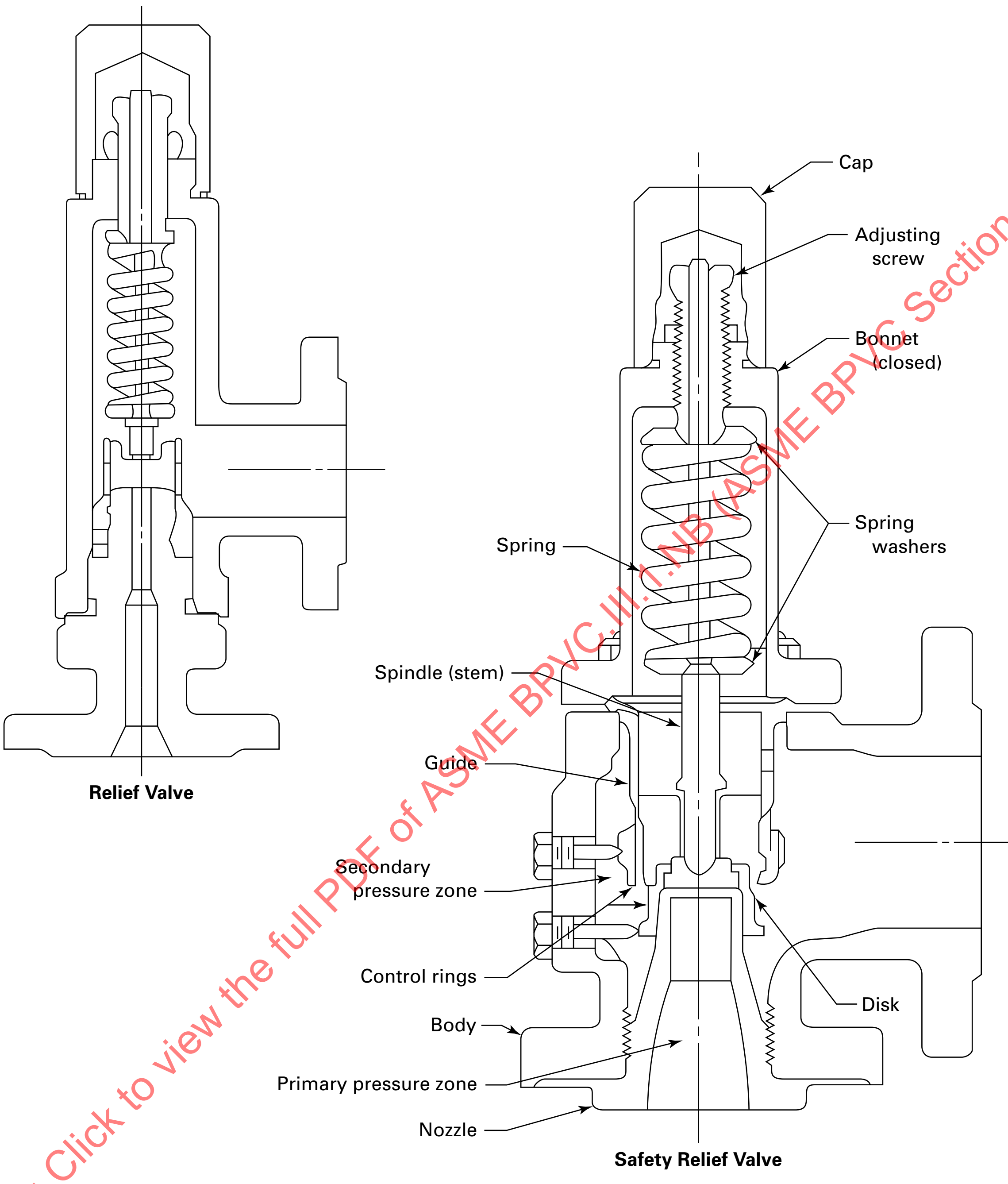
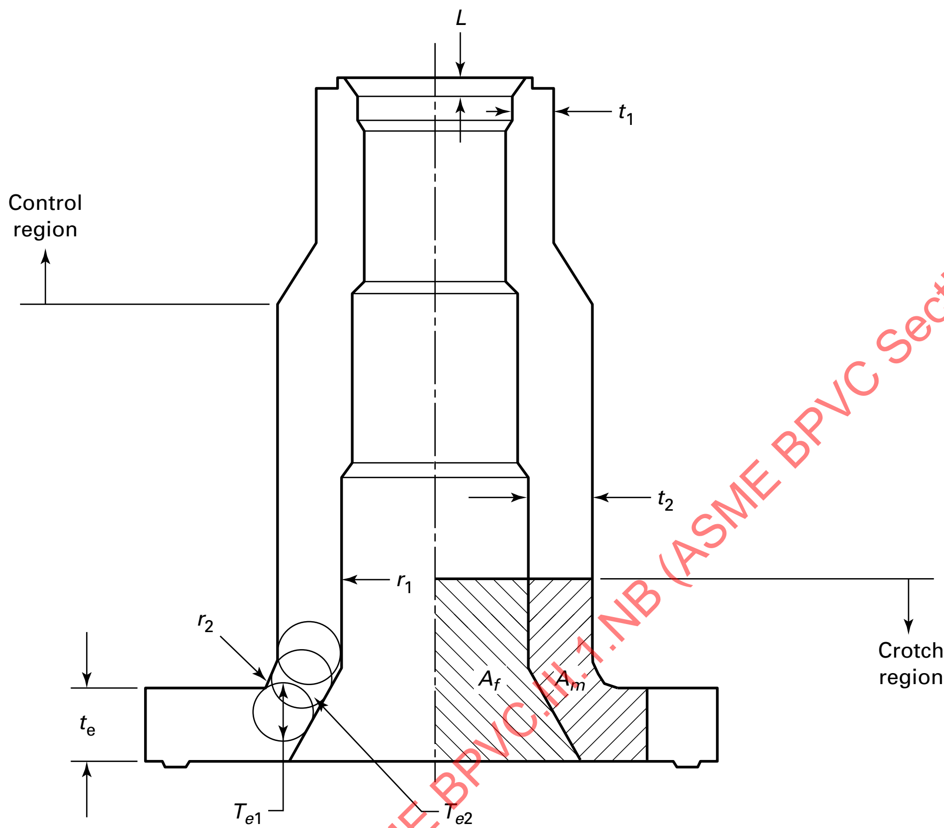


Figure NB-3594.3-1
Valve Nozzle



Legend:

A_f = fluid area, in.^{2} (mm^2)
A_m = metal area, in.^{2} (mm^2)
L = length of seat transition region, in. (mm)
r_1 = inside radius at crotch region, in. (mm)
r_2 = outside fillet radius at crotch, in. (mm)
t_1, t_2 = nozzle wall thickness, in. (mm)
t_e = minimum body wall thickness adjacent to crotch, in. (mm)
T_{e1} = maximum effective thickness in crotch region, in. (mm)
T_{e2} = effective crotch wall thickness, in. (mm)

be determined and shall not exceed the stress limits of NB-3592.2.

NB-3594.3 Nozzle. The nozzle shall be analyzed in accordance with the applicable rules of NB-3540 and NB-3550, with a basic analytical model configuration as shown in Figure NB-3594.3-1. The sections of the nozzle where dimensions are limited by the flow capacity and the operational control requirements may be considered as simple cylindrical sections. The minimum wall thickness of these sections shall be determined in accordance with NB-3324.1. These requirements are not applicable to the transition region to the seat contacting area of the nozzle, defined by L in Figure NB-3594.3-1, provided dimension L is less than the nominal wall thickness t_1. In accordance with NB-2121(c), for materials not listed in Section II, Part D, Subpart 1, Tables 2A and 2B, the S_m value shall be determined in accordance with the rules of Section II, Part D, Mandatory Appendix 2.

NB-3594.4 Body-to-Bonnet Joint. The body-to-bonnet joint shall be analyzed in accordance with NB-3546.1.

NB-3594.5 Disk. The valve disk shall satisfy the requirements of NB-3546.2. In accordance with NB-2121(c), for materials not listed in Section II, Part D, Subpart 1, Tables 2A and 2B, the S_m value shall be determined in accordance with the rules of Section II, Part D, Mandatory Appendix 2.

NB-3594.6 Spring Washer. The average shear stress shall not exceed $0.6S_m$. The primary bending stress intensity shall not exceed the stress limits of NB-3592.2.

NB-3594.7 Spindle (Stem). The general primary membrane stress intensity shall not exceed the stress limits of NB-3592.2.

NB-3594.8 Adjusting Screw. The adjusting screw shall be analyzed for thread shear stress in accordance with the method of ASME B1.1 and this stress shall not exceed $0.6S_m$. The general primary membrane stress intensity of the adjusting screw shall not exceed the stress limits of NB-3592.2, based on the root diameter of the thread.

NB-3594.9 Spring. The valve spring shall be designed so that the full lift spring compression shall be no greater than 80% of the nominal solid deflection. The permanent set of the spring (defined as the difference between the free height and height measured a minimum of 10 min after the spring has been compressed solid three additional times after presetting at room temperature) shall not exceed 0.5% of the free height.

NB-3595 Design Report

NB-3595.1 General Requirements. A Design Report shall be prepared in sufficient detail to show that the valve satisfies the rules of this subsubarticle and NCA-3211.40.

NB-3600 PIPING DESIGN

NB-3610 GENERAL REQUIREMENTS

NB-3611 Acceptability

The requirements for acceptability of a piping system are given in the following subparagraphs.

NB-3611.1 Stress Limits. The design shall be such that the stresses will not exceed the limits described in NB-3630 except as provided in NB-3611.2.

NB-3611.2 Acceptability When Stresses Exceed Stress Limits. When the stresses as determined by the methods given in NB-3630 exceed the limits thereof, the design can be accepted, provided it meets the requirements of NB-3200.

NB-3611.3 Conformance to NB-3600. In cases of conflict between NB-3100 and NB-3600, the requirements of NB-3600 shall apply.

NB-3611.4 Dimensional Standards. For the applicable year of issue of all dimensional standards referred to in NB-3600, see Table NCA-7100-1.

NB-3611.5 Prevention of Nonductile Fracture. The requirements for prevention of nonductile fracture as set forth in NB-3210(d) shall be met.

NB-3612 Pressure–Temperature Ratings

NB-3612.1 Standard Piping Products.

(a) When standard piping products are used, the pressure ratings given as functions of temperature in the appropriate standards listed in Table NCA-7100-1 shall not be exceeded. In addition, the requirements of NB-3625 shall be met. When established pressure ratings of standard products do not extend to the upper temperature limits for the material, the ratings between those established and the upper temperature limit may be determined in accordance with NB-3649.

(b) When the adequacy of the pressure design of a standard product is established by burst tests, the manufacturer of the product shall maintain a record of burst tests conducted to ensure adequacy of product and shall so certify. Such records shall be available to the purchaser.

NB-3612.2 Piping Products Without Specific Ratings. If piping products are used for which methods of construction are not covered by this Subsection, the manufacturer of the product shall use methods of construction that will be as safe as otherwise provided by the rules of this Subsection. When products are used for which pressure–temperature ratings have not been established by the standards listed in Table NCA-7100-1, the products shall be designed and tested in accordance with NB-3640. The manufacturer's recommended pressure–temperature ratings shall not be exceeded.

NB-3612.4 Considerations for Local Conditions and Transients.

(a) When piping systems operating at different pressures are connected by a valve or valves, the valve or valves shall be designed for the higher pressure system requirements of pressure and temperature. The lower pressure system shall be designed in accordance with (1), (2), or (3) below.

(1) The requirements of the pressure system shall be met.

(2) Pressure relief devices or safety valves shall be included to protect the lower pressure system in accordance with NB-7311.

(3) Ensure compliance with all the conditions of (-a) through (-e) below.

(-a) Redundant check or remote actuated valves shall be used in series at the interconnection, or a check in series with a remote actuated valve.

(-b) When mechanical or electrical controls are provided, redundant and diverse controls shall be installed that will prevent the interconnecting valves from opening when the pressure in the high pressure system exceeds the Design Pressure of the lower pressure system.

(-c) Means shall be provided such that operability of all components, controls, and interlocks can be verified by test.

(-d) Means shall be provided to ensure that the leakage rate of the interconnecting valves does not exceed the relieving capacity of the relief devices on the lower pressure system.

(-e) Adequate consideration shall be given to the control of fluid pressure caused by heating of the fluid trapped between two valves.

The low pressure system relieving capacity may be determined in accordance with NB-7311, on the basis of interconnecting valve being closed but leaking at a specified rate, when (-a) through (-e) above are met. The pressure relief devices or safety valves shall adjoin or be as close as possible to the interconnecting valve and shall relieve preferably to a system where the relieved effluent may be contained. The design of the overpressure protection system shall be based on pressure transients that are specified in the Design Specification, and all other applicable requirements of Article NB-7000 shall be met.

(b) When pressure-reducing valves are used and one or more pressure relief devices or safety valves are provided, bypass valves may be provided around the pressure-reducing valves. The combined relieving capacity of the pressure relief devices, safety valves, and relief piping shall be such that the lower pressure system service pressure will not exceed the lower pressure system Design Pressure by more than 10% if the pressure-reducing valve fails in the open position and the bypass valve is open at the same time. If the pressure-reducing valve and its bypass valve are mechanically or electrically interlocked so that only one may be open at any time the high pressure system is at a pressure higher than the Design Pressure of the low pressure system, then the relieving capacity of the pressure relief devices, safety valves, and relief piping shall be at least equal to the maximum capacity of the larger of the two valves. The interlocks shall be redundant and diverse.

(c) Exhaust and pump suction lines for any service and pressure shall have relief valves of a suitable size unless the lines and attached equipment are designed for the maximum pressure and temperature to which they may be accidentally or otherwise subjected.

(d) The effluent from relief devices may be discharged outside the containment only if provisions are made for the disposal of the effluent.

(e) Drip lines from steam headers, mains, separators, or other equipment operating at different pressures shall not discharge through the same trap. Where several traps discharge into a single header that is or may be under pressure, a stop valve and a check valve shall be provided in the discharge line from each trap. The Design Pressure of trap discharge piping shall not be less than the maximum discharge pressure to which it may be subjected. Trap discharge piping shall be designed for the same pressure as the trap inlet piping unless the discharge piping is vented to a system operated under lower pressure and has no intervening stop valves.

(f) Blowdown, dump, and drain piping from water spaces of a steam generation system shall be designed for saturated steam at the pressures and temperatures given below.

Vessel Pressure, psi (MPa)	Design Pressure, psi (MPa)	Design Temperature, °F (°C)
600 (4) and below	250 (1.7)	410 (210)
601 to 900 (4.01 to 6)	400 (2.8)	450 (230)
901 to 1,500 (6.01 to 10)	600 (4.1)	490 (255)
1,501 (10.01) and above	900 (6.2)	535 (280)

These requirements for blowdown, dump, and drain piping apply to the entire system beyond the blowdown valves to the blowdown tank or other points where the pressure is reduced to approximately atmospheric and cannot be increased by closing a valve. When pressures can be increased because of calculated pressure drop or otherwise, this shall be taken into account in the design. Such piping shall be designed for the maximum pressure to which it may be subjected.

(g) Pump discharge piping shall be designed for the maximum pressure exerted by the pump at any load and for the highest corresponding temperature actually existing.

(h) Where a fluid passes through heat exchangers in series, the design temperature of the piping in each section of the system shall conform to the most severe temperature condition expected to be produced by heat exchangers in that section.

NB-3613 Allowances

NB-3613.1 Corrosion or Erosion. When corrosion or erosion is expected, the wall thickness of the piping shall be increased over that required by other design requirements. This allowance shall be consistent with the specified design life of the piping.

NB-3613.2 Threading and Grooving. The calculated minimum thickness of piping that is to be threaded or grooved shall be increased by an allowance equal to the depth of the cut.

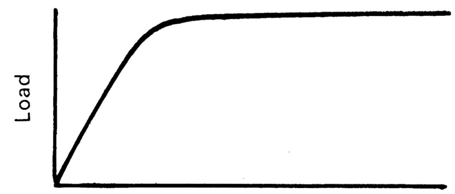
NB-3613.3 Mechanical Strength. When necessary to prevent damage, collapse, or buckling of pipe due to superimposed loads from supports or other causes, the wall thickness of the pipe shall be increased, or, if this is impractical or would cause excessive local stresses, the superimposed loads or other causes shall be reduced or eliminated by other design methods.

NB-3620 DESIGN CONSIDERATIONS

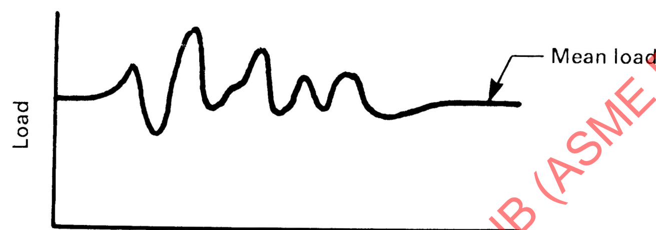
NB-3621 Design and Service Loadings

The provisions of NB-3110 apply.

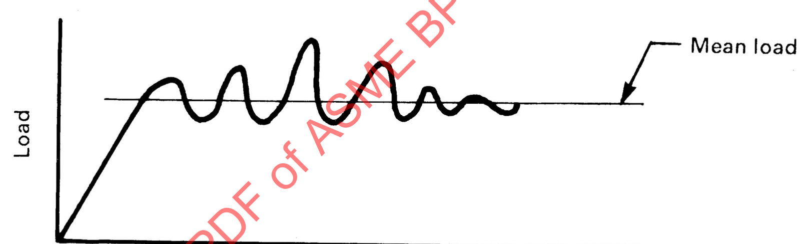
(23) **Figure NB-3622.2-1**
Examples of Reversing and Nonreversing Dynamic Loads



(a) Nonreversing Dynamic Load
(Relief/Safety Valve Open-End Discharge)



(b) Reversing Dynamic Load
(Earthquake Load Cycling About Normal Operating Condition)



(c) Nonreversing Dynamic Load
(Initial Water Slug Followed by Reflected Waves)

NB-3622 Dynamic Effects

NB-3622.1 Impact. Impact forces caused by either external or internal loads shall be considered in the piping design.

(23) **NB-3622.2 Reversing Dynamic Loads.** Reversing dynamic loads (see Figure NB-3622.2-1) are those loads that cycle about a mean value and include building filtered loads and earthquake loads. A reversing dynamic load shall be treated as a nonreversing dynamic load in applying the rules of NB-3600 when the number of reversing dynamic load cycles, exclusive of earthquake, exceeds 20.

NB-3622.3 Vibration. Piping shall be arranged and supported so that vibration will be minimized. The designer shall be responsible, by design and by observation under startup or initial service conditions, for ensuring that vibration of piping systems is within acceptable levels.

NB-3622.4 Nonreversing Dynamic Loads. Non- (23)
reversing dynamic loads (see Figure NB-3622.2-1) are those loads that do not cycle about a mean value and include the initial thrust force due to sudden opening or closure of valves and waterhammer resulting from entrapped water in two-phase flow systems. Reflected

waves in a piping system due to flow transients are classified as nonreversing dynamic loads.

NB-3623 Weight Effects

Piping systems shall be supported to provide for the effects of live and dead weights, as defined in the following subparagraphs, and they shall be arranged or properly restrained to prevent undue strains on equipment.

NB-3623.1 Live Weight. The live weight shall consist of the weight of the fluid being handled or of the fluid used for testing or cleaning, whichever is greater.

NB-3623.2 Dead Weight. The dead weight shall consist of the weight of the piping, insulation, and other loads permanently imposed upon the piping.

NB-3624 Thermal Expansion and Contraction Loads

NB-3624.1 Loadings, Displacements, and Restraints. The design of piping systems shall take into account the forces and moments resulting from thermal expansion and contraction, equipment displacements and rotations, and the restraining effects of hangers, supports, and other localized loadings.

NB-3624.2 Analysis of Thermal Expansion and Contraction Effects. The analysis of the effects of thermal expansion and contraction is covered in NB-3672.

NB-3624.3 Provision for Rapid Temperature Fluctuation Effects. The Designer shall provide for unusual thermal expansion and contraction loads caused by rapid temperature fluctuations.

NB-3625 Stress Analysis

A stress analysis shall be prepared in sufficient detail to show that each of the stress limitations of NB-3640 and NB-3650 is satisfied when the piping is subjected to the loadings required to be considered by this subarticle.

(23) NB-3630 PIPING DESIGN AND ANALYSIS CRITERIA

(a) The design and analysis of piping when subjected to the individual or combined effects of the loadings defined in NB-3100 and NB-3620 may be performed in accordance with this subarticle. Design for pressure loading shall be performed in accordance with the rules of NB-3640. Standard piping products that meet the requirements of ASME B16.9 or NB-3649 satisfy the requirements of NB-3640, and only the analysis required by NB-3650 need be performed.

(b) Within a given piping system, the stress and fatigue analysis shall be performed in accordance with one of the methods given in NB-3650, NB-3200, or Section III Appendices, Mandatory Appendix II. Stress indices are given in NB-3680 for standard piping products, for some fabricated joints, and for some fabricated piping products. Some piping products designed for pressure by applying the rules of NB-3649 may not be listed in NB-3680. For such products, the designer shall determine the stress indices as required in NB-3650.

(c) When a design does not satisfy the requirements of NB-3640 and NB-3650, the more detailed alternative analysis given in NB-3200 or the experimental stress analysis of Section III Appendices, Mandatory Appendix II may be used to obtain stress values for comparison with the criteria of NB-3200.

(d) The requirements of this subarticle shall apply to all Class 1 piping except as exempted under (1) or (2) below.

(1) Piping of NPS 1 (DN 25) or less that has been classified as Class 1 in the Design Specification may be designed in accordance with the Class 2 design requirements of Subsection NCD.

(2) Class 1 piping may be analyzed in accordance with the Class 2 analysis of piping systems in Subsection NCD, using the allowable Class 2 stresses and stress limits, provided the specified service loads for which Level A and B Service Limits are designated meet all of the requirements stipulated in (-a) through (-e) below.

(-a) Atmospheric to Service Pressure Cycle. The specified number of times (including startup and shutdown) that the pressure will be cycled from atmospheric pressure to service pressure and back to atmospheric pressure during normal service does not exceed the number of cycles on the applicable fatigue curve of Section III Appendices, Mandatory Appendix I corresponding to an S_a value of three times the S_m value for the material at service temperature.

(-b) Normal Service Pressure Fluctuation. The specified full range of pressure fluctuations during normal service does not exceed the quantity $^1\!/_3$ × Design Pressure × (S_a/S_m), where S_a is the value obtained from the applicable design fatigue curve for the total specified number of significant pressure fluctuations and S_m is the allowable stress intensity for the material at service temperature. If the total specified number of significant pressure fluctuations exceeds the maximum number of cycles defined on the applicable design fatigue curve, the S_a value corresponding to the maximum number of cycles defined on the curve may be used. Significant pressure fluctuations are those for which the total excursion exceeds the quantity: Design Pressure × $^1\!/_3$ × (S/S_m), where S is defined as follows:

(-1) If the total specified number of service cycles is 10^6 cycles or less, S is the value of S_a obtained from the applicable design fatigue curve for 10^6 cycles.

(-2) If the total specified number of service cycles exceeds 10^6 cycles, S is the value of S_a obtained from the applicable design fatigue curve for the maximum number of cycles defined on the curve.

(-c) Temperature Difference — Startup and Shutdown. The temperature difference, °F (°C), between any two points spaced less than $2\sqrt{Rt}$ apart, where R and t are the mean radius and thickness, respectively, during normal service does not exceed $S_a/2E\alpha$, where S_a is the value obtained from the applicable design fatigue curves for the specified number of startup–shutdown cycles, α is the value of the instantaneous coefficient of thermal expansion and E is the modulus of elasticity at the mean value of the temperatures at the two points as given by Section II, Part D, Subpart 2, Tables TE and TM.

(-d) Temperature Difference — Normal Service.[12] The algebraic range of the temperature difference, °F (°C), between any two points spaced less than $2\sqrt{Rt}$ apart, where R and t are the mean radius and thickness, respectively, does not fluctuate during normal service by more than the quantity $S_a/2E\alpha$, where S_a is the value obtained from the applicable design fatigue curve of Section III Appendices, Mandatory Appendix I for the total specified number of significant temperature difference fluctuations. A temperature difference fluctuation shall be considered to be significant if its total algebraic range exceeds the quantity $S/2E\alpha$, where S is defined as follows:

(-1) If the total specified number of service cycles is 10^6 cycles or less, S is the value of S_a obtained from the applicable design fatigue curve for 10^6 cycles.

(-2) If the total specified number of service cycles exceeds 10^6 cycles, S is the value of S_a obtained from the applicable design fatigue curve for the maximum number of cycles defined on the curve.

(-e) Temperature Difference — Dissimilar Materials. For components fabricated from materials of differing moduli of elasticity or coefficients of thermal expansion, the total algebraic range of temperature fluctuation, °F (°C), experienced by the component during normal service does not exceed the magnitude $S_a/2(E_1\,\alpha_1 - E_2\,\alpha_2)$, where S_a is the value obtained from the applicable design fatigue curve for the total specified number of significant temperature fluctuations, E_1 and E_2 are the moduli of elasticity, and α_1 and α_2 are the values of the instantaneous coefficients of thermal expansion (Section II, Part D, Subpart 2, Tables TE and TM) at the mean temperature value involved for the two materials of construction. A temperature fluctuation shall be considered to be significant if its total excursion exceeds the quantity $S/2(E_1\,\alpha_1 - E_2\,\alpha_2)$, where S is defined as follows:

(-1) If the total specified number of service cycles is 10^6 cycles or less, S is the value of S_a obtained from the applicable design fatigue curve for 10^6 cycles.

(-2) If the total specified number of service cycles exceeds 10^6 cycles, S is the value of S_a obtained from the applicable design fatigue curve for the maximum number of cycles defined on the curve. If the two materials used have different applicable design fatigue curves, the lower value of S_a shall be used in applying the rules of this paragraph.

NB-3640 PRESSURE DESIGN

NB-3641 Straight Pipe

NB-3641.1 Straight Pipe Under Internal Pressure. The minimum thickness of a pipe wall required for Design Pressure shall be determined from one of the following equations:

$$t_m = \frac{PD_o}{2(S_m + Py)} + A \tag{1}$$

$$t_m = \frac{Pd + 2A(S_m + Py)}{2(S_m + Py - P)} \tag{2}$$

where

A = additional thickness, in. (mm):

(a) to compensate for material removed or wall thinning due to threading or grooving, required to make a mechanical joint. The values of A listed in Table NB-3641.1(a)-1 are minimum values for material removed in threading.

(b) to provide for mechanical strength of the pipe. Small diameter, thin wall pipe or tubing is susceptible to mechanical damage due to erection, operation, and maintenance procedures. Accordingly, appropriate means must be employed to protect such piping against these types of loads if they are not considered as Design Loads. Increased wall thickness is one way of contributing to resistance against mechanical damage.

(c) to provide for corrosion or erosion. Since corrosion and erosion vary widely from installation to installation, it is the responsibility of designers to determine the proper amounts that must be added for either or both of these conditions.

D_o = outside diameter of the pipe, in. (mm.) (For design calculations, the specified outside diameter of pipe disregarding outside tolerances shall be used to obtain the value of t_m.)

d = inside diameter, in. (mm)

P = internal Design Pressure, psi (MPa)

S_m = maximum allowable stress intensity for the material at the Design Temperature taken from Section II, Part D, Subpart 1, Tables 2A and 2B, psi (MPa)

t_m = the minimum required wall thickness, in. (mm) [eq. (2) is valid only if $d = D_o - 2t_m$. If pipe is ordered by its nominal wall thickness, the manufacturer's tolerance on wall thickness must be taken into account.]

y = 0.4

Table NB-3641.1(a)-1
Values of *A*

Type of Pipe	*A*, in. (mm)
Threaded steel and nonferrous pipe:	
3/4 in. (19 mm) nominal and smaller	0.065 (1.65 mm)
1 in. (25 mm) nominal and larger	Depth of thread
Grooved steel and nonferrous pipe	Depth of groove plus 1/64 in. (0.40 mm)

The allowable working pressure of pipe may be determined from the following equation:

$$P_a = \frac{2S_m t}{D_o - 2yt} \tag{3}$$

where

P_a = the calculated maximum allowable internal pressure for a straight pipe that shall at least equal the Design Pressure, psi (MPa).

(a) P_a may be used for piping products with pressure ratings equal to that of straight pipe (see ASME B16.9).

(b) For standard flanged joints, the rated pressure shall be used instead of P_a.

(c) For reinforced branch connections (see NB-3643) where part of the required reinforcement is in the run pipe, the Design Pressure shall be used instead of P_a.

(d) For other piping products where the pressure rating may be less than that of the pipe (for example, flanged joints designed to Section III Appendices, Mandatory Appendix XI), the Design Pressure shall be used instead of P_a.

(e) P_a may be rounded out to the next higher unit of 10 psi (0.1 MPa).

t = the specified or actual wall thickness minus, as appropriate, material removed in threading, corrosion or erosion allowance, material manufacturing tolerances, bending allowance (see NB-3642.1), or material to be removed by counterboring, in. (mm).

NB-3641.2 Straight Pipe Under External Pressure. The rules of NB-3133 shall be used.

NB-3642 Curved Segments of Pipe

NB-3642.1 Pipe Bends. The wall thickness for pipe bends shall be determined in the same manner as determined for straight pipe in accordance with NB-3641, subject to the limitations given in (a), (b), and (c) below.

(a) The wall thickness after bending shall not be less than the minimum wall thickness required for straight pipe.

(b) The information in Section III Appendices, Nonmandatory Appendix GG is given to guide the designer when ordering pipe.

(c) For the effects of ovality on stress levels, see NB-3680.

NB-3642.2 Elbows. Elbows, manufactured in accordance with the standards listed in Table NCA-7100-1 as limited by NB-3612.1, shall be considered as meeting the requirements of NB-3640, except that the minimum thickness in the crotch region of short radius welding elbows in accordance with ASME B16.9 shall be 20% greater than the minimum thickness required for the straight pipe by NB-3641.1, eq. (1). The crotch region is defined as that portion of the elbow between ϕ = 210 deg and 330 deg, where ϕ is defined in Figure NB-3685.2-1.

NB-3643 Intersections

NB-3643.1 General Requirements.

(a) The rules contained in this paragraph meet the requirements of NB-3640 in the vicinity of branch connections.

(b) Openings shall be circular, elliptical, or of any other shape that results from the intersection of a circular or elliptical cylinder with a cylindrical shape. Additional restrictions affecting stress indices are given in NB-3680.

(c) Openings are not limited in size except to the extent provided for in connection with the stress indices listed in NB-3680.

(d) Any type of opening permitted in these rules may be located in a welded joint.

(e) Where intersecting pipes are joined by welding a branch to a run pipe as shown in Figure NB-3643.3(a)-2, the angle α between axes of the intersecting pipes shall not be less than 60 deg or more than 120 deg. For angles outside this range, use fittings as specified in NB-3643.2(a) or NB-3643.2(b).

NB-3643.2 Branch Connections. Branch connections in piping may be made by using one of the products or methods set forth in (a) through (d) below.

(a) Flanged, butt welding, or socket welding fittings meeting the applicable standards listed in Table NCA-7100-1, subject to the limitations or requirements of this Subsection, are acceptable. Fittings that comply with the test requirements of ASME B16.9 or of NB-3649 are not required to meet requirements for reinforcement given in NB-3643.3.

(b) Welded outlet fittings, cast or forged branches, pipe adapters, couplings, or similar products with butt welding, socket welding, or flanged ends are acceptable for attachment to the run pipe when limited to types that have integral reinforcement and are attached to the main run by welding per NB-4246. Welded connections per NB-4244

are permitted; however, the stress indices of NB-3683.8 are not applicable to all configurations.

(c) An extruded outlet at right angles to the run pipe is acceptable.

(d) Branch pipe attached to the run pipe with fillet or partial penetration welds per NB-3661.3 is acceptable.

NB-3643.3 Reinforcement for Openings.

(a) *Nomenclature*

(1) The following terms are as shown in Figure NB-3643.3(a)-1.

d_o = outside diameter of the branch pipe
L_1 = height of nozzle reinforcement for branch connections
R_m = mean radius of the run pipe
r_i = inside radius of branch pipe
r_m = mean radius of the branch pipe
= $r_i + 0.5T_b$
r'_m = mean radius of the branch pipe
= $r_i + 0.5T'_b$
r_n = nominal radius [sketch (c) only]
= $r_i + 0.5T'_b + 0.5y \cos \theta$
r_p = outside radius of reinforced branch connection
r_1, r_2, r_3 = designated radii for reinforced branch connections
T_b = nominal thickness of the reinforced branch, not including corrosion allowance or mill tolerance
T'_b = nominal thickness of the branch pipe, not including corrosion allowance or mill tolerance
T_o = corroded finished thickness or extruded outlet measured at a height of r_2 above the outside surface of the run pipe
T_r = nominal thickness of the run pipe, not including corrosion allowance or mill tolerance
y = slope offset distance
θ = angle between vertical and slope, deg

(2) The following terms are as shown on Figure NB-3643.3(a)-2.

A_1 = metal area available for reinforcement
A_2 = metal area available for reinforcement
A_3 = metal area available for reinforcement
d = diameter in the given plane of the finished opening in its corroded condition
L_A = half-width of reinforcement zone measured along the midsurface of the run pipe
L'_A = half-width of zone in which two-thirds of compensation must be placed
L_N = limit of reinforcement measured normal to run pipe wall
r = radius of the finished opening in the corroded condition
T_r = nominal thickness of the run pipe, not including corrosion allowance or mill tolerance
t_b = minimum required thickness of the branch pipe, not including corrosion allowance, according to NB-3641.1
= $t_m - A$
t_r = minimum required thickness of the run pipe, not including corrosion allowance, according to NB-3641.1
= $t_m - A$
α = angle between axes of branch and run (90 deg $\geq \alpha \geq$ 60 deg), deg

(3) The following terms are as shown in Figure NB-3643.3(a)-3.

D_o = outside diameter of the run pipe
h = height of the extruded lip, equal to or greater than r_2
T_o = finished thickness of the extruded outlet in the corroded condition measured at a height equal to r_2 above the outside surface of the main run
T'_r = minimum thickness of the run pipe after extrusion of the opening, not including corrosion allowance or mill tolerance, in. (mm). Allowance shall be made for thinning of the run pipe wall by the extrusion of the opening, if it occurs.

(b) *Requirements*

(1) Reinforcement shall be provided in amount and distribution so that the requirements for the area of reinforcement are satisfied for all planes through the center of the opening and normal to the surface of the run pipe, except that openings need not be provided with reinforcement if all of the requirements of (-a), (-b), and (-c) below are met.

(-a) A single opening has a diameter not exceeding $0.2\sqrt{R_m T_r}$, or, if there are two or more openings within any circle of diameter, $2.5\sqrt{R_m T_r}$, but the sum of the diameters of such unreinforced openings shall not exceed $0.25\sqrt{R_m T_r}$.

(-b) No two unreinforced openings shall have their centers closer to each other, measured on the inside wall of the run pipe, than the sum of their diameters.

(-c) No unreinforced opening shall have its center closer than $2.5\sqrt{R_m T_r}$ to the edge of any other locally stressed area.

(2) The total cross-sectional area of reinforcement A required in any given plane for a pipe under internal pressure shall not be less than:

$$A = dt_r(2 - \sin \alpha)$$

(3) The required reinforcing material shall be uniformly distributed around the periphery of the branch except that, in the case of branches not at right angles, the designer may elect to provide additional reinforcement in the area of the crotch.

Figure NB-3643.3(a)-1
Branch Connection Nomenclature

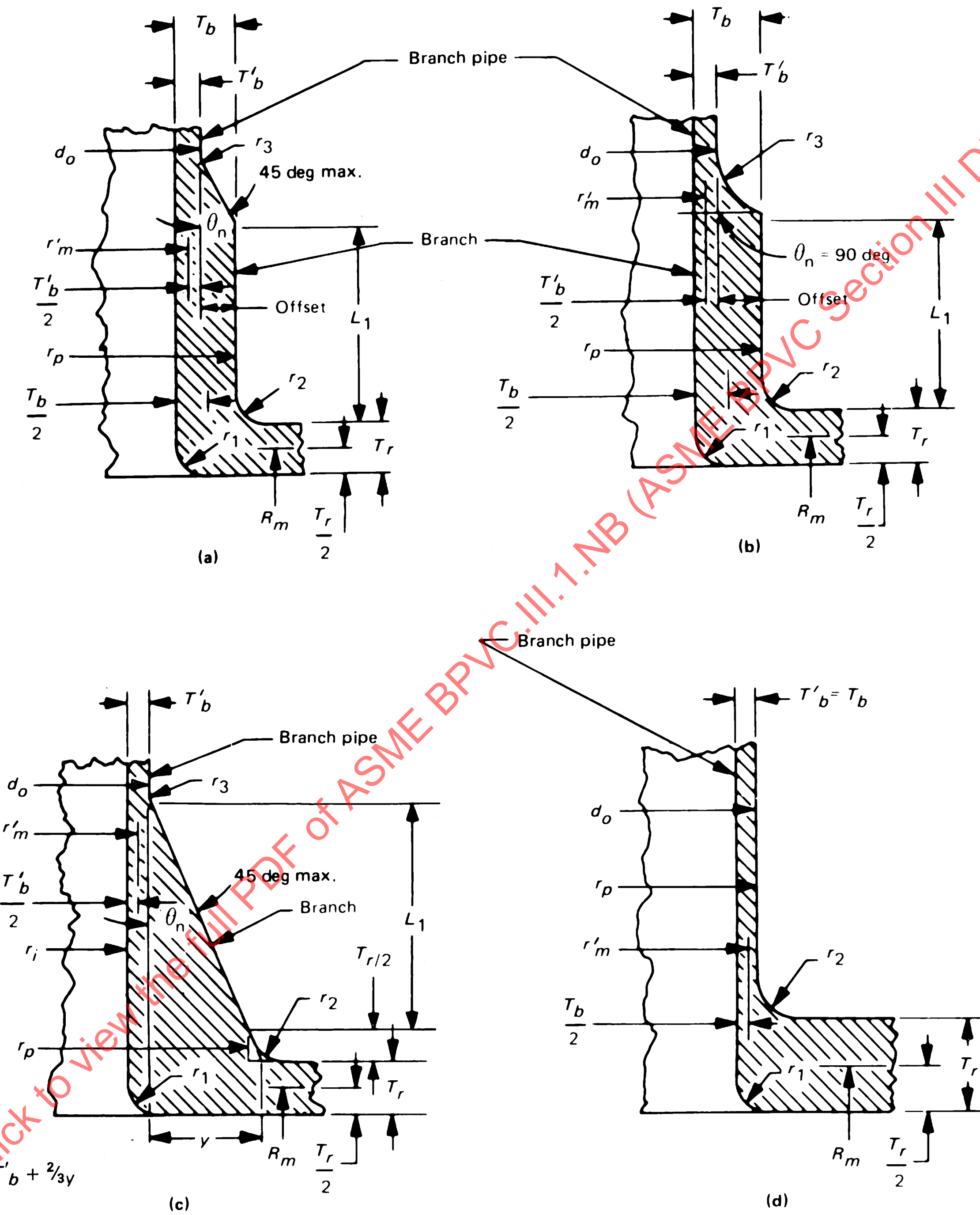


Figure NB-3643.3(a)-2
Typical Reinforcement of Openings

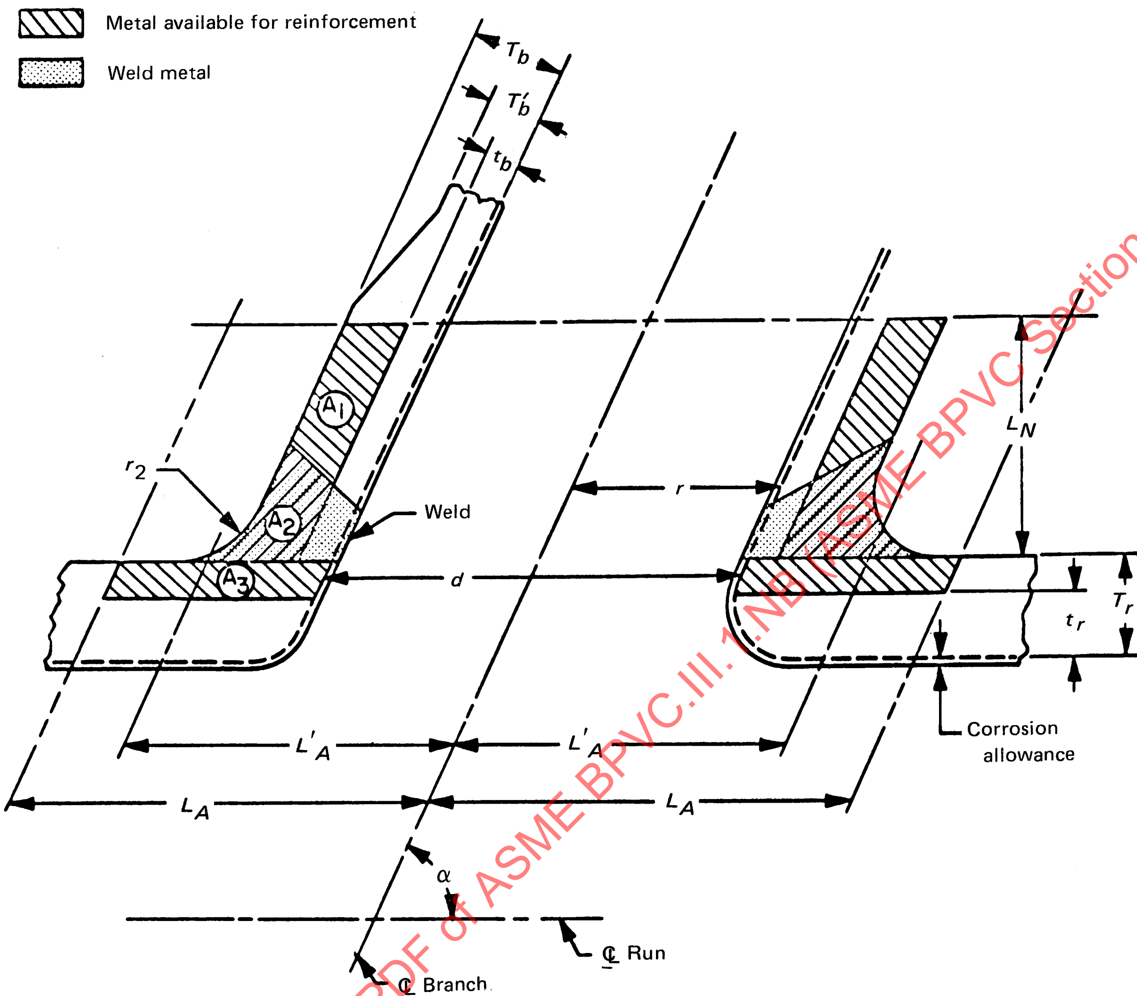
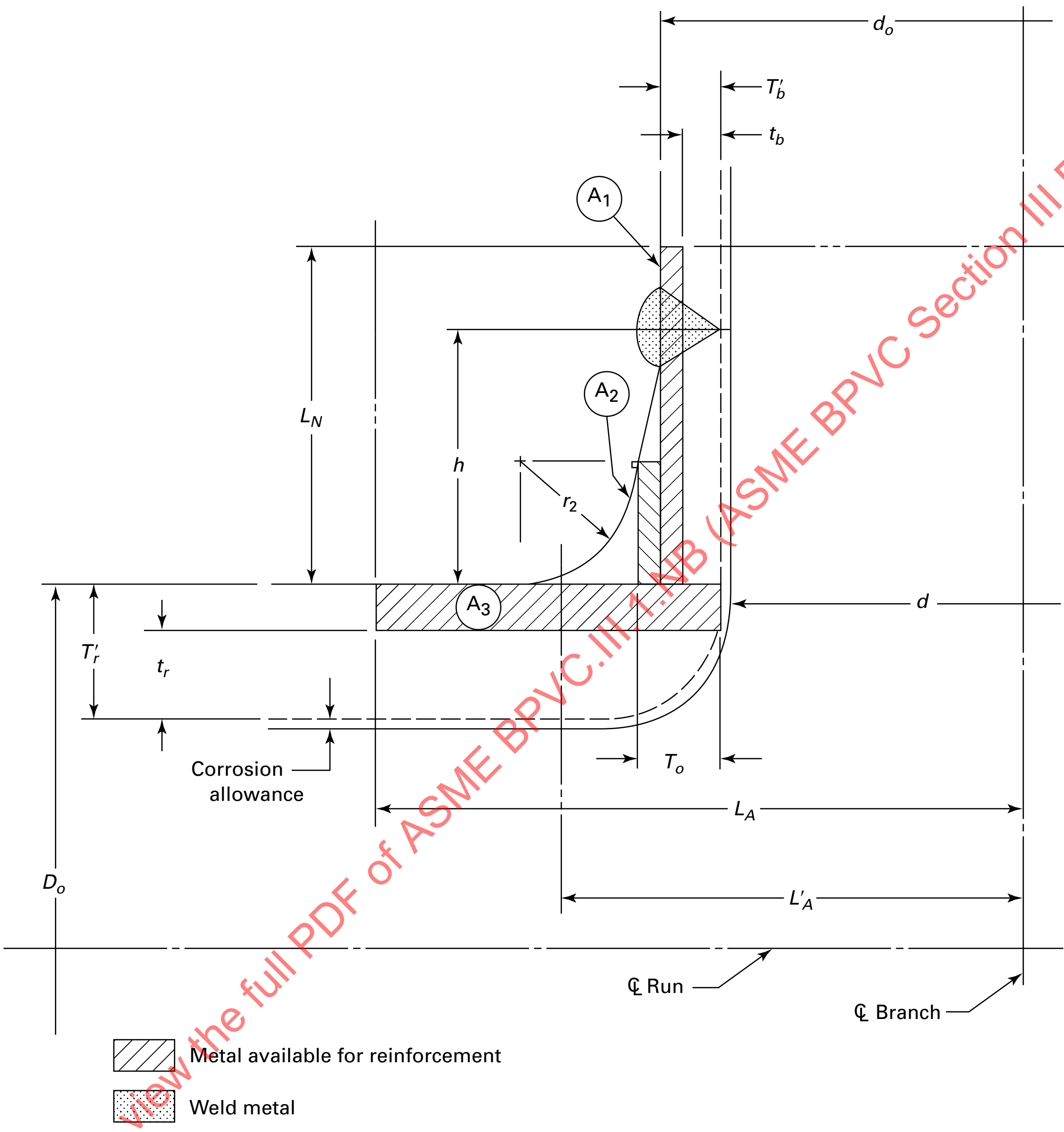


Figure NB-3643.3(a)-3
Typical Reinforced Extruded Outlet



(c) Limits of Reinforcement. The boundaries of the cross-sectional area in any plane passing through the axis of the opening within which metal may be located to have value as reinforcement are designated as the limits of reinforcement for that plane, and they are given in (1) and (2) below.

(1) The limits of reinforcement, measured along the midsurface of the nominal wall thickness of the run pipe, L_A, shall be at a distance on each side of the axis of the opening that is equal to the greater of (-a) or (-b) below:

(-a) the diameter of the finished opening in the corroded condition; or

(-b) the radius of the finished opening in the corroded condition r, plus the nominal thickness of the run pipe T_r, plus the nominal thickness of the branch wall T_b.

(-c) In addition, two-thirds of the required reinforcement shall be provided within the greater of the limit given in (-b) above and the limit L'_A that is the greater of either

$$r + 0.5\sqrt{R_m T_r}$$

or

$$r + T_b / \sin\alpha + T_r$$

(2) The limits of reinforcement measured normal to the wall of the run pipe L_N shall conform to the contour of the surface of the branch at a distance from each surface equal to the limits given in (-a) and (-b) below and as shown in Figure NB-3643.3(a)-1.

(-a) For nozzle types of Figure NB-3643.3(a)-1, sketches (a), (b), and (d):

$$L_N = 0.5\sqrt{r_m T_b} + 0.5 r_2$$

(-b) For Figure NB-3643.3(a)-1, sketch (c):

$$L_N = 0.5\sqrt{r_n T_b}$$

(d) Metal Available for Reinforcement

(1) Metal may be counted as contributing to the area of reinforcement called for in (b) if it lies within the area of reinforcement specified in (c), and it shall be limited to material that meets the requirements of (-a), (-b), and (-c) below:

(-a) metal forming a part of the run wall that is in excess of that required on the basis of NB-3641.1 and is exclusive of corrosion allowance shown in Figure NB-3643.3(a)-2;

(-b) similar excess metal in the branch wall, if the branch is integral with the run wall or is joined to it by a full penetration weld, as denoted by A_1 in Figure NB-3643.3(a)-2;

(-c) weld metal that is fully continuous with the wall of the run pipe, as denoted by area A_2 in Figure NB-3643.3(a)-2.

(2) The mean coefficient of thermal expansion of the metal to be included as reinforcement under (1)(-b) and (1)(-c) above shall be within 15% of the value for the metal in the wall of the run pipe.

(3) Metal available for reinforcement shall not be considered as applying to more than one opening.

(4) Metal not fully continuous with the run pipe, as that in branches attached by partial penetration welds, shall not be counted as reinforcement.

(e) Strength of Metal. Material used for reinforcement shall preferably be the same as that of the wall of the run pipe. If material with a lower design stress intensity S_m is used, the area provided by such material shall not be counted at full value but shall be multiplied by the ratio (less than unity) of the design stress intensity values S_m of the reinforcement material and of the run pipe material before being counted as reinforcement. No reduction in the reinforcement requirement may be taken for the increased strength of either the branch material or weld metal having a higher design stress intensity value than that of the material of the run pipe wall. The strength of the material at the point under consideration shall be used in the fatigue analysis.

(f) Requirements for Extruded Outlets. Extruded outlets shall meet all of the requirements of (a) and (b), and these rules apply only where the axis of the outlet intersects and is perpendicular to the axis of the run pipe.

(1) Geometric Requirements

(-a) An extruded outlet is one in which the extruded lip at the outlet has a height h above the surface of the run pipe that is equal to or greater than the transition radius between the extruded lip and the run pipe r_2.

(-b) The minimum value of the transition radius r_2 shall not be less than $0.05d_o$, except that on branch pipe sizes larger than 30 in. (750 mm) the transition radius need not exceed 1.5 in. (38 mm). The maximum value of the transition radius r_2 shall be limited as follows: for branch pipes nominally NPS 8 (DN 200) and larger, the dimension of the transition radius shall not exceed $0.10d_o$ + 0.50 in. (13 mm); for branch pipe sizes nominally less than NPS 8 (DN 200), r_2 shall not be greater than 1.25 in. (32 mm).

(-c) When the external contour contains more than one radius, the radius of any arc sector of approximately 45 deg shall meet the requirements given in (-b) above.

(-d) Machining shall not be employed to meet the requirements of (-b) and (-c) above.

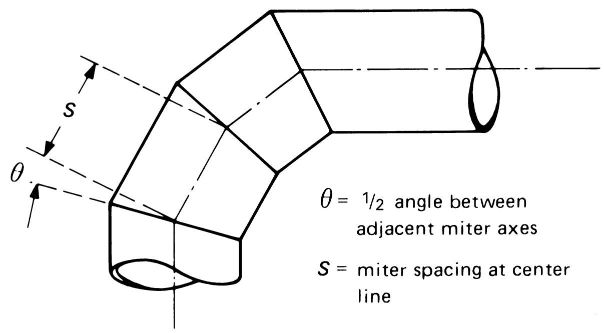
(2) Limits of Reinforcement

(-a) The height of the reinforcement zone shall be limited as shown in Figure NB-3643.3(a)-3:

$$L_N = 0.5\sqrt{d_o T_o}$$

(-b) The half width of the reinforcement zone shall be limited as shown in Figure NB-3643.3(a)-3:

Figure NB-3644(b)-1
Miter Joint Geometry



$$L_A = d$$

(3) Metal Available for Reinforcement. The reinforcement area shall be the sum of areas $A_1 + A_2 + A_3$ defined in (-a), (-b), and (-c) below and shown in Figure NB-3643.3(a)-3. Metal counted as reinforcement shall not be applied to more than one opening.

(-a) Area A_1 is the area lying within the reinforcement zone that results from any excess thickness available in the wall of the branch pipe:

$$A_1 = 2L_N(T'_b - t_b)$$

(-b) Area A_2 is the area lying within the reinforcement zone that results from excess thickness available in the lip of the extruded outlet:

$$A_2 = 2r_2(T_o - T'_b)$$

(-c) Area A_3 is the area lying within the reinforcement zone that results from any excess thickness in the run pipe wall:

$$A_3 = d(T'_r - t_r)$$

NB-3644 Miters

Mitered joints may be used in piping systems under the conditions stipulated in (a) through (d) below.

(a) The minimum thickness of a segment of a miter shall be determined in accordance with NB-3641. The minimum thickness thus determined does not allow for the discontinuity stresses that exist at the junction between segments. The discontinuity stresses are reduced for a given miter as the number of segments is increased.

(b) The angle θ in Figure NB-3644(b)-1 shall not be more than $22\frac{1}{2}$ deg.

(c) The center line distance S between adjacent miters shall be in accordance with Figure NB-3644(b)-1.

(d) Stress indices and flexibility factors shall be determined in accordance with the requirements of NB-3681(d).

NB-3646 Closures

(a) Closures in piping systems may be made by use of closure fittings, such as blind flanges or threaded or welded plugs or caps, either manufactured in accordance with standards listed in Table NCA-7100-1 and used within the specified pressure–temperature ratings, or made in accordance with (b) below.

(b) Closures not manufactured in accordance with the standards listed in Table NCA-7100-1 may be made in accordance with the rules for Class 2 vessels using the equation:

$$t_m = t + A$$

where

t = pressure design thickness, in. (mm), calculated for the given closure shape and direction of loading using appropriate equations and procedures for Class 2 Vessels, except that the symbols used to determine t shall be defined as

A = sum of mechanical allowances (see NB-3613), in. (mm)

P = Design Pressure, psi (MPa)

S = applicable design stress intensity value S_m from Section II, Part D, Subpart 1, Tables 2A and 2B, psi (MPa)

t_m = minimum required thickness, in. (mm)

(c) Connections to closures may be made by welding or extruding. Connections to the closure shall be in accordance with the limitations provided for such connections in NB-3643 and Figures NB-4243-1, NB-4244(a)-1, NB-4244(b)-1, and NB-4244(c)-1 for branch connections. If the size of the opening is greater than one-half the inside diameter of the closure, the opening should be considered as a reducer in accordance with NB-3648.

(d) Openings in closures may be reinforced in accordance with the requirements of NB-3643.

(e) Flat heads that have an opening with a diameter that does not exceed one-half of the head diameter shall have a total cross-sectional area of reinforcement not less than $dt/2$, where

d = the diameter of the finished opening, in. (mm)

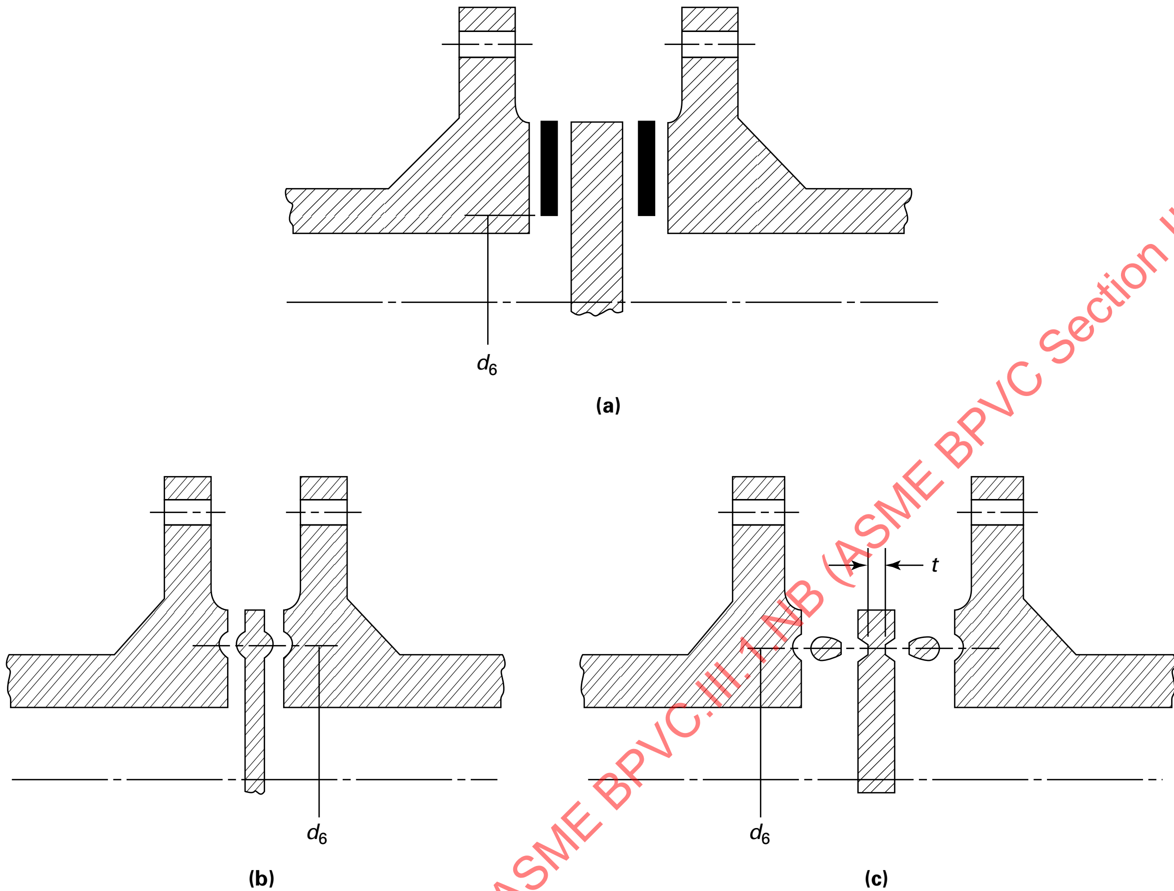
t = the design thickness for the closure, in. (mm)

NB-3647 Pressure Design of Flanged Joints and Blanks

NB-3647.1 Flanged Joints.

(a) Flanged joints manufactured in accordance with the standards listed in Table NCA-7100-1, as limited by NB-3612.1, shall be considered as meeting the requirements of NB-3640.

Figure NB-3647.2-1
Types of Permanent Blanks



(b) Flanged joints not included in Table NCA-7100-1 shall be designed in accordance with Section III Appendices, Mandatory Appendix XI, Article XI-3000, including the use of the appropriate allowable stress given in Section II, Part D, Subpart 1, Tables 1A, 1B, and 3.

NB-3647.2 Permanent Blanks. The minimum required thickness of permanent blanks (Figure NB-3647.2-1) shall be calculated from the following equations:

$$t_m = t + A \tag{7}$$

where

A = sum of the mechanical allowances, in. (mm) (see NB-3613)
t = pressure design thickness, in. (mm), calculated from eq. (8)
t_m = minimum required thickness, in. (mm)

$$t = d_6 \left(\frac{3P}{16S_m} \right)^{\frac{1}{2}} \tag{8}$$

where

d_6 = inside diameter of the gasket for raised or flat face flanges or the pitch diameter of the gasket for retained gasketed flanges, in. (mm)
P = Design Pressure, psi (MPa)
S_m = the design stress intensity value in accordance with Section II, Part D, Subpart 1, Tables 2A and 2B, psi (MPa)

NB-3647.3 Temporary Blanks. Blanks to be used for test purposes only shall have a minimum thickness not less than the Design Pressure thickness t, calculated from NB-3647.2, eq. (8), except that P shall not be less than the test pressure and the design stress intensity value S_m may be taken as 95% of the specified minimum yield strength of the blank material (Section II, Part D, Subpart 1, Table Y-1).

NB-3648 Reducers

Reducer fittings manufactured in accordance with the standards listed in Table NCA-7100-1 shall be considered suitable for use. Where butt welding reducers are made to a nominal pipe thickness, the reducers shall be considered suitable for use with pipe of the same nominal thickness.

NB-3649 Pressure Design of Other Piping Products

Other piping products manufactured in accordance with the standards listed in Table NCA-7100-1 shall be considered suitable for use provided the design is consistent with the design philosophy of this Subsection. Piping products not included in Table NCA-7100-1 may be used if they satisfy the requirements of NB-3200. The pressure design shall be based on an analysis consistent with this Subsection, or experimental stress analysis as described in Section III Appendices, Mandatory Appendix II, or an ASME B16.9 type burst test. The bursting pressure in a B16.9 type burst test shall be equal to or greater than that of the weakest pipe to be attached to the piping product, where the burst pressure [psi (MPa)] of the weakest pipe is calculated by the equation:

$$P = 2St / D_o$$

where

D_o = outside diameter of pipe, in. (mm)
S = specified minimum tensile strength of pipe material, psi (MPa)
t = minimum specified wall thickness of pipe, in. (mm)

NB-3649.1 Expansion Joints. Rules are currently under development for the application of expansion joints in piping systems. Until these rules are available, expansion joints shall not be used in piping.

NB-3650 ANALYSIS OF PIPING PRODUCTS

NB-3651 General Requirements

NB-3651.1 Piping Products for Which Stress Indices Are Given. Piping products, for which values of stress indices B, C, and K are given in NB-3683.2 and that meet the requirements of NB-3640, satisfy the design criteria of NB-3611 provided they comply with these rules. To validate a design in accordance with these rules, it is necessary to perform several flexibility analyses in accordance with the requirements of NB-3672 and to use the moments and forces obtained from these analyses as required in NB-3650.

NB-3651.2 Piping Products for Which Stress Indices Are Not Available. For analysis of flanged joints, see NB-3658. For other piping products for which stress indices are not available, see NB-3680.

NB-3651.3 Attachments.

(a) Lugs, brackets, stiffeners, and other attachments may be welded, bolted, and studded to, or bear upon the outside or inside of piping. The interaction effects of attachments on the pressure boundary, producing thermal gradients, localized bending stresses, stress concentrations, or restraint of the pressure boundary shall be considered by the piping designer. Standard clamps generally have a negligible effect on the pressure boundary. However, the effects of clamps on thin-wall piping may need to be evaluated.

(b) Attachments shall meet the requirements of NB-3135.

(c) Figure NB-4433-1 shows some typical types of attachment welds (see NB-4430).

(d) The effect of rectangular and circular cross-section welded attachments on straight pipes may be evaluated using the procedures in Section III Appendices, Nonmandatory Appendix Y.

NB-3651.4 Allowable Design Stress Intensity for Branch Connections of Different Materials. In NB-3652 through NB-3657, S_m is the allowable design stress intensity for the material under consideration. For branch connections in which the run pipe and branch connection are different materials, S_m shall be taken as the lower of the two material allowable design stress intensity values for the evaluation of the branch connection.

NB-3652 Consideration of Design Conditions

The primary stress intensity limit is satisfied if the requirement of eq. (9) is met:

$$B_1 \frac{PD_o}{2t} + B_2 \frac{D_o}{2I} M_i \leq 1.5 S_m \tag{9}$$

where

B_1, B_2 = primary stress indices for the specific product under investigation (see NB-3680)
D_o = outside diameter of pipe, in. (mm) (see NB-3683)
I = moment of inertia, in.^{4} (mm^4) (see NB-3683)
M_i = resultant moment due to a combination of Design Mechanical Loads, in.-lb (N·mm). All Design Mechanical Loads, and combinations thereof shall be provided in the Design Specification. The rules of NB-3683.1(d) shall be followed. In the combination of loads, all directional moment components in the same direction shall be combined before determining the resultant moment (i.e., resultant moments from different load sets shall not be used in calculating the moment M_i). If the method of analysis for earthquake or other dynamic loads is such that only magnitudes without relative algebraic signs are obtained, the

most conservative combination shall be assumed.

P = Design Pressure, psi (MPa)

S_m = allowable design stress intensity value at Design Temperature, psi (MPa) (Section II, Part D, Subpart 1, Tables 2A and 2B)

t = nominal wall thickness of product, in. (mm) (see NB-3683)

NB-3653 Consideration of Level A Service Limits

All load sets, for which Level A Service Limits are to be evaluated, shall satisfy the fatigue requirements of NB-3653.1 through NB-3653.6 and the thermal stress ratchet requirement of NB-3653.7. Stresses due to the effects of thermal stratification may be evaluated using Section III Appendices, Nonmandatory Appendix JJ.

NB-3653.1 Satisfaction of Primary Plus Secondary Stress Intensity Range.

(a) This calculation is based upon the effect of changes that occur in mechanical or thermal loadings that take place as the system goes from one load set, such as pressure, temperature, moment, and force loading, to any other load set that follows it in time. It is the range of pressure, temperature, and moment between two load sets that is to be used in the calculations. For example, one of the load sets to be included is that corresponding to zero pressure, zero moment, and room temperature. Equation (10) shall be satisfied for all pairs of load sets:

$$S_n = C_1\frac{P_oD_o}{2t} + C_2\frac{D_o}{2I}M_i + C_3E_{ab} \times |\alpha_aT_a - \alpha_bT_b| \leq 3S_m \qquad (10)$$

(b) If for one or more pairs of load sets (a), eq. (10) is not met, the piping product may still be satisfactory, provided that the conditions of NB-3653.6 are met or provided that the requirements of NB-3200 are satisfied.

(c) The nomenclature used in (a), eq. (10) is defined as follows:

C_1, C_2, C_3 = secondary stress indices for the specific component under investigation (see NB-3680)

D_o, t, I = as defined for NB-3652, eq. (9)

$d_a(d_b)$ = inside diameter on side *a(b)* of a gross structural discontinuity or material discontinuity, in. (mm)

E_{ab} = average modulus of elasticity of the two sides of a gross structural discontinuity or material discontinuity at room temperature, psi (MPa) (Section II, Part D, Subpart 2, Tables TM)

M_i = resultant range of moment that occurs when the system goes from one service load set to another, in.-lb (N·mm). Service loads and combinations thereof shall be provided in the Design Specification. The rules of NB-3683.1(d) shall be followed. In the combination of moments from load sets, all directional moment components in the same direction shall be combined before determining the resultant moment (i.e., resultant moments from different load sets shall not be used in calculating the moment range M_i). If both service load sets have the same weight effects, then the weight effects need not be considered in determining the loading range. If the method of analysis is such that only magnitudes without relative algebraic signs are obtained, the most conservative combination shall be assumed. If a combination includes reversing dynamic loads, M_i shall be either:

(a) the resultant range of moment due to the combination of all loads considering one-half the range of the reversing dynamic loads; or

(b) the resultant range of moment due to the full range of the reversing dynamic loads alone, whichever is greater.

P_o = range of service pressure, psi (MPa)

S_m = average of the allowable stress intensity value for the highest and the lowest temperatures of the metal during the transient, when secondary stress is due to a temperature transient at the point at which the stresses are being analyzed, or due to restraint of free-end deflection. When part or all of the secondary stress is due to mechanical load, S_m shall not exceed the allowable stress intensity value at the highest temperature during the transient.

$T_a(T_b)$ = range of average temperature on side *a(b)* of gross structural discontinuity or material discontinuity, °F (°C). For generally cylindrical shapes, the averaging of T (see NB-3653.2) shall be over a distance of $\sqrt{d_at_a}$ for T_a and over a distance of $\sqrt{d_bt_b}$ for T_b.

$t_a(t_b)$ = average wall thickness through the length $\sqrt{d_at_a}$ ($\sqrt{d_bt_b}$), in. (mm). A trial and error solution for t_a and t_b may be necessary.

$\alpha_a(\alpha_b)$ = coefficient of thermal expansion on side *a(b)* of a gross structural discontinuity or material discontinuity, at room temperature, 1/°F (1/°C) (Section II, Part D, Subpart 2, Tables TE)

NB-3653.2 Satisfaction of Peak Stress Intensity Range.

(a) For every pair of load sets (see NB-3653.1), calculate S_p values using eq. (11):

$$S_p = K_1 C_1 \frac{P_o D_o}{2t} + K_2 C_2 \frac{D_o}{2I} M_i + \frac{1}{2(1-\nu)} K_3 E\alpha \left|\Delta T_1\right| + K_3 C_3 E_{ab} \times \left|\alpha_a T_a - \alpha_b T_b\right| + \frac{1}{1-\nu} E\alpha \left|\Delta T_2\right| \quad (11)$$

NOTE: This simplified analysis is intended to provide a value of S_p that conservatively estimates the sum of (P_m or P_L) + P_b + P_e + Q + F as required in Section III Appendices, Mandatory Appendix XIII, Figure XIII-2100-1.

The nomenclature used in eq. (11) is defined as follows:

$E\alpha$ = modulus of elasticity, E, times the mean coefficient of thermal expansion, α, both at room temperature, psi/°F (MPa/°C)

K_1, K_2, K_3 = local stress indices for the specific component under investigation (see NB-3680)

$|\Delta T_1|$ = absolute value of the range of the temperature difference between the temperature of the outside surface T_o and the temperature of the inside surface T_i of the piping product assuming moment generating equivalent linear temperature distribution, °F (°C)

$|\Delta T_2|$ = absolute value of the range for that portion of the nonlinear thermal gradient through the wall thickness not included in ΔT_1 as shown below, °F (°C)

For a quantitative definition of $|\Delta T_1|$ and $|\Delta T_2|$, see (b) below. All other terms are as defined for NB-3653.1(a), eq. (10).

(b) Quantitative Definitions of $|\Delta T_1|$ and $|\Delta T_2|$. The following nomenclature is used:

T_i = value of $T(y)$ at inside surface, °F (°C)
= $T(-t/2)$

$T_j(y)$, $T_k(y)$ = temperature, as a function of radial position, for load set j and load set k, respectively, °F (°C)

T_o = value of $T(y)$ at outside surface, °F (°C)
= $T(t/2)$

$T(y)$ = temperature distribution range from condition j to condition k, °F (°C)
= $T_k(y) - T_j(y)$

t = thickness of the wall of the pipe or element, in. (mm)

y = radial position in the wall, measured positive outward from the midthickness position ($-t/2 \le y \le t/2$), in. (mm)

Then the temperature distribution range $T(y)$ may be thought of as being composed of three parts:

(1) a constant value:

$$\bar{T} = (1/t) \int_{-t/2}^{t/2} T(y) dy$$

that is the average value through the thickness. $\bar{T}$ may be used in determining free thermal expansions. Also, the values of $\bar{T}$ determined (for the same pair of load sets) or two locations a and b on either side of a gross discontinuity may be used for T_a and T_b in NB-3653.1(a), eq. (10), and NB-3653.2(a), eq. (11).

(2) a linear portion, with zero average value, having variation given by:

$$V = \left(12/t^2\right) \int_{-t/2}^{t/2} yT(y) dy$$

(3) a nonlinear portion with a zero average value and a zero first moment with respect to the mid-thickness. This decomposition of $T(y)$ into three parts is illustrated in Figure NB-3653.2(b)-1. The value of ΔT_1 to be used in (a), eq. (11) is the variation V of the linear portion:

$$\Delta T_1 = V$$

The value of ΔT_2 to be used in (a), eq. (11) is as follows:

$$\Delta T_2 = \max\left(\left|T_o - \bar{T}\right| - \frac{1}{2}\left|\Delta T_1\right|, \left|T_i - \bar{T}\right| - \frac{1}{2}\left|\Delta T_1\right|, 0\right)$$

NB-3653.3 Alternating Stress Intensity. The alternating stress intensity S_{alt} is equal to one-half the value of S_p ($S_{alt} = S_p/2$) calculated in NB-3653.2(a), eq. (11).

NB-3653.4 Use of Design Fatigue Curve. Enter the applicable design fatigue curve, Section III Appendices, Mandatory Appendix I, on the ordinate using $S_a = S_{alt}$, and find the corresponding number of cycles on the abscissa. If the service cycle being considered is the only one that produces significant fluctuating stresses, this is the allowable number of cycles.

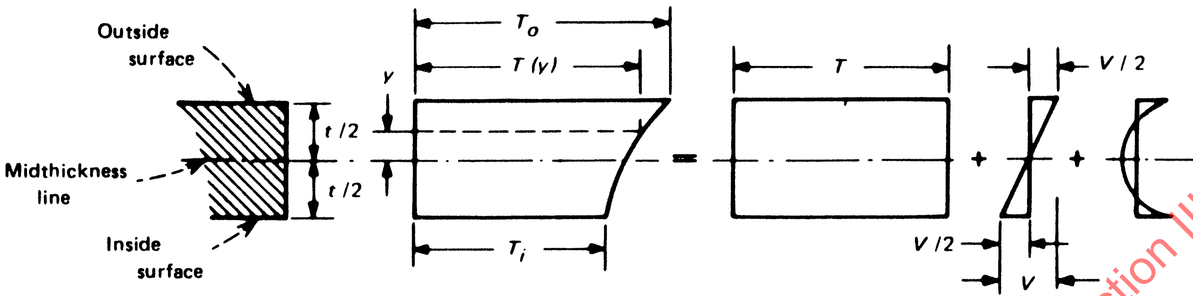
NB-3653.5 Cumulative Damage. The cumulative damage shall be evaluated in accordance with Section III Appendices, Mandatory Appendix XIII, XIII-3520(e). If N_i is greater than the maximum number of cycles defined on the applicable design fatigue curve, the value of n_i/N_i may be taken as zero.

NB-3653.6 Simplified Elastic–Plastic Discontinuity Analysis. If NB-3653.1(a), eq. (10) cannot be satisfied for all pairs of load sets, the alternative analysis described below may still permit qualifying the component under NB-3650. Only those pairs of load sets that do not satisfy NB-3653.1(a), eq. (10) need be considered.

(a) Equation (12) shall be met:

$$S_e = C_2 \frac{D_o}{2I} M_i^* \le 3S_m \quad (12)$$

Figure NB-3653.2(b)-1
Decomposition of Temperature Distribution Range



where

M_i^* = same as defined in NB-3653.1 for the pair of load sets under review except it includes only moments due to thermal expansion and thermal anchor movements, in.-lb (N·mm)

S_e = nominal value of expansion stress, psi (MPa)

S_m = the average of the tabulated S_m values for the highest and the lowest temperatures of the metal during the transient

All other variables as defined in NB-3653.1.

(b) The primary plus secondary membrane plus bending stress intensity, excluding thermal bending and thermal expansion stresses, shall be < $3S_m$. This requirement is satisfied by meeting eq. (13) below:

$$C_1 \frac{P_o D_o}{2t} + C_2 \frac{D_o M_i}{2I} + C'_3 E_{ab} \times |\alpha_a T_a - \alpha_b T_b| \leq 3S_m \quad (13)$$

where

C'_3 = values in Table NB-3681(a)-1

M_i = same as defined in NB-3653.1 for the pair of load sets under review except it excludes the moments due to thermal expansion and thermal anchor movements, in.-lb (N·mm)

S_m = as defined in NB-3653.1

All other variables as defined in NB-3653.1.

(c) If these conditions are met, the value of S_{alt} shall be calculated by eq. (14):

$$S_{alt} = K_e \frac{S_p}{2} \quad (14)$$

where

K_e = 1.0 for $S_n \leq 3S_m$

= $1.0 + \frac{(1-n)}{n(m-1)}\left(\frac{S_n}{3S_m} - 1\right)$ for $3S_m < S_n < 3mS_m$

= $1/n$ for $S_n \geq 3mS_m$

m, n = material parameters given in Section III Appendices, Mandatory Appendix XIII, Table XIII-3450-1

S_{alt} = alternating stress intensity, psi (MPa)

S_n = primary plus secondary stress intensity value calculated in NB-3653.1(a), eq. (10), psi (MPa)

S_p = peak stress intensity value calculated by NB-3653.2(a), eq. (11), psi (MPa)

S_{alt} for all load sets shall be calculated in accordance with NB-3653.3 or eq. (14). Using the alternating stress intensity values calculated by the above procedures, determine the cumulative usage factor in accordance with NB-3653.4 and NB-3653.5. The cumulative usage factor shall not exceed 1.0.

NB-3653.7 Thermal Stress Ratchet. For all pairs of load sets, the value of the range of ΔT_1 cannot exceed that calculated as follows:

$$\Delta T_1 \text{ range} \leq \frac{y' S_y}{0.7\ E\alpha} C_4$$

where

C_4 = 1.1 for ferritic material

= 1.3 for austenitic material

$E\,\alpha$ = as defined for NB-3653.2(a), eq. (11), psi/°F (MPa/°C)

P = maximum pressure for the set of conditions under consideration, psi (MPa)

S_y = yield strength value, psi (MPa), taken at average fluid temperature of the transient under consideration

$x = (PD_o/2t)\ (1/S_y)$

$$y' = \begin{cases} \frac{1}{x} & \text{for } 0 < x < 0.5 \\ 4(1 - x) & \text{for } 0.5 \le x < 1.0 \end{cases}$$

NB-3654 Consideration of Level B Service Limits

The procedures for analyzing Service Loadings for which Level B Service Limits are designated, are the same as those given in NB-3653 for Level A Service Limits. All load sets, including Level A and Level B Service Loadings, shall satisfy the fatigue requirements of NB-3653.1 through NB-3653.6 and the thermal stress ratchet requirement of NB-3653.7.

NB-3654.1 Permissible Pressure. For Level B Service Limits [NCA-2142.4(b)(2)], the permissible pressure shall not exceed the pressure P_a, calculated in accordance with NB-3641.1, eq. (3) by more than 10%. The calculation of P_a shall be based on the allowable stress intensity for the material at the coincident temperature.

NB-3654.2 Analysis of Piping Components. For Service Loadings for which Level B Service Limits are designated, the requirements of (a) or (b) below shall apply.

(a) For Service Loadings for which Level B Service Limits are designated that do not include reversing dynamic loads (see NB-3622.2) or have reversing dynamic loads combined with nonreversing dynamic loads (see NB-3622.4), the conditions of NB-3652, eq. (9) shall be met using Service Level B coincident pressure P and moments M_i that result in the maximum calculated stress. The allowable stress to be used for this condition is $1.8S_m$, but not greater than $1.5S_y$.

S_m = allowable design stress intensity value at a temperature consistent with the loading under consideration, psi (MPa)

S_y = material yield strength at a temperature consistent with the loading under consideration, psi (MPa)

(b) For Service Loadings for which Level B Service Limits are designated that include reversing dynamic loads that are not required to be combined with nonreversing dynamic loads, the requirements of NB-3653 for Level A Service Limits shall be met. In addition, any deflection limits prescribed by the Design Specification must be satisfied.

NB-3655 Consideration of Level C Service Limits

NB-3655.1 Permissible Pressure. When Level C Service Limits [NCA-2142.4(b)(3) and NB-3113(b)] are specified, the permissible pressure shall not exceed the pressure P_a, calculated in accordance with NB-3641.1, eq. (3) by more than 50%. The calculation of P_a shall be based on the allowable stress intensity for the material at the coincident temperature.

NB-3655.2 Analysis of Piping Components. For Service Loadings for which Level C Service Limits [NCA-2142.4(b)(3) and NB-3113(b)] are designated, the following requirements shall apply.

(a) For Service Loadings for which Level C Service Limits are designated except as permitted by (b) below, the conditions of NB-3652, eq. (9) shall be met using Service Level C coincident pressure P and moments M_i that result in the maximum calculated stress. The allowable stress to be used for this condition is $2.25S_m$ but not greater than $1.8S_y$. In addition, if the effects of anchor motion, M_{AM}, from reversing dynamic loads are not considered in NB-3654, then the requirements of NB-3656(b)(4) shall be satisfied using 70% of the allowable stress given in NB-3656(b)(4).

S_m = allowable design stress intensity value at a temperature consistent with the loading under consideration, psi (MPa)

S_y = material yield strength at a temperature consistent with the loading under consideration, psi (MPa)

(b) As an alternative to (a), for Service Loadings for which Level C Service Limits are designated, which include reversing dynamic loads (see NB-3622.2) that are not required to be combined with nonreversing dynamic loads (see NB-3622.2), the requirements of NB-3656(b) shall be satisfied using the allowable stress in NB-3656(b)(2), 70% of the allowable stress in NB-3656(b)(3), and 70% of the allowable loads in NB-3656(b)(4).

NB-3655.3 Deformation Limits. Any deformation or deflection limits prescribed by the Design Specifications shall be considered with respect to Level C Service Limits.

NB-3656 Consideration of Level D Service Limits

If the Design Specifications specify any Service Loading for which Level D Limits are designated [NCA-2142.2(b)(4)], the following requirements shall apply.

(a) For Service Loadings for which Level D Service Limits are designated except as permitted by (b) below, the requirements of (1), (2), and (3) below shall apply.

(1) The permissible pressure shall not exceed 2.0 times the pressure P_a calculated in accordance with NB-3641.1, eq. (3). The calculation of P_a shall be based

on the allowable stress intensity for the material at the coincident temperature.

(2) The conditions of NB-3652, eq. (9) shall be met using Service Level D coincident pressure P and moment M_i, which results in the maximum calculated stress. The allowable stress to be used for this condition is $3.0S_m$, but not greater than $2.0S_y$.

S_m = allowable design stress intensity value at a temperature consistent with the loading under consideration, psi (MPa)

S_y = material yield strength at a temperature consistent with the loading under consideration, psi (MPa)

(3) If the effects of anchor motion, M_{AM}, from reversing dynamic loads are not considered in NB-3654, then the requirements of (b)(4) shall be satisfied.

(b) As an alternative to (a), for piping fabricated from material designated P-No. 1 through P-No. 9 in Section II, Part D, Subpart 1, Table 2A and limited to $D_O/t_n \leq 40$ if Level D Service Limits are designated that include reversing dynamic loads (see NB-3622.2) that are not required to be combined with nonreversing dynamic loads (see NB-3622.4), the requirements of (1) through (5) below shall apply.

(1) The pressure occurring coincident with the earthquake or other reversing type loading, P_E, shall not exceed the Design Pressure.

(2) The sustained stress due to weight loading shall not exceed the following:

$$B_2 \frac{D_o}{2I} M_W \leq 0.5\, S_m$$

where

M_W = resultant moment due to weight effects, in.-lb (N·mm) (see NB-3623)

S_m = allowable design stress intensity value at a temperature consistent with the loading under consideration, psi (MPa)

(3) The stress due to weight and inertial loading due to reversing dynamic loads in combination with the Level D coincident pressure shall not exceed the following:

$$B_1 \frac{P_E D_o}{2t} + B_2{'} \frac{D_o}{2I} M_E \leq 3S_m$$

where

$B_2{'}$ = B_2 from Table NB-3681(a)-1, except as follows:

$B_2{'}$ = 1.33 for girth butt welds between items that do *not* have nominally identical wall thicknesses [see NB-3683.4(b)]

= $0.87/h^{2/3}$ for curved pipe or butt-welding elbows (h as defined in NB-3683.7), but not less than 1.0

$B_{2b}{'}$ = $0.27(R_m/T_r)^{2/3}$ and

$B_{2r}{'}$ = $0.33(R_m/T_r)^{2/3}$ for ASME B16.9 or MSS SP-87 butt-welding tees (terms as defined in NB-3683), but neither less than 1.0

M_E = the amplitude of the resultant moment due to weight and the inertial loading resulting from reversing dynamic loads, in.-lb (N·mm). In the combination of loads, all directional moment components in the same direction shall be combined before determining the resultant moment. If the method of analysis is such that only magnitude without algebraic signs is obtained, the most conservative combination shall be assumed.

P_E = the pressure occurring coincident with the reversing dynamic load, psi (MPa)

S_m = allowable design stress intensity value at a temperature consistent with the loading under consideration, psi (MPa)

(4) The range of the resultant moment M_{AM} and the amplitude of the longitudinal force F_{AM} resulting from the anchor motions due to earthquake and other reversing type dynamic loading shall not exceed the following:

$$C_2 \frac{M_{AM}\, D_o}{2I} < 6.0S_m$$

$$\frac{F_{AM}}{A_M} < S_m$$

where

A_M = cross-sectional area of metal in the piping component wall, in.^{2} (mm^2)

S_m = allowable design stress intensity value at a temperature consistent with the loading under consideration, psi (MPa)

(5) The use of the $6S_m$ limit in (4) assumes essentially linear behavior of the entire piping system. This assumption is sufficiently accurate for systems where plastic straining occurs at many points or over relatively wide regions, but fails to reflect the actual strain distribution in unbalanced systems where only a small portion of the piping undergoes plastic strain. In these cases, the weaker or higher stressed portions will be subjected to strain concentrations due to elastic follow-up of the stiffer or lower stressed portions. Unbalance can be produced

(-a) by the use of small pipe runs in series with larger or stiffer pipe, with the small lines relatively highly stressed.

(-b) by local reduction in size or cross section, or local use of a weaker material.

In the case of unbalanced systems, the design shall be modified to eliminate the unbalance or the piping shall be qualified to the equations given in (4) with allowable $6S_m$ replaced by $3S_m$.

(6) Piping displacements shall satisfy Design Specification limitations.

(c) As an alternative to (a) and (b), the rules contained in Section III Appendices, Mandatory Appendix XIII, XIII-3144(a) and XIII-3144(b) or Section III Appendices, Mandatory Appendix XXVII may be used in evaluating these service loadings independently of all other Design and Service Loadings. When using Section III Appendices, Mandatory Appendix XXVII, the exclusion of XXVII-1300 shall not apply to anchor motion effects and the secondary stresses resulting from anchor motion effects shall be considered if either of the following applies:

(1) The loads under consideration are reversing dynamic loads in combination with nonreversing dynamic loads and the anchor motion effects were not considered in NB-3654.

(2) The loads under consideration are reversing dynamic loads not in combination with nonreversing dynamic loads.

NB-3657 Test Loadings

The evaluation of Test Loadings shall be carried out in accordance with Section III Appendices, Mandatory Appendix XIII, XIII-3600.

NB-3658 Analysis of Flanged Joints

The pressure design of flanged joints is covered by NB-3647.1. Flanged joints subjected to combinations of moment and pressure shall meet the requirements of this paragraph. In addition, the pipe-to-flange welds shall meet the requirements of NB-3652 through NB-3656 using appropriate stress indices from Table NB-3681(a)-1. Flanged joints using flanges, bolting, and gaskets as specified in ASME B16.5 and using a bolt material having an S_m value at 100°F (38°C) not less than 20.0 ksi (138 MPa) may be analyzed in accordance with the following rules or in accordance with NB-3200. Other flanged joints shall be analyzed in accordance with NB-3200.

NB-3658.1 Design Limits, Level A and B Service Limits.

(a) The pressure shall not exceed the rated pressure for Level A Service Limits or 1.1 times the rated pressure for Level B Service Limits.

(b) The bolting shall meet the requirements of Section III Appendices, Mandatory Appendix XIII, XIII-4200. In addition, the limitations given by eqs. (15) and (16) shall be met:

(U.S. Customary Units)

$$M_{fs} \le 3{,}125 \left(S_y/36{,}000\right) CA_b \qquad (15)$$

(SI Units)

$$M_{fs} \le 21.7 \left(S_y/250\right) CA_b$$

where

A_b = total cross-sectional area of bolts at root of thread or section of least diameter under stress, in.^{2} (mm^2)

C = diameter of bolt circle, in. (mm)

M_{fs} = bending or torsional moment (considered separately) applied to the joint due to weight, thermal expansion of the piping, sustained anchor movements, relief valve steady-state thrust, and other sustained mechanical loads applied to the flanged joint during the design or service conditions, in.-lb. (N·mm). If cold springing is used, the moment may be reduced to the extent permitted by NB-3672.8.

S_y = yield strength of flange material at Design Temperature (Section II, Part D, Subpart 1, Table Y-1), psi (MPa). The value of $S_y/36{,}000$ ($S_y/250$) shall not be taken as greater than unity.

(U.S. Customary Units)

$$M_{fd} \le 6{,}250 \left(S_y/36{,}000\right) CA_b \qquad (16)$$

(SI Units)

$$M_{fd} \le 43.4 \left(S_y/250\right) CA_b$$

where

M_{fd} = bending or torsional moment (considered separately) as defined for M_{fs}, but including dynamic loadings, in.-lb (N·mm)

NB-3658.2 Level C Service Limits.

(a) The pressure shall not exceed 1.5 times the rated pressure.

(b) The limitation given by eq. (17) shall be met:

(U.S. Customary Units)

$$M_{fd} \le \left[11{,}250A_b - (\pi/16)D_f^{\,2}P_{fd}\right]C\left(S_y/36{,}000\right) \qquad (17)$$

(SI Units)

$$M_{fd} \le \left[78.1A_b - (\pi/16)D_f^{\,2}P_{fd}\right]C\left(S_y/250\right)$$

where

D_f = outside diameter of raised face, in. (mm)

P_{fd} = pressure concurrent with M_{fd}, psi (MPa)

M_{fd}, C, S_y, the limitation on S_y /36,000 (S_y /250), and A_b are defined in NB-3658.1(b).

NB-3658.3 Level D Service Limits.

(a) The pressure shall not exceed 2.0 times the rated pressure.

(b) The limitation given by NB-3658.2(b), eq. (17) shall be met, where P_{fd} and M_{fd} are pressures, psi (MPa), and moments, in.-lb (N·mm), occurring concurrently.

NB-3658.4 Test Loadings. Analysis for Test Loadings is not required.

NB-3660 DESIGN OF WELDS

NB-3661 Welded Joints

NB-3661.1 General Requirements. Welded joints shall be made in accordance with NB-4200.

NB-3661.2 Socket Welds.

(a) Socket welded piping joints shall be limited to pipe sizes of NPS 2 (DN 50) and less.

(b) Socket welds shall comply with the requirements of NB-4427. Socket welds shall not be used where the existence of crevices could accelerate corrosion.

NB-3661.3 Fillet Welds and Partial Penetration Welds for Branch Connections. Fillet welds and partial penetration welds are allowed for branch connections provided the following requirements of (a) and (b) are met:

(a) The ratio of the run pipe NPS to the branch NPS shall not be less than 10; the branch shall not be larger than NPS 2; and, all reinforcement for the opening required by NB-3643.3 shall be provided in the wall of the run pipe.

(b) The welds are fillet or groove welds as shown in Figure NB-4246(b)-1. These welds shall allow for examination in accordance with NB-5245.

NB-3670 SPECIAL PIPING REQUIREMENTS

NB-3671 Selection and Limitation of Nonwelded Piping Joints

The type of piping joint used shall be suitable for the Design Loadings and shall be selected with consideration of joint tightness, mechanical strength, and the nature of the fluid handled. Piping joints shall conform to the requirements of this Subsection with leak tightness being a consideration in selection and design of joints for piping systems to satisfy the requirements of the Design Specifications.

NB-3671.1 Flanged Joints. Flanged joints are permitted.

NB-3671.2 Expanded Joints. Expanded joints shall not be used.

NB-3671.3 Threaded Joints. Threaded joints in which the threads provide the only seal shall not be used. If a seal weld is employed as the sealing medium, the stress analysis of the joint must include the stresses in the weld resulting from the relative deflections of the mated parts.

NB-3671.4 Flared, Flareless, and Compression Joints. Flared, flareless, and compression type tubing fittings may be used for tubing sizes not exceeding 1 in. O.D. (25 mm) within the limitations of applicable standards and specifications listed in Table NCA-7100-1 and requirements (b) and (c) below. In the absence of such standards or specifications, the Designer shall determine that the type of fitting selected is adequate and safe for the Design Loadings in accordance with the requirements of (a), (b), and (c) below.

(a) The pressure design shall meet the requirements of NB-3649.

(b) Fittings and their joints shall be suitable for the tubing with which they are to be used in accordance with the minimum wall thickness of the tubing and method of assembly recommended by the manufacturer.

(c) Fittings shall not be used in services that exceed the manufacturer's maximum pressure–temperature recommendations.

NB-3671.5 Caulked Joints. Caulked or leaded joints shall not be used.

NB-3671.6 Brazed and Soldered Joints.

(a) *Brazed Joints*

(1) Brazed joints of a maximum nominal pipe size of 1 in. (DN 25) may be used only at dead end instrument connections and in special applications where space and geometry conditions prevent the use of joints permitted under NB-3661.2, NB-3661.3, and NB-3671.4. The depth of socket shall be at least equal to that required for socket welding fittings and shall be of sufficient depth to develop a rupture strength equal to that of the pipe at Design Temperature (see NB-4500).

(2) Brazed joints that depend upon a fillet rather than a capillary type filler addition are not acceptable.

(3) Brazed joints shall not be used in systems containing flammable fluids or in areas where fire hazards are involved.

(b) *Soldered Joints*. Soldered joints shall not be used.

NB-3671.7 Sleeve Coupled and Other Patented Joints. Mechanical joints, for which no standards exist, and other patented joints may be used provided the requirements of (a), (b), and (c) below are met.

(a) Provision is made to prevent separation of the joints under all Service Loadings.

(b) They are accessible for maintenance, removal, and replacement after service.

(c) Either of the following two criteria are met.

(1) A prototype joint has been subjected to performance tests to determine the safety of the joint under simulated service conditions. When vibration, fatigue, cyclic conditions, low temperature, thermal expansion, or hydraulic shock is anticipated, the applicable conditions shall be incorporated in the tests. The mechanical joints shall be sufficiently leak tight to satisfy the requirements of the Design Specifications.

(2) Joints are designed in accordance with the rules of NB-3200.

NB-3672 Expansion and Flexibility

(a) In addition to meeting the design requirements for pressure, weight, and other loadings, piping systems shall be designed to absorb or resist thermal expansion or contraction or similar movements imposed by other sources and shall meet the criteria for allowable stress intensity as specified in NB-3611. Piping systems shall be designed to have sufficient flexibility to prevent the movements from causing:

(1) failure of piping or anchors from overstress or overstrain;

(2) leakage at joints;

(3) detrimental distortion of connected equipment resulting from excessive thrusts and moments.

(b) The effects of stresses, caused by pressure, thermal expansion, and other loads and their stress intensification factors, shall be considered cumulatively.

NB-3672.1 Properties. Thermal expansion data and moduli of elasticity shall be determined from Section II, Part D, Subpart 2, Tables TE and TM, which cover more commonly used piping materials. For materials not included in these tables, reference shall be to authoritative source data, such as publications of the National Institute of Standards and Technology.

NB-3672.2 Unit Thermal Expansion Range. The unit thermal expansion range in in./100 ft (mm/m), used in calculating the expansion range, shall be determined from Section II, Part D, Subpart 2, Tables TE as the algebraic difference between the unit expansion shown for the highest metal temperature and that for the lowest metal temperature resulting from service or shutdown conditions.

NB-3672.3 Moduli of Elasticity. The moduli of elasticity for ferrous and nonferrous materials shall be as given in Section II, Part D, Subpart 2, Tables TM.

NB-3672.4 Poisson's Ratio. When required for flexibility calculations, Poisson's ratio shall be taken as 0.3 for all metals at all temperatures.

NB-3672.5 Stresses. Flexibility calculations of the moments and forces in the piping system due to thermal expansion and end motions shall be based on the hot modulus E_h. Calculations for the expansion stresses shall be based on the least cross-sectional area of the pipe or fitting, using nominal dimensions. The expansion stress computed from the forces and moments shall be multiplied by the ratio E_c/E_h, where E_c is the modulus of elasticity at room temperature. The effect of expansion stresses in combination with stresses from other causes shall be evaluated in accordance with NB-3611 or NB-3630.

NB-3672.6 Method of Analysis. All systems shall be analyzed for adequate flexibility by a rigorous structural analysis unless they can be judged technically adequate by an engineering comparison with previously analyzed systems.

NB-3672.7 Basic Assumptions and Requirements.

(a) When calculating the flexibility of a piping system between anchor points, the system between the anchor points shall be treated as a whole. The significance of all parts of the line and of all restraints, such as supports or guides, including intermediate restraints introduced for the purpose of reducing moments and forces on equipment or small branch lines, shall be considered.

(b) Comprehensive calculations shall take into account the flexibility factors and stress indices found to exist in piping products other than straight pipe. Credit may be taken where extra flexibility exists in the piping system. Flexibility factors and stress indices are given in NB-3680.

(c) The total expansion range shall be used in all calculations whether or not the piping is cold sprung. Not only the expansion of the line itself, but also linear and angular movements of the equipment and supports to which it is attached, shall be considered.

(d) Where assumptions are used in calculations or model tests, the likelihood of underestimates of forces, moments, and stresses, including the effects of stress intensification, shall be evaluated.

NB-3672.8 Cold Springing. Cold springing provides a beneficial effect in assisting a system to attain its most favorable position sooner. The effect of cold springing shall be analyzed as any other movement in the system is analyzed. The maximum stress allowed due to cold springing is $2.0S_m$ at the cold spring temperature. Since the usual erection procedures may not permit accurate determination of cold spring in a piping system, the allowable reduction of forces and moments at anchors or equipment caused by cold springing shall be limited to no more than two-thirds of the calculated reduction.

NB-3674 Design of Pipe Supports

Pipe supports shall be designed in accordance with the requirements of Subsection NF.

NB-3677 Pressure Relief Piping

NB-3677.1 General Requirements. Pressure relief piping within the scope of this Subsection shall be supported to sustain reaction forces and shall conform to the requirements of the following subparagraphs.

NB-3677.2 Piping to Pressure-Relieving Safety Devices.

(a) Piping that connects a pressure-relieving safety device to a piping system shall comply with all the requirements of the class of piping of the system that it is designated to relieve.

(b) There shall be no intervening stop valves between systems being protected and their protective device or devices except as provided for in NB-7142.

NB-3677.3 Discharge Piping From Pressure-Relieving Safety Devices.

(a) Discharge piping from pressure-relieving safety devices shall comply with the requirements applicable to the conditions under which it operates.

(b) There shall be no intervening stop valve between the protective device or devices and the point of discharge except as provided for in NB-7142.

(c) The effluent from relief devices may be discharged outside the containment only if adequate provisions are made for the safe disposal of the effluent. It shall not impinge on other piping or structure or equipment and shall be directed away from platforms and other areas that might be used by personnel.

(d) It is recommended that individual discharge lines be used. For requirements on discharge piping, see NB-7141(f).

(e) When the umbrella or drip pan type of connection between the pressure-relieving safety device and the discharge piping is used, the discharge piping shall be so designed as to prevent binding due to expansion movements and shall be so dimensioned as to prevent the possibility of blow back of the effluent. Individual discharge lines shall be used in this application. Drainage shall be provided to remove water collected above the safety valve seat.

(f) Discharge lines from pressure-relieving safety devices within the scope of this Subsection shall be designed to facilitate drainage if there is any possibility that the effluent can contain liquid.

NB-3680 STRESS INDICES AND FLEXIBILITY FACTORS

NB-3681 Scope

(a) There are two types of analyses allowed by the rules of this subarticle. The applicable B, C, and K indices to be used with NB-3652, eq. (9), NB-3653.1(a), eq. (10), and NB-3653.2(a), eq. (11) are given in Table NB-3681(a)-1. The applicable indices to be used with the detailed analysis of Section III Appendices, Mandatory Appendix XIII are given in NB-3685 and NB-3338.

(b) Methods of determining flexibility factors for some commonly used piping products are given in NB-3686.

(c) Values of stress indices are tabulated for commonly used piping products and joints. Unless specific data, which shall be referenced in the Design Report, exist that would warrant lower stress indices than those tabulated or higher flexibility factors than those calculated by the methods of NB-3686, the stress indices given shall be used as minimums and the flexibility factors shall be used as maximums.

(d) For piping products not covered by NB-3680, stress indices and flexibility factors shall be established by experimental analysis (Section III Appendices, Mandatory Appendix II) or theoretical analysis. Such test data or theoretical analysis shall be included in the Design Report.

(e) When determining stress indices by experimental methods, the nominal stress at the point under consideration (crack site, point of maximum stress intensity, etc.) shall be used.

NB-3682 Definitions of Stress Indices and Flexibility Factors

(a) The general definition of a stress index for mechanical loads is:

$$B,\ C,\ K,\ \text{or}\ i\ =\ \frac{\sigma}{S}$$

where

S = nominal stress, psi (MPa), due to load L
σ = elastic stress, psi (MPa), due to load L

For B indices, σ represents the stress magnitude corresponding to a limit load. For C or K indices, σ represents the maximum stress intensity due to load L. For i factors, σ represents the principal stress at a particular point, surface, and direction due to load L.

(b) The general definition of a stress index for thermal loads is:

$$C\ \text{or}\ K\ =\ \frac{\sigma}{E\alpha\Delta T}$$

where

E = modulus of elasticity, psi (MPa)
α = coefficient of thermal expansion, 1/°F (1/°C)
ΔT = thermal difference, °F (°C)
σ = maximum stress intensity, psi (MPa), due to thermal difference ΔT

The values of E, α, and ΔT are defined in detail in NB-3650.

Table NB-3681(a)-1
Stress Indices for Use With Equations in NB-3650

Piping Products and Joints [Note (3)]	Applicable for $D_o/t \le 100$ for C or K Indices and $D_o/t \le 50$ for B Indices [Note (1)]									Notes
	Internal Pressure [Note (2)]			Moment Loading [Note (2)]			Thermal Loading			
	B_1	C_1 [Note (4)]	K_1 [Note (4)]	B_2	C_2 [Note (4)]	K_2 [Note (4)]	C_3	C_3'	K_3 [Note (4)]	
Straight pipe, remote from welds or other discontinuities	0.5	1.0	1.0	1.0	1.0	1.0	0.6	0.5	1.0	(5)
Longitudinal butt welds in straight pipe										
(a) flush	0.5	1.0	1.1	1.0	1.0	1.1	1.0	...	1.1	(6)
(b) as-welded $t > 3/16$ in. (5 mm)	0.5	1.1	1.2	1.0	1.2	1.3	1.0	...	1.2	(6)
(c) as-welded $t \le 3/16$ in. (5 mm)	0.5	1.4	2.5	1.0	1.2	1.3	1.0	...	1.2	(6)
Girth butt welds between nominally identical wall thickness items										
(a) flush	0.5	1.0	1.1	1.0	1.0	1.1	0.60	0.50	1.1	(7)
(b) as-welded	0.5	1.0	1.2	1.0	...	1.8	0.60	0.50	1.7	(7)
Girth fillet weld to socket weld, fittings, socket weld valves, slip-on or socket welding flanges	...	...	3.0	...	...	2.0	2.0	1.0	3.0	(8)
NB-4250 transitions										
(a) flush	0.5	...	1.1	1.0	...	1.1	...	1.0	1.1	(9)
(b) as-welded	0.5	...	1.2	1.0	...	1.8	...	1.0	1.7	(9)
Transitions within a 1:3 slope envelope										
(a) flush	0.5	...	1.2	1.0	...	1.1	...	0.60	1.1	(10)
(b) as-welded	0.5	...	1.2	1.0	...	1.8	...	0.60	1.7	(10)
Butt welding reducers per ASME B16.9 or MSS SP-87	...	...	...	1.0	...	...	1.0	0.5	1.0	(11)
Curved pipe or butt welding elbows	...	...	1.0	...	...	1.0	1.0	0.5	1.0	(12)
Branch connections per NB-3643	0.5	...	2.0	...	...	...	1.8	1.0	1.7	(13)
Butt welding tees	0.5	1.5	4.0	...	...	...	1.0	0.5	1.0	(14)

GENERAL NOTE: For indices not listed, see the note referenced at the end of the applicable line.

NOTES:

(1) For products and joints with $50 < D_o/t \le 100$, see NB-3683.2(c).

(2) For the calculation of pressure and moment loads and special instructions regarding NB-3652, eq. (9) through NB-3653.6(b), eq. (13), see NB-3683.1(d).

(3) For definitions, applicability, and specific restrictions, see NB-3683.

(4) For special instructions regarding the use of these indices for welded products, intersecting welds, abutting products, or out-of-round products, see NB-3683.2.

(5) See NB-3683.3, Straight Pipe Remote From Welds.

(6) See NB-3683.4(a), Longitudinal Butt Welds.

(7) See NB-3683.4(b), Girth Butt Welds.

(8) See NB-3683.4(c), Girth Fillet Welds.

(9) See NB-3683.5(a), NB-4250 Transitions.

(10) See NB-3683.5(b), Transitions Within a 1:3 Slope.

(11) See NB-3683.6, Concentric and Eccentric Reducers.

(12) See NB-3683.7, Curved Pipe or Butt Welding Elbows. See also NB-3683.2(a) and NB-3683.2(b).

(13) See NB-3683.8, Branch Connections per NB-3643. See also NB-3683.1(d).

(14) See NB-3683.9, Butt Welding Tees. See also NB-3683.1(d).

(c) Flexibility factors are identified herein by k with appropriate subscripts. The general definition of a flexibility factor is:

$$k = \theta_{ab} / \theta_{\text{nom}}$$

where

θ_{ab} = rotation of end a, with respect to end b, due to a moment load M and in the direction of the moment M
θ_{nom} = nominal rotation due to moment load M

The flexibility factor k and nominal rotation θ_{nom} are defined in detail for specific components in NB-3686.

NB-3683 Stress Indices for Use With NB-3650

The stress indices given herein and in Table NB-3681(a)-1 and subject to the additional restrictions specified herein are to be used with the analysis methods of NB-3650. For piping products outside the applicable range, stress indices shall be established in accordance with NB-3681.

NB-3683.1 Nomenclature.

(a) *Dimensions.* Nominal dimensions as specified in the dimensional standards of Table NCA-7100-1 shall be used for calculating the numerical values of the stress indices given herein and in Table NB-3681(a)-1, and for evaluating NB-3652, eq. (9) through NB-3653.6(c), eq. (14). For ASME B16.9 or MSS SP-87 piping products, the nominal dimensions of the equivalent pipe (for example, Schedule 40) as certified by the manufacturer shall be used. Not more than one equivalent pipe size shall be certified for given product items of the same size, shape, and weight.

For piping products such as reducers and tapered-wall transitions that have different dimensions at either end, the nominal dimensions of the large or small end, whichever gives the larger value of D_o/t, shall be used. Dimensional terms are defined as follows:

D_o = nominal outside diameter of pipe, in. (mm)
D_i = nominal inside diameter of pipe, in. (mm)
D_m = mean diameter of designated run pipe, in. (mm) [see NB-3683.8(c) and Figure NB-3643.3(a)-1]
= $2R_m = (D_o - T_r)$
$D_{\max}$ = maximum outside diameter of cross section, in. (mm)
$D_{\min}$ = minimum outside diameter of cross section, in. (mm)
D_1 = nominal outside diameter at large end of concentric and eccentric reducers, in. (mm) (see NB-3683.6)
D_2 = nominal outside diameter at small end of concentric and eccentric reducers, in. (mm) (see NB-3683.6)
d_o = nominal outside diameter of attached branch pipe, in. (mm)
d_i = nominal inside diameter of branch, in. (mm)
d_m = nominal mean diameter of reinforced or unreinforced branch, in. (mm) [see NB-3683.8(c)]
= $(d_i + t_n)$
h = characteristic bend parameter of a curved pipe or butt welding elbow
= tR/r_m^2
I = moment of inertia of pipe, in.^{4} (mm^4)
= $0.0491\ (D_o^4 - D_i^4)$
L_1 = height of nozzle reinforcement for branch connections, in. (mm) [see Figure NB-3643.3(a)-1]
L_1, L_2 = length of cylindrical portion at the large end and small end of a reducer, respectively, in. (mm) (see NB-3683.6)
R = nominal bend radius of curved pipe or elbow, in. (mm)
R_m = mean radius of designated run pipe, in. (mm) [see NB-3683.8 and Figure NB-3643.3(a)-1]
= $(D_o - T_r)/2$
r_i = inside radius of branch, in. (mm) [see Figure NB-3643.3(a)-1]
= $d_i/2$
r_m = mean pipe radius, in. (mm)
= $(D_o - t)/2$
r'_m = mean radius of attached branch pipe, in. (mm) [see Figure NB-3643.3(a)-1]
= $(d_o - T'_b)/2$
r_p = outside radius of reinforced nozzle or branch connection, in. (mm) [see Figure NB-3643.3(a)-1]
r_1, r_2, r_3 = designated radii for reinforced branch connections, concentric and eccentric reducers, in. (mm) [see NB-3683.6, NB-3683.8, and Figure NB-3643.3(a)-1]
T_b = wall thickness of branch connection reinforcement, in. (mm) [see Figure NB-3643.3(a)-1]
T'_b = nominal wall thickness of attached branch pipe, in. (mm) [see Figure NB-3643.3(a)-1]
T_r = nominal wall thickness of designated run pipe, in. (mm) [see Figure NB-3643.3(a)-1]
t = nominal wall thickness of pipe, in. (mm). For piping products purchased to a minimum wall specification, the nominal wall thickness shall be taken as 1.14 times the minimum wall.

t_{max} = maximum wall thickness of a welding transition within a distance of $\sqrt{D_o t}$ from the welding end, in. (mm) [see NB-3683.5(b)], in. (mm)

t_n = wall thickness of nozzle or branch connection reinforcement, in. (mm) (see NB-3683.8; also used for concentric and eccentric reducers, see NB-3683.6)

t_1 = nominal wall thickness at large end of concentric and eccentric reducers, in. (mm) (see NB-3683.6)

t_2 = nominal wall thickness at small end of concentric and eccentric reducers, in. (mm) (see NB-3683.6)

t_{1m}, t_{2m} = minimum wall thickness at the large end and small end of a reducer, respectively, that is required to resist the Design Pressure P in accordance with NB-3641.1, eq. (1), in. (mm)

Z = section modulus of pipe, in.^{3} (mm^3)
= $2I/D_o$

Z_b = approximate section modulus of attached branch pipe, in.^{3} (mm^3)
= $\pi(r'_m)^2 T'_b$

Z_r = approximate section modulus of designated run pipe, in.^{3} (mm^3)
= $\pi(R_m)^2 T_r$

α = cone angle of concentric and eccentric reducers, deg (see NB-3683.6)

Δ = radial weld shrinkage measured from the nominal outside surface, in. (mm)

θ_n = slope of nozzle-to-pipe transition for branch connections, deg [see Figure NB-3643.3(a)-1]

(b) Material Properties. Unless otherwise specified, material properties at the appropriate temperature, as given in Section II, Part D, Subparts 1 and 2, shall be used. Terms are defined as follows:

E = modulus of elasticity for the material at room temperature, psi (MPa), taken from Section II, Part D, Subpart 2, Tables TM

M = materials constant
= 2, for ferritic steels and nonferrous materials except nickel–chrome–iron alloys and nickel–iron–chrome alloys
= 2.7, for austenitic steel, nickel–chrome–iron alloys and nickel–iron–chrome alloys [see NB-3683.2(b)]

S_y = yield strength of the material at the Design Temperature, psi (MPa), taken from Section II, Part D, Subpart 1, Table Y-1

ν = Poisson's ratio
= 0.3

(c) Connecting Welds. Connecting welds in accordance with the requirements of this Subsection are defined as either *flush* or *as-welded* welds.

(1) Flush welds are those welds with contours as defined in Figure NB-3683.1(c)-1. The total thickness (both inside and outside) of the weld reinforcement shall not exceed $0.1t$. There shall be no concavity on either the interior or exterior surfaces and the finished contour shall not have any slope greater than 7 deg where the angle is measured from a tangent to the surface of the pipe or on the tapered transition side of the weld to the nominal transition surface.

(2) As-welded welds are those welds not meeting the special requirements of flush welds.

(d) Loadings. Loadings for which stress indices are given include internal pressure, bending and torsional moments, and temperature differences. The indices are intended to be sufficiently conservative to account also for the effects of transverse shear forces normally encountered in flexible piping systems. If, however, thrust or shear forces account for a significant portion of the loading on a given piping product, the effect of these forces shall be included in the design analysis. The values of the moments and forces shall be obtained from an analysis of the piping system in accordance with NB-3672. Loading terms are defined as follows:

M_1, M_2, M_3 = orthogonal moment loading components at a given position in a piping system, in.-lb (N·mm)

M_{ij} = orthogonal moment components of a tee or branch connection as shown in Figure NB-3683.1(d)-1 where i = x, y, z and j = 1, 2, 3, in.-lb (N·mm)

M_t = resultant moment loading applied during the specified operating cycle for straight-through products such as straight pipe, curved pipe or elbows, and concentric reducers, in.-lb (N·mm)
= $\sqrt{M_1^2 + M_2^2 + M_3^2}$

P = Design Pressure, psi (MPa)

P_o = range of service pressure, psi (MPa)

P^* = maximum value of pressure in the load cycle under consideration, psi (MPa)

Figure NB-3683.1(c)-1

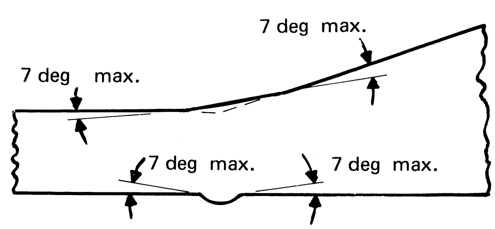
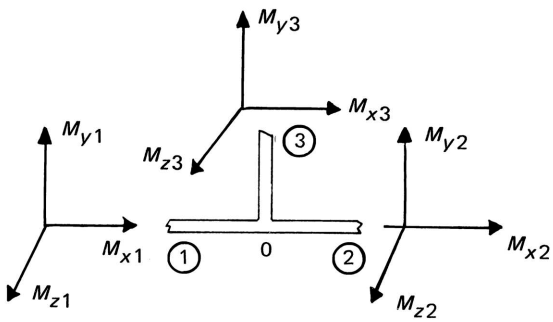


Figure NB-3683.1(d)-1



The moment components M_{x1}, M_{x2}, M_{y1}, M_{y2}, M_{z1}, and M_{z2} for the run are calculated at the intersection of the run and branch center lines. The moment components M_{x3}, M_{y3}, and M_{z3} for a branch connection where $d_o/D_o \le 0.5$ may be calculated for a point on the branch center line at a distance $D_o/2$ from the intersection of the run and branch center lines. Otherwise, M_{x3}, M_{y3}, and M_{z3} are calculated at the intersection of the run and branch center lines.

M_b = resultant moment on the branch for branch connections or tees, in.-lb (N·mm)

$$= \sqrt{(M_{x3})^2 + \left(M_{y3}\right)^2 + (M_{z3})^2}$$

M_b* = same as M_b, except it includes only moments due to thermal expansion and thermal anchor movements, in.-lb (N·mm)

M_r = resultant moment on the run for branch connections or tees, in.-lb (N·mm)

$$= \sqrt{(M_{xr})^2 + \left(M_{yr}\right)^2 + (M_{zr})^2}$$

M_r* = same as M_r except it includes only moments due to thermal expansion and thermal anchor movements, in.-lb (N·mm)

M_{xr}, M_{yr}, M_{zr} = run moment components for use with the stress indices of NB-3683.8 and NB-3683.9, in.-lb (N·mm). Their numerical values are calculated as follows. If M_{i1} and M_{i2} (where $i = x, y, z$) have the same algebraic sign (±), then M_{ir} equals zero. If M_{i1} and M_{i2} have opposite algebraic signs, then M_{ir} equals the smaller of M_{i1} or M_{i2}. If M_{i1} and M_{i2} are unsigned, then M_{ir} may be taken as the smaller of M_{i1} or M_{i2}. Combination of signed and unsigned moments from different load sources shall be done after determination of M_{ir}.

For branch connections or tees, the pressure term of NB-3652, eq. (9); NB-3653.1(a), eq. (10); NB-3653.2(a), eq. (11); and NB-3653.6(b), eq. (13) shall be replaced by the following terms:

For NB-3652, eq. (9): $B_1\ (PD_o\ /2T_r)$

For NB-3653.1(a), eq. (10), and NB-3653.6(b), eq. (13): $C_1\ (P_o\ D_o/2T_r)$

For NB-3653.2(a), eq. (11): $K_1\ C_1\ (P_o\ D_o/2T_r)$

For branch connections or tees, the moment term of NB-3652, eq. (9), through NB-3653.6(b), eq. (13) shall be replaced by the following pairs of terms:

For NB-3652, eq. (9): $B_{2b}\ (M_b/Z_b) + B_{2r}\ (M_r/Z_r)$

For NB-3653.1(a), eq. (10), and NB-3653.6(b), eq. (13): $C_{2b}\ (M_b/Z_b) + C_{2r}\ (M_r/Z_r)$

For NB-3653.2(a), eq. (11): $C_{2b}K_{2b}(M_b/Z_b) + C_{2r}K_{2r}(M_r/Z_r)$

For NB-3653.6(a), eq. (12): $C_{2b}\ (M_b*/Z_b) + C_{2r}\ (M_r*/Z_r)$ where the approximate section moduli are:

$$Z_b = \pi(r'_m)^2 T'_b$$

$$Z_r = \pi(R_m)^2 T_r$$

NB-3683.2 Applicability of Indices — General. The B, C, and K stress indices given herein and in Table NB-3681(a)-1 predict stresses at a weld joint or within the body of a particular product. The stress indices given for ASME B16.9 and MSS SP-87 piping products apply only to seamless products with no connections, attachments, or other extraneous stress raisers on the body thereof. The stress indices for welds are not applicable if the radial weld shrinkage Δ is greater than $0.25t$.

For products with longitudinal butt welds, the K_1, K_2, and K_3 indices shown shall be multiplied by 1.1 for flush welds or by 1.3 for as-welded welds. At the intersection of a longitudinal butt weld in straight pipe with a girth butt weld or girth fillet weld, the C_1, K_1, C_2, K_2, and K_3 indices shall be taken as the product of the respective indices.

(a) Abutting Products. In general and unless otherwise specified, it is not required to take the product of stress indices for two piping products, such as a tee and a reducer when welded together, or a tee and a girth butt weld. The piping product and the weld shall be qualified separately.

For curved pipe or butt welding elbows welded together or joined by a piece of straight pipe less than one pipe diameter long, the stress indices shall be taken as the product of the indices for the elbow or curved pipe and the indices for the girth butt weld, except for B_1 and C'_3 that are exempted.

(b) Out-of-Round Products. The stress indices given in Table NB-3681(a)-1 are applicable for products and welds with out-of-roundness not greater than $0.08t$ where out-of-roundness is defined as $D_{max} - D_{min}$. For straight pipe, curved pipe, longitudinal butt welds in straight pipe, girth butt welds, NB-4250 transitions, and 1:3 transitions not meeting this requirement, the stress indices shall be modified as specified below.

(1) If the cross section is out-of-round but with no discontinuity in radius, e.g., an elliptical cross section, an acceptable value of K_1 may be obtained by multiplying the tabulated values of K_1 by the factor F_{1a}:

$$F_{1a} = 1 + \frac{D_{max} - D_{min}}{t}\left[\frac{1.5}{1 + 0.455(D_o/t)^3(p/E)}\right]$$

where

D_o = nominal outside diameter, in. (mm)
E = modulus of elasticity of material at room temperature, psi (MPa)
p = internal pressure (use maximum value of pressure in the load cycle under consideration), psi (MPa)

Other symbols are defined in (b) above.

(2) If there are discontinuities in radius, e.g., a flat spot, and if $D_{max} - D_{min}$ is not greater than $0.08D_o$, an acceptable value of K_1 may be obtained by multiplying the tabulated values of K_1 by the factor F_{1b}:

$$F_{1b} = 1 + MS_y/(PD_o/2t)$$

where

M = 2, for ferritic steels and nonferrous materials except nickel–chromium–iron alloys and nickel–iron–chromium alloys
= 2.7, for austenitic steel, nickel–chromium–iron alloys, and nickel–iron–chromium alloys
P = Design Pressure, psi (MPa)
S_y = yield strength at Design Temperature (Section II, Part D, Subpart 1, Table Y-1), psi (MPa)

D_o and t are defined in (a) and (b) above.

(c) Products and Joints With $50 < D_o/t \le 100$. The B_1 index in Table NB-3681(a)-1 is valid. The B_2 index shall be multiplied by the factor $1/(XY)$, where

X = $1.3 - 0.006(D_o/t)$, not to exceed 1.0
Y = $1.033 - 0.00033T$ for ferritic material, not to exceed 1.0, where T is the Design Temperature, °F
= $1.0224 - 0.000594T$ for ferritic material, not to exceed 1.0, where T is the Design Temperature, °C
= 1.0 for other materials

NB-3683.3 Straight Pipe Remote From Welds. The stress indices given in Table NB-3681(a)-1 apply for straight pipe remote from welds or other discontinuities, except as modified by NB-3683.2.

NB-3683.4 Welds.

(a) Longitudinal Butt Welds. The stress indices given in Table NB-3681(a)-1 are applicable for longitudinal butt welds in straight pipe, except as modified in NB-3683.2.

(b) Girth Butt Welds. The stress indices given in Table NB-3681(a)-1, except as modified herein and in NB-3683.2, are applicable to girth butt welds connecting abutting products for which the wall thickness is between $0.875t$ and $1.1t$ for an axial distance of $\sqrt{D_o t}$ from the welding ends. Girth welds may also exhibit a reduction in diameter due to shrinkage of the weld material during cooling. The indices are not applicable if Δ/t is greater than 0.25 where Δ is the radial shrinkage measured from the nominal outside surface.

For as-welded girth butt welds joining items with nominal wall thicknesses $t < 0.237$ in. ($t < 6.0$ mm), the C_2 index shall be taken as:

(U.S. Customary Units)

$$C_2 = 1.0 + 0.094/t \text{ but not} > 2.1$$

(SI Units)

$$C_2 = 1.0 + 2.4/t \text{ but not} > 2.1$$

for $t \ge 0.237$ in. (6.0 mm), $C_2 = 1.0$

(c) Girth Fillet Welds. The stress indices given in Table NB-3681(a)-1 are applicable to girth fillet welds used to attach socket welding fittings, socket welding valves, slip-on flanges, or socket welding flanges, except as added to or modified in NB-3683.1, and in (1) and (2) below.

(1) Primary Stress Indices. The B_1 and B_2 indices shall be taken as:

$$B_1 = 0.75(t_n/C_x) \ge 0.5$$
$$B_2 = 1.5(t_n/C_x) \ge 1.0$$

where C_x and t_n are defined in Figure NB-4427-1, sketches (c) and (d). In Figure NB-4427-1 sketch (c), C_x shall be taken as X_{min} and $C_x \ge 1.25t_n$. In Figure NB-4427-1 sketch (d), $C_x \ge 0.75t_n$. For unequal leg lengths use the smaller leg length for C_x.

(2) Primary Plus Secondary Stress Indices. The C_1 and C_2 indices shall be taken as:

$$C_1 = 1.8(t_n/C_x) \ge 1.4$$
$$C_2 = 2.1(t_n/C_x) \ge 1.3$$

If C_x on the pipe side of the weld is greater than C_x on the fitting side, and if C_x on the fitting side is greater than or equal to either x min. in Figure NB-4427-1 sketch (c) or C_x min. in Figure NB-4427-1 sketch (d), C_x on the pipe side may be used in the equation for C_2.

NB-3683.5 Welded Transitions. The stress indices given in Table NB-3681(a)-1, except as modified herein and in NB-3683.2, are applicable for NB-4250 welded transitions as defined under (a) and for 1:3 welded transitions as defined under (b). Girth butt welds may also exhibit a reduction in diameter due to shrinkage of the weld material during cooling. The indices are not applicable if Δ/t is greater than 0.25.

(a) NB-4250 Transitions. The stress indices given in Table NB-3681(a)-1, except as modified herein and in NB-3683.2, are applicable to girth butt welds between a product for which the wall thickness is between $0.875t$ and $1.1t$ for an axial distance of $\sqrt{D_o t}$ from the welding end and an abutting product for which the welding end is within the envelope of Figure NB-4250-1, but with inside and outside surfaces that do not slope in the same direction. For transitions meeting these requirements, the C_1, C_2, and C_3 indices shall be taken as:

(U.S. Customary Units)

$$C_1 = 0.5 + 0.33(D_o/t)^{0.3} + 0.047/t \text{ but not} > 1.8$$
$$C_2 = 1.7 + 0.094/t \text{ but not} > 2.1$$
$$C_3 = 1.0 + 0.03(D_o/t) \text{ but not} > 2.0$$

(SI Units)

$$C_1 = 0.5 + 0.33(D_o/t)^{0.3} + 1.2/t \text{ but not} > 1.8$$
$$C_2 = 1.7 + 2.4/t \text{ but not} > 2.1$$
$$C_3 = 1.0 + 0.03(D_o/t) \text{ but not} > 2.0$$

For flush welds and for as-welded joints between items with $t > 0.237$ in. ($t > 6.0$ mm), C_1 and C_2 shall be taken as:

$$C_1 = 0.5 + 0.33(D_o/t)^{0.3} \text{ but not} > 1.8$$
$$C_2 = 1.7$$

(b) Transitions Within a 1:3 Slope. The stress indices given in Table NB-3681(a)-1, except as modified herein and in NB-3683.2, are applicable for girth butt welds between a product for which the wall thickness is between $0.875t$ and $1.1t$ for an axial distance of $\sqrt{D_o t}$ from the welding end and an abutting product for which the welding end is within an envelope defined by a 1:3 slope on the inside, outside, or both surfaces for an axial distance of $\sqrt{D_o t}$ but with inside and outside surfaces that do not slope in the same direction. For transitions meeting these requirements, the C_1, C_2, and C_3 indices shall be taken as:

(U.S. Customary Units)

$$C_1 = 1.0 + 0.047/t \text{ but not} > 1.8$$
$$C_2 = t_{max}/t + 0.094/t \text{ but not} > \text{the smaller of } \left(1.33 + 0.04\sqrt{D_o/t} + 0.094/t\right) \text{ or } 2.1$$
$$C_3 = 0.35(t_{max}/t) + 0.25 \text{ but not} > 2.0$$

(SI Units)

$$C_1 = 1.0 + 1.2/t \text{ but not} > 1.8$$
$$C_2 = t_{max}/t + 2.4/t \text{ but not} > \text{the smaller of } \left(1.33 + 0.04\sqrt{D_o/t} + 2.4/t\right) \text{ or } 2.1$$
$$C_3 = 0.35(t_{max}/t) + 0.25 \text{ but not} > 2.0$$

where t_{max} is the maximum wall thickness within the transition zone. If $(t_{max}/t) \le 1.10$, the stress indices given in NB-3683.4(b) for girth butt welds may be used. For flush welds and for as-welded joints between items with $t > 0.237$ in. ($t > 6.0$ mm), C_1 and C_2 shall be taken as:

$$C_1 = 1.0$$
$$C_2 = t_{max}/t \text{ but not} > \text{the smaller of } \left(1.33 + 0.04\sqrt{D_o/t}\right) \text{ or } 2.1$$

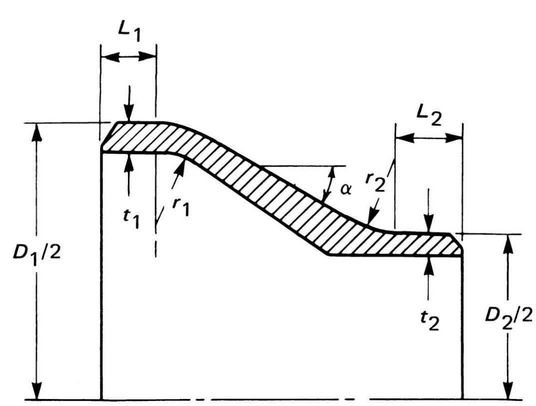
NB-3683.6 Concentric and Eccentric Reducers. The stress indices given in Table NB-3681(a)-1, except as modified herein and in NB-3683.2, are applicable to butt welding reducers manufactured to the requirements of ASME B16.9 or MSS SP-87 if the cone angle α defined in Figure NB-3683.6-1 is less than 60 deg and if the wall thickness is not less than t_{1m} throughout the body of the reducer, except in and immediately adjacent to the cylindrical portion on the small end where the thickness shall not be less than t_{2m}. The wall thicknesses t_{1m} and t_{2m} are the minimum thicknesses required to resist the Design Pressure P at the large end and small end, respectively, in accordance with NB-3641.1, eq. (1). For eccentric reducers, the dimensions shown in Figure NB-3683.6-1 are to be taken at the location on the circumference where α is the maximum.

(a) Primary Stress Indices. The B_1 stress indices given in (1) or (2) below shall be used depending on the cone angle α.

(1) $B_1 = 0.5$ for $\alpha \le 30$ deg

(2) $B_1 = 1.0$ for 30 deg $< \alpha \le 60$ deg

Figure NB-3683.6-1



(b) Primary Plus Secondary Stress Indices. The C_1 and C_2 stress indices given in (1) or (2) below shall be used depending on the dimensions of the transition radii r_1 and r_2.

(1) For reducers with r_1 and $r_2 \geq 0.1D_1$:

$$C_1 = 1.0 + 0.0058\,\alpha\sqrt{D_n/t_n}$$

$$C_2 = 1.0 + 0.36\,\alpha^{0.4}\,(D_n/t_n)^{0.4(D_2/D_1 - 0.5)}$$

where D_n/t_n is the larger of D_1/t_1 and D_2/t_2.

(2) For reducers with r_1 and/or $r_2 < 0.1D_1$:

$$C_1 = 1.0 + 0.00465\,\alpha^{1.285}\,(D_n/t_n)^{0.39}$$

$$C_2 = 1.0 + 0.0185\,\alpha\,\sqrt{D_n/t_n}$$

where D_n/t_n is the larger of D_1/t_1 and D_2/t_2.

(c) Peak Stress Indices. The K_1 and K_2 indices given in (1), (2), or (3) below shall be used depending on the type of connecting weld and thickness dimensions.

(1) For reducers connected to pipe with flush girth butt welds:

$$K_1 = 1.1 - 0.1\,L_m/\sqrt{D_m t_m} \text{ but not} < 1.0$$

$$K_2 = 1.1 - 0.1\,L_m/\sqrt{D_m t_m} \text{ but not} < 1.0$$

where $L_m/\sqrt{D_m t_m}$ is the smaller of $L_1/\sqrt{D_1 t_1}$ and $L_2/\sqrt{D_2 t_2}$.

(2) For reducers connected to pipe with as-welded girth butt welds where t_1 and $t_2 > {}^3\!/_{16}$ in. (5 mm):

$$K_1 = 1.2 - 0.2\,L_m/\sqrt{D_m t_m} \text{ but not} < 1.0$$

$$K_2 = 1.8 - 0.8\,L_m/\sqrt{D_m t_m} \text{ but not} < 1.0$$

where $L_m/\sqrt{D_m t_m}$ is the smaller of $L_1/\sqrt{D_1 t_1}$ and $L_2/\sqrt{D_2 t_2}$.

(3) For reducers connected to pipe with as-welded girth butt welds where t_1 or $t_2 \leq {}^3\!/_{16}$ in. (5 mm):

$$K_1 = 1.2 - 0.2\,L_m/\sqrt{D_m t_m} \text{ but not} < 1.0$$

$$K_2 = 2.5 - 1.5\,L_m/\sqrt{D_m t_m} \text{ but not} < 1.0$$

where $L_m/\sqrt{D_m t_m}$ is the smaller of $L_1/\sqrt{D_1 t_1}$ and $L_2/\sqrt{D_2 t_2}$.

(d) Alternative C_2 and K_2 stress indices may be used for reducers meeting the following requirements:

$$5 < (D_2/t_2) < 80$$

$$5 < \alpha < 60 \text{ deg}$$

$$0.08 < r_2/D_2 < 0.7$$

$$1 < t_1/t_2 < 2.12$$

(1) See below.

$$C_2 = 1 + 0.0056\,(D_2/t_2)^{0.25}\alpha^{0.8}\,(r_2/D_2)^{-1}(t_1/t_2)^{-0.8}$$

(2) For reducers connected to pipe with flush girth butt welds

$$K_2 = 1.1 - 0.15L_2/(D_2 t_2)^{0.5} \geq 1.0$$

(3) For reducers connected to pipe with as-welded girth butt welds where t_1 and $t_2 > {}^3\!/_{16}$ in. (5 mm)

$$K_2 = 1.8 - 1.25L_2/(D_2 t_2)^{0.5} \geq 1.0$$

(4) For reducers connected to pipe with as-welded girth butt welds where t_1 or $t_2 \leq {}^3\!/_{16}$ in. (5 mm)

$$K_2 = 2.5 - 2.35L_2/(D_2 t_2)^{0.5} \geq 1.0$$

NB-3683.7 Curved Pipe or Butt Welding Elbows. The stress indices given in Table NB-3681(a)-1, except as modified herein and in NB-3683.2, are applicable to curved pipe or butt welding elbows manufactured to the requirements of ASME B16.9 or MSS SP-87.

(a) Primary Stress Index. The B_1 and B_2 indices shall be taken as:

$$B_1 = -0.1 + 0.4h \text{ but not} < 0 \text{ nor} > 0.5$$

$$B_2 = 1.30 / h^{2/3} \text{ but not} < 1.0$$

where

$$h = tR/r_m^2$$

(b) Primary Plus Secondary Stress Indices. The C_1 and C_2 indices shall be taken as:

$$C_1 = (2R - r_m) / 2(R - r_m)$$

$$C_2 = 1.95 / h^{2/3} \text{ but not} < 1.5$$

where

$$h = tR/r_m^2$$

NB-3683.8 Branch Connections Per NB-3643. The stress indices given in Table NB-3681(a)-1, except as modified herein and in NB-3683.2, are applicable to reinforced or unreinforced branch connections meeting the general requirements of NB-3643 and the additional requirements of (a). Symbols are defined in NB-3683.1 and in NB-3643.3.

(a) Applicability. The stress indices are applicable, provided the following limitations are met.

(1) The branch connection is in straight pipe.

(2) For branch connections in a pipe, the arc distance measured between the centers of adjacent branches along the outside surface of the run pipe is not less than three times the sum of the two adjacent branch inside radii in the longitudinal direction, or is not less than two times the

sum of the two adjacent branch radii along the circumference of the run pipe.

(3) The axis of the branch connection is normal to the run pipe surface.

(4) The run pipe radius-to-thickness ratio R_m/T_r is less than 50, and the branch-to-run radius ratio r'_m/R_m is less than 0.50.

(5) If the branch-to-run fillet radius r_2 is not less than the larger of $T_b/2$, $T_r/2$, or $(T'_b + y)/2$ [Figure NB-3643.3(a)-1 sketch (c)], the K_{2b} index is reduced from 2.0 to 1.0. Stress indices for run moments are independent of r_2.

(b) Primary Stress Indices. The primary stress indices B_{2b} and B_{2r} shall be taken as:

$$B_{2b} = 0.5C_{2b} \text{ but not} < 1.0$$

$$B_{2r} = 0.75\left(\frac{r'_m}{t_n}\right)^{0.3} \text{ but not} < 1.0$$

(c) Primary Plus Secondary Stress Indices. The C_1, C_{2b}, and C_{2r} indices [for moment loadings, see NB-3683.1(d)] shall be taken as:

$$C_1 = 1.4\left(\frac{D_m}{T_r}\right)^{0.182}\left(\frac{d_m}{D_m}\right)^{0.367}\left(\frac{T_r}{t_n}\right)^{0.382}\left(\frac{t_n}{r_2}\right)^{0.148} \text{ but not} < 1.2$$

If $r_2/t_n > 12$, use $r_2/t_n = 12$ for computing C_1.

$$C_{2b} = 1.5\left(\frac{R_m}{T_r}\right)^{\frac{2}{3}}\left(\frac{r'_m}{R_m}\right)^{\frac{1}{2}}\left(\frac{T'_b}{T_r}\right)\left(\frac{r'_m}{r_p}\right) \text{ but not} < 1.5$$

$$C_{2r} = \left(\frac{r'_m}{t_n}\right)^{0.3}$$

but not less than the larger of 1.25 and 1.875 $(1 - Q)$

where

$$Q = 0.5(t_n/T_r)(t_n/d_i)^{0.5} \text{ but not} > 0.5$$

and where

(1) for Figures NB-3643.3(a)-1, sketches (a) and (b):

$$t_n = T_b \text{ if } L_1 \geq 0.5\,(d_m T_b)^{1/2}$$
$$= T'_b \text{ if } L_1 < 0.5(d_m T_b)^{1/2}$$

(2) for Figure NB-3643.3(a)-1, sketch (c):

$$t_n = T'_b + (2/3)y \text{ if } \theta \leq 30 \text{ deg}$$
$$= T'_b + 0.385\,L_1 \text{ if } \theta > 30 \text{ deg}$$

(3) for Figure NB-3643.3(a)-1, sketch (d):

$$t_n = T'_b = T_b$$

(d) Peak Stress Indices. The peak stress indices K_{2b} and K_{2r} for moment loadings [see NB-3683.1(d)] shall be taken as:

$$K_{2b} = 2.0$$
$$K_{2r} = 1.6$$

(e) For branch connections made with fillet or partial penetration welds per NB-3661.3, the stress indices given in Table NB-3681(a)-1 and in NB-3683.8 shall be increased as follows:

(1) The B_1 index shall be multiplied by 1.5. The B_{2r} and B_{2b} indices calculated using the equations in (b) shall be multiplied by 1.5, and the resulting B_{2r} and B_{2b} indices shall be not less than 1.5.

(2) C_1, C_{2r}, and C_{2b} indices shall be calculated using the equations in (c) and multiplied by 2.0, and the resulting C_1, C_{2r}, and C_{2b} indices shall be not less than the minimum values given in (c).

(3) K_1 and K_3 shall be multiplied by 3.

(4) K_{2b} shall be increased such that when using the C_{2b} determined in (2) above, the resulting product $C_{2b}K_{2b}$ shall be a minimum of 6.0.

(5) K_{2r} shall be increased such that when using the C_{2r} determined in (2) above, the resulting product $C_{2r}K_{2r}$ shall be taken as a minimum of 4.2.

In calculating the indices for fillet and partial penetration welded branch connections, r_2 may be taken to be t_n, with the other dimensions consistent with Figure NB-3643.3(a)-1.

NB-3683.9 Butt Welding Tees. The stress indices given in Table NB-3681(a)-1, except as modified herein and in NB-3683.2, are applicable to butt welding tees manufactured to the requirements of ASME B16.9 or MSS SP-87.

(a) Primary Stress Indices. The primary stress indices B_{2b} and B_{2r} shall be taken as:

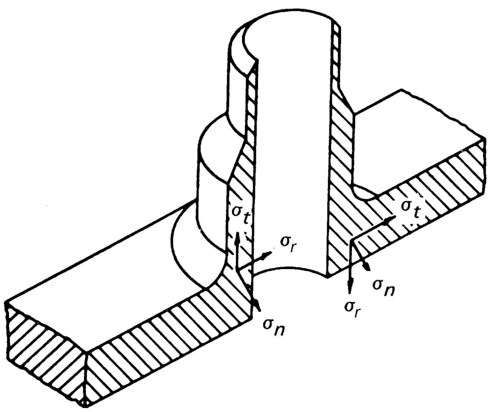
$$B_{2b} = 0.4\,(R_m/T_r)^{2/3} \text{ but not} < 1.0$$
$$B_{2r} = 0.50\,(R_m/T_r)^{2/3} \text{ but not} < 1.0$$

(b) Primary Plus Secondary Stress Indices. The C_{2b} and C_{2r} stress indices for moment loadings [see NB-3683.1(d)] shall be taken as:

$$C_{2b} = 0.67\,(R_m/T_r)^{2/3} \text{ but not} < 2.0$$
$$C_{2r} = 0.67\,(R_m/T_r)^{2/3} \text{ but not} < 2.0$$

(c) Peak Stress Indices. The peak stress indices K_{2b} and K_{2r} for moment loadings [see NB-3683.1(d)] shall be taken as:

Figure NB-3684-1
Direction of Stress Components



Legend:
σ = stress intensity (combined stress) at the point under consideration
σ_n = stress component normal to the plane of the section
σ_r = stress component normal to the boundary of the section
σ_t = stress component in the plane of the section under consideration and parallel to the boundary of the section

$$K_{2b} = 1.0$$
$$K_{2r} = 1.0$$

NB-3684 Stress Indices for Detailed Analysis

The symbols for the stress components and their definitions are given in Figure NB-3684-1. These definitions are applicable to all piping products, and the stress indices given in the tables in NB-3685 and NB-3338 are so defined.

NB-3685 Curved Pipe or Welding Elbows

NB-3685.1 Applicability of Indices. The indices given in Tables NB-3685.1-1 and NB-3685.1-2 give stresses in curved pipe or elbows at points remote from girth or longitudinal welds or other local discontinuities. Stresses in curved pipe or welding elbows with local discontinuities, such as longitudinal welds, support lugs, and branch connections in the elbow, shall be obtained by appropriate theoretical analysis or by experimental analysis in accordance with Section III Appendices, Mandatory Appendix II.

NB-3685.2 Nomenclature (Figure NB-3685.2-1).

A = an additional thickness, in. (mm) (see NB-3641.1)
D_i = $D_o - 2(t_m - A)$, in. (mm)
D_o = nominal outside diameter of cross section, in. (mm)
$D_1(D_2)$ = maximum (minimum) outside diameter of elbow with out-of-round cross section essentially describable as an ellipse or oval shape (Figure NB-3685.2-1), in. (mm)
E = modulus of elasticity, psi (MPa) (Section II, Part D, Subpart 2, Tables TM)
P = internal pressure, psi (MPa)
R = bend radius
r = mean cross section radius
t_m = minimum specified wall thickness
Z = section modulus of cross section
= $0.0982\ (D_o^4 - D_i^4)/\ D_o$
λ = $t_m R / \left(r^2 \sqrt{1 - \nu^2} \right)$ (Table NB-3685.1-2 limited to $\lambda \geq 0.2$)

NB-3685.3 Stress From Stress Indices. To obtain stresses from stress index:

Load	Multiply Stress Index by
Internal Pressure	P
M_x	$M_x/2Z$
M_y	M_y/Z
M_z	M_z/Z

NB-3685.4 Classification of Stresses. For analysis of a curved pipe or welding elbow to NB-3210, the following rules shall apply to the classification of stresses developed under a load-controlled in-plane or out-of-plane moment as distinguished from a displacement controlled loading.

(a) The entire membrane portion of the axial, circumferential, and torsional stresses shall be considered as primary (P_L).

(b) Seventy-five percent of the through-wall bending stresses in both the axial and the circumferential directions shall be classified as primary (P_b). The remaining 25% shall be classified as secondary (Q). The stresses induced by displacement controlled in-plane or out-of-plane moments shall be classified as secondary (Q).

NB-3686 Flexibility Factors [See NB-3682(c) for Definition]

NB-3686.1 Straight Pipe. For $M = M_1$ or M_2(see Figure NB-3686.1-1):

$$k = 1.0$$

$$\theta_{\text{nom}} = \frac{Ml}{EI}$$

Table NB-3685.1-1
Curved Pipe or Welding End Elbows, Internal Pressure

Location	Surface	Stress Direction	Stress Index [Note (1)]
Round Cross Section			
ϕ	Inside	σ_n	
ϕ	Mid	σ_n	$\left[\frac{D_o - 0.8(t_m - A)}{2(t_m - A)}\right]\left[\frac{0.5(2R + r\sin\phi)}{R + r\sin\phi}\right] = i_1$
ϕ	Outside	σ_n	
ϕ	Inside	σ_t	
ϕ	Mid	σ_t	$\frac{D_i}{4(t_m - A)} = i_2$
ϕ	Outside	σ_t	
Out-of-Round Cross Section [Note (2)]			
α	Inside	σ_n	$i_1 + i_3$
α	Mid	σ_n	i_1
α	Outside	σ_n	$i_1 - i_3$
α	Inside	σ_t	$i_2 + 0.3i_3$
α	Mid	σ_t	i_2
α	Outside	σ_t	$i_2 - 0.3i_3$

NOTES:
(1) The radial stress σ_r is equal to $-P$ on the inside surface, to $-P/2$ on the midsurface, and to 0 on the outside surface.
(2) For out-of-round cross section:

$$i_3 = \left[\frac{D_o(D_1 - D_2)}{2t_m{}^2}\right]\left[\frac{1.5}{1 + 0.455(D_o/t_m)^3\,(P/E)}\right]\cos 2\alpha$$

Table NB-3685.1-2
Curved Pipe or Welding End Elbows, Moment Loading ($\lambda \geq 0.2$)

Location	Surface	Stress Direction	Stress Index [Note (1)]
		Torsional Moment, M_x	
All	All	τ_{nt} [Note (2)]	1.0
		In-Plane or Out-of-Plane Moments M_y or M_z [Note (3)]	
ϕ	Outside	σ_n	$\nu\,\sigma_{tm} + \sigma_{nb}$
ϕ	Mid	σ_n	$\nu\,\sigma_{tm}$
ϕ	Inside	σ_n	$\nu\,\sigma_{tm} - \sigma_{nb}$
ϕ	Outside	σ_t	$\sigma_{tm} + \nu\,\sigma_{nb}$
ϕ	Mid	σ_t	σ_{tm}
ϕ	Inside	σ_t	$\sigma_{tm} - \nu\,\sigma_{nb}$

NOTES:

(1) The radial stress σ_r is zero for all surfaces.

(2) τ_{nt} is a shear stress in the n–t plane and must be appropriately combined with the principal stresses σ_n and σ_t to obtain principal stresses due to combinations of M_x with M_y or M_z.

(3) Nomenclature for stress indices:

ν = Poisson's ratio

$\sigma_{tm} = \sin\phi + [(1.5X_2 - 18.75)\sin 3\phi + 11.25\sin 5\phi]/X_4$ — In-plane M_z

$\sigma_{nb} = \lambda\,(9X_2\cos 2\phi + 225\cos 4\phi)/X_4$ — In-plane M_z

$\sigma_{tm} = \cos\phi + [(1.5X_2 - 18.75)\cos 3\phi + 11.25\cos 5\phi]/X_4$ — Out-of-plane M_y

$\sigma_{nb} = -\lambda\,(9X_2\sin 2\phi + 225\sin 4\phi)/X_4$ — Out-of-plane M_y

$X_1 = 5 + 6\lambda^2 + 24\psi$

$X_2 = 17 + 600\lambda^2 + 480\psi$

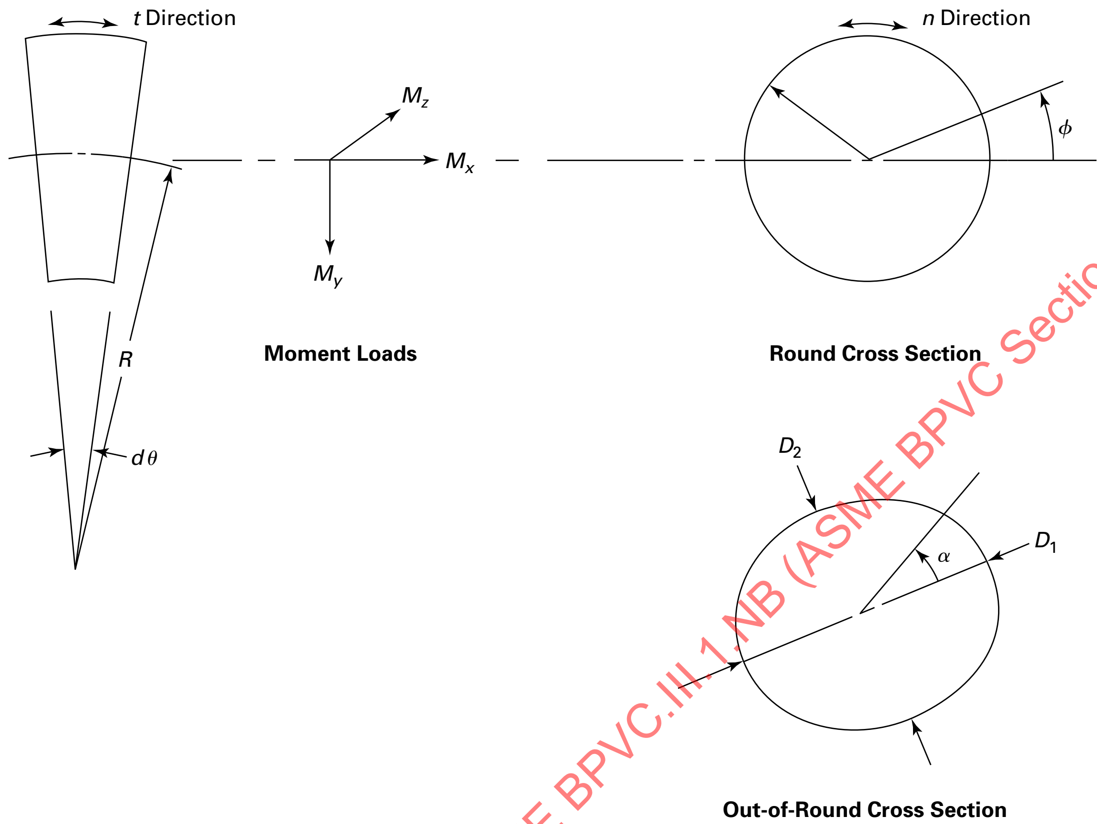
$X_3 = X_1 X_2 - 6.25$

$X_4 = (1 - \nu^2)(X_3 - 4.5X_2)$

$\lambda = t_m R / \left(r^2\sqrt{1 - \nu^2}\right)$ (Equations are valid for $\lambda \geq 0.2$ only.)

$\psi = PR^2/Ert_m$

Figure NB-3685.2-1
Elbow Nomenclature



For $M = M_3$ (see Figure NB-3686.1-1):

$$k = 1.0$$

$$\theta_{\text{nom}} = \frac{Ml}{GJ}$$

where

E = modulus of elasticity, psi (MPa)
G = shear modulus, psi (MPa)
I = plane moment of inertia, in.^{4} (mm^4)
J = polar moment of inertia, in.^{4} (mm^4)
l = one pipe diameter, in. (mm)

NB-3686.2 Curved Pipe and Welding Elbows. The flexibility of a curved pipe or welding elbow is reduced by end effects, provided either by the adjacent straight pipe, or by the proximity of other relatively stiff members that inhibit ovalization of the cross section. In certain cases, these end effects may also reduce the stress. The flexibility factors may be calculated by the equations given below for k, provided that:

(a) R/r is not less than 1.7;
(b) center line length $R\alpha$ is greater than $2r$;
(c) there are no flanges or other similar stiffeners within a distance r from either end of the curved section of pipe or from the ends of welding elbows.

For M_1 or M_2 (see Figure NB-3686.2-1):

$$k = \frac{1.65}{h}\left[\frac{1}{1 + (Pr/tE)X_k}\right]$$

but not less than 1.0, and

$$\theta_{\text{nom}} = \frac{R}{EI}\int_o^A M(d\alpha)$$

For M_3 (see Figure NB-3686.2-1):

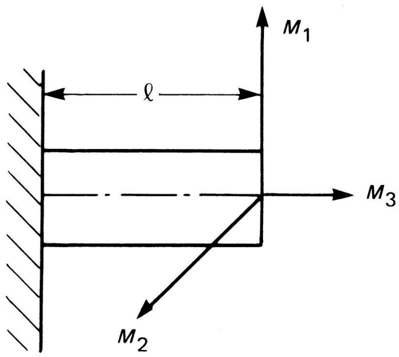
$$k = 1.0$$

$$\theta_{\text{nom}} = \frac{R}{GJ}\int_o^A M(d\alpha)$$

In both cases

A = total angle of curved pipe or welding elbow, rad
E = modulus of elasticity, psi (MPa)
G = shear modulus of elasticity, psi (MPa)
h = tR/r^2
I = plane moment of inertia of cross section, in.^{4} (mm^4)

Figure NB-3686.1-1



J = polar moment of inertia of cross section, in.^{4} (mm^4)
P = internal pressure, psi (MPa)
R = bend radius, in. (mm)
r = pipe or elbow mean radius, in. (mm)
t = pipe or elbow nominal wall thickness, in. (mm)
X_k = $6(r/t)^{4/3}(R/r)^{1/3}$
α = arc angle, rad

NB-3686.3 Miter Bends. The requirements of NB-3681(d) apply.

NB-3686.4 Welding Tee or Branch Connections. For welding tees (ASME B16.9) or branch connections (see NB-3643) not included in NB-3686.5, the load displacement relationships shall be obtained by assuming that the run pipe and branch pipe extend to the intersection of the run pipe center line with the branch pipe center line. The imaginary juncture is to be assumed rigid, and the imaginary length of branch pipe from the juncture to the run pipe surface is also to be assumed rigid.

NB-3686.5 Branch Connections in Straight Pipe. (For branch connections in straight pipe meeting the dimensional limitations of NB-3683.8.) The load displacement relationships may be obtained by modeling the branch connections in the piping system analysis (see NB-3672) as shown in (a) through (d) below. (see Figure NB-3686.5-1.)

(a) The values of k are given below.

For M_{x3}:

$$k = 0.1\,(D/T_r)^{1.5}\left[(T_r/t_n)(d/D)\right]^{1/2}(T'_b/T_r)$$

For M_{z3}:

$$k = 0.2\,(D/T_r)\left[(T_r/t_n)(d/D)\right]^{1/2}(T'_b/T_r)$$

where

D = run pipe outside diameter, in. (mm)
d = branch pipe outside diameter, in. (mm)
E = modulus of elasticity, psi (MPa)
I_b = moment of inertia of branch pipe, in.^{4} (mm^4) (to be calculated using d and T'_b)
M = M_{x3} or M_{z3}, as defined in NB-3683.1(d)
T_r = run pipe wall thickness, in. (mm)
ϕ = rotation in direction of moment, rad

(b) For branch connections per Figure NB-3643.3(a)-1, sketches (a) and (b):

$$t_n = T_b \text{ if } L_1 \geq 0.5\left[(2r_i + T_b)T_b\right]^{1/2}$$
$$= T_b' \text{ if } L_1 < 0.5\left[(2r_i + T_b)T_b\right]^{1/2}$$

(c) For branch connections per Figure NB-3643.3(a)-1, sketch (c):

$$t_n = T'_b + \left(\frac{2}{3}\right)y \quad \text{if} \quad \theta_n \leq 30 \text{ deg}$$
$$= T'_b + 0.385L_1 \quad \text{if} \quad \theta_n > 30 \text{ deg}$$

(d) For branch connections per Figure NB-3643.3(a)-1, sketch (d):

$$t_n = T'_b = T_b$$

NB-3686.6 Reducers.

(a) The reducer flexibility can be accurately represented by modeling a section of large-end diameter pipe rigidly connected to a section of small-end diameter pipe at the midpoint of the reducer as per Figure NB-3686.6-1.

(b) Where the ratio $D_2/t_2 > 55$, additional flexibility should be considered. If the geometry requirements of NB-3683.6(d) are met, the reducer flexibility may be adjusted by applying the flexibility factor, k, below:

$$k = 0.2(D_2/t_2)^{0.24}\alpha^{0.4}(t_1/t_2)^{-0.66}$$

NB-3690 DIMENSIONAL REQUIREMENTS FOR PIPING PRODUCTS

NB-3691 Standard Piping Products

Dimensions of standard piping products shall comply with the standards and specifications listed in Table NCA-7100-1. However, compliance with these standards does not replace or eliminate the requirements of NB-3625.

NB-3692 Nonstandard Piping Products

The dimensions of nonstandard piping products shall be such as to provide strength and performance as required by this Subsection. Nonstandard piping products shall be designed in accordance with NB-3640.

Figure NB-3686.2-1

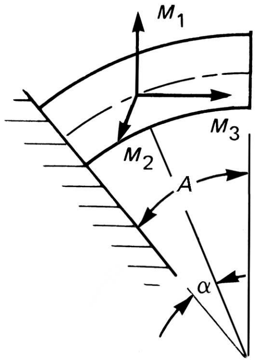


Figure NB-3686.5-1
Branch Connections in Straight Pipe

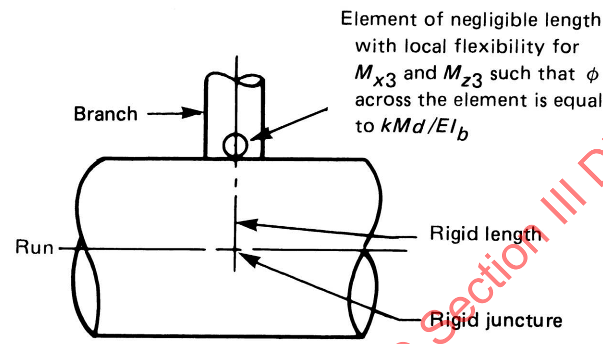
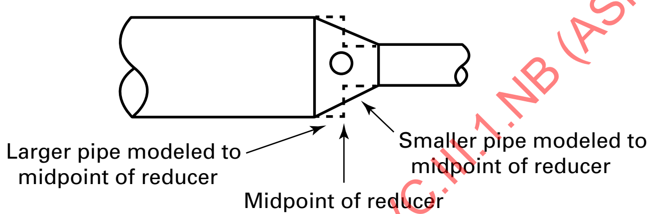


Figure NB-3686.6-1
Reducers



ARTICLE NB-4000
FABRICATION AND INSTALLATION

NB-4100 GENERAL REQUIREMENTS

NB-4110 INTRODUCTION

Components, parts, and appurtenances shall be fabricated and installed in accordance with the requirements of this Article and shall be manufactured from materials that meet the requirements of Article NB-2000.

NB-4120 CERTIFICATION OF MATERIALS AND FABRICATION BY CERTIFICATE HOLDER

NB-4121 Means of Certification

The Certificate Holder for an item shall certify, by application of the appropriate Certification Mark and completion of the appropriate Data Report in accordance with Article NCA-8000, that the materials used comply with the requirements of Article NB-2000 and that the fabrication or installation complies with the requirements of this Article.

(23) **NB-4121.1 Certification of Treatments, Tests, and Examinations.** If the Certificate Holder or Subcontractor performs treatments, tests, repairs, or examinations required by other Articles of this Subsection, the Certificate Holder shall certify that this requirement has been fulfilled (see NCA-1224 and NCA-1225, or NCA-8410). Reports of all required treatments and of the results of all required tests, repairs, and examinations performed shall be available to the Inspector.

NB-4121.2 Repetition of Tensile or Impact Tests. If during the fabrication or installation of the item the material is subjected to heat treatment that has not been covered by treatment of the test coupons (see NB-2200) and that may reduce either tensile or impact properties below the required values, the tensile and impact tests shall be repeated by the Certificate Holder on test specimens taken from test coupons that have been taken and treated in accordance with the requirements of Article NB-2000.

NB-4121.3 Repetition of Surface Examination After Machining. If, during the fabrication or installation of an item, materials for pressure-containing parts are machined, then the Certificate Holder shall reexamine the surface of the material in accordance with NB-2500 when:

(a) the surface was required to be examined by the magnetic particle or liquid penetrant method in accordance with NB-2500; and

(b) the amount of material removed from the surface exceeds the lesser of $\frac{1}{8}$ in. (3 mm) or 10% of the minimum required thickness of the part.

NB-4122 Material Identification

(a) Material for pressure-retaining parts shall carry identification markings that will remain distinguishable until the component is assembled or installed. If the original identification markings are cut off or the material is divided, the marks shall either be transferred to the parts cut or a coded marking shall be used to ensure identification of each piece of material during subsequent fabrication or installation. In either case, an as-built sketch or a tabulation of materials shall be made identifying each piece of material with the Certified Material Test Report, where applicable, and the coded marking. For studs, bolts, nuts, and heat exchanger tubes it is permissible to identify the Certified Material Test Reports for material in each component in lieu of identifying each piece of material with the Certified Material Test Report and the coded marking. Material supplied with a Certificate of Compliance, and welding and brazing material, shall be identified and controlled so that they can be traced to each component or installation of a piping system, or else a control procedure shall be employed that ensures that the specified materials are used.

(b) Material from which the identification marking is lost shall be treated as nonconforming material until appropriate tests or other verifications are made and documented to ensure material identification. Testing is required unless positive identification can be made by other documented evidence. The material may then be re-marked upon establishing positive identification.

NB-4122.1 Marking Material. Material shall be marked in accordance with NB-2150.

NB-4123 Examinations

Visual examination activities that are not referenced for examination by other specific Code paragraphs, and are performed solely to verify compliance with requirements of Article NB-4000, may be performed by the persons who perform or supervise the work. These visual examinations are not required to be performed by personnel and procedures qualified to NB-5500 and NB-5100, respectively, unless so specified.

(23) NB-4125 Testing of Welding and Brazing Material

All welding material shall meet the requirements of NB-2400. All brazing material shall meet the requirements of NB-4512.

NB-4130 REPAIR OF MATERIAL

NB-4131 Elimination and Repair of Defects

Material originally accepted on delivery in which defects exceeding the limits of NB-2500 are known or discovered during the process of fabrication or installation is unacceptable. The material may be used provided the condition is corrected in accordance with the requirements of NB-2500 for the applicable product form, except:

(a) the limitation on the depth of the weld repair does not apply;

(b) the time of examination of the weld repairs to weld edge preparations shall be in accordance with NB-5130;

(c) radiographic examination is not required for weld repairs to seal membrane material when the material thickness is $^1\!/_4$ in. (6 mm) or less.

NB-4132 Documentation of Repair Welds of Base Material

The Certificate Holder who makes a repair weld exceeding in depth the lesser of $^3\!/_8$ in. (10 mm) or 10% of the section thickness, shall prepare a report that shall include a chart that shows the location and size of the prepared cavity, the welding material identification, the welding procedure, the heat treatment, and the examination results of repair welds.

NB-4200 FORMING, FITTING, AND ALIGNING

NB-4210 CUTTING, FORMING, AND BENDING

NB-4211 Cutting

Materials may be cut to shape and size by mechanical means, such as machining, shearing, chipping, or grinding, or by thermal cutting.

NB-4211.1 Preheating Before Thermal Cutting. When thermal cutting is performed to prepare weld joints or edges, to remove attachments or defective material, or for any other purpose, consideration shall be given to preheating the material, using preheat schedules such as suggested in Section III Appendices, Nonmandatory Appendix D.

NB-4212 Forming and Bending Processes

Any process may be used to hot or cold form or bend pressure-retaining material (see NB-4223), including weld metal, provided the required dimensions are attained (see NB-4214 and NB-4220), and provided the impact properties of the material, when required, are not reduced below the minimum specified values, or they are effectively restored by heat treatment following the forming operation. *Hot forming* is defined as forming with the material temperature higher than 100°F (56°C) below the lower transformation temperature of the material. When required, the process shall be qualified for impact properties as outlined in NB-4213. When required, the process shall be qualified to meet thickness requirements as outlined in NB-4223.1.

NB-4213 Qualification of Forming Processes for Impact Property Requirements

A procedure qualification test shall be conducted using specimens taken from material of the same specification, grade or class, heat treatment, and with similar impact properties, as required for the material in the component. These specimens shall be subjected to the equivalent forming or bending process and heat treatment as the material in the component. Applicable tests shall be conducted to determine that the required impact properties of NB-2300 are met after straining.

NB-4213.1 Exemptions. Procedure qualification tests are not required for materials listed in (a) through (f) below:

(a) hot formed material, such as forgings, in which the hot forming is completed by the Material Organization prior to removal of the impact test specimens;

(b) hot formed material represented by test coupons that have been subjected to heat treatment representing the hot forming procedure and the heat treatments to be applied to the parts;

(c) material that does not require impact tests in accordance with NB-2300;

(d) material that has a final strain less than 0.5%;

(e) material where the final strain is less than that of a previously qualified procedure for that material;

(f) material from which the impact testing is required by NB-2300 is performed on each heat and lot, as applicable, after forming.

NB-4213.2 Procedure Qualification Test. The procedure qualification test shall be performed in the manner stipulated in (a) through (f) below.

(a) The tests shall be performed on three different heats of material both before straining and after straining and heat treatment to establish the effects of the forming and subsequent heat treatment operations.

(b) Specimens shall be taken in accordance with the requirements of Article NB-2000 and shall be taken from the tension side of the strained material.

(c) The percent strain shall be established by the following equations.

For cylinders:

$$\%\ \text{strain} = \frac{50t}{R_f}\left(1 - \frac{R_f}{R_o}\right)$$

For spherical or dished surfaces:

$$\%\ \text{strain} = \frac{75t}{R_f}\left(1 - \frac{R_f}{R_o}\right)$$

For pipe:

$$\%\ \text{strain} = \frac{100r}{R}$$

where

R = nominal bending radius to the center line of the pipe
R_f = final radius to center line of shell
R_o = original radius (equal to infinity for a flat part)
r = nominal radius of the pipe
t = nominal thickness

(d) The procedure qualification shall simulate the maximum percent surface strain, employing a bending process similar to that used in the fabrication of the material or by direct tension on the specimen.

(e) Sufficient C_v test specimens shall be taken from each of the three heats of material to establish a transition curve showing both the upper and lower shelves. On each of the three heats, tests consisting of three impact specimens shall be conducted at a minimum of five different temperatures distributed throughout the transition region. The upper and lower shelves may be established by the use of one test specimen for each shelf. Depending on the product form, it may be necessary to plot the transition curves using both lateral expansion and energy level data (see NB-2300). In addition, drop weight tests shall be made when required by NB-2300.

(f) Using the results of the impact test data from each of three heats, taken both before and after straining, determine either:

(1) the maximum change in NDT temperature along with:

(-a) the maximum change of lateral expansion and energy at the temperature under consideration; or

(-b) the maximum change of temperature at the lateral expansion and energy levels under consideration; or

(2) when lateral expansion is the acceptance criterion (see NB-2300), either the maximum change in temperature or the maximum change in lateral expansion.

NB-4213.3 Acceptance Criteria for Formed Material. To be acceptable, the formed material used in the component shall have impact properties before forming sufficient to compensate for the maximum loss of impact properties due to the qualified forming processes used.

NB-4213.4 Requalification. A new procedure qualification test is required when any of the changes in (a), (b), or (c) below are made.

(a) The actual postweld heat treatment time at temperature is greater than previously qualified considering NB-2211. If the material is not postweld heat treated, the procedure must be qualified without postweld heat treatment.

(b) The maximum calculated strain of the material exceeds the previously qualified strain by more than 0.5%.

(c) Preheat over 250°F (120°C) is used in the forming or bending operation but not followed by a subsequent postweld heat treatment.

NB-4214 Minimum Thickness of Fabricated Material

If any fabrication operation reduces the thickness below the minimum required to satisfy the rules of Article NB-3000, the material may be repaired in accordance with NB-4130.

NB-4220 FORMING TOLERANCES

NB-4221 Tolerance for Vessel Shells

Cylindrical, conical, or spherical shells of a completed vessel, except formed heads covered by NB-4222, shall meet the requirements of the following subparagraphs at all cross sections.

NB-4221.1 Maximum Difference in Cross-Sectional Diameters. The difference in in. (mm) between the maximum and minimum diameters at any cross section shall not exceed the smaller of

(U.S. Customary Units)

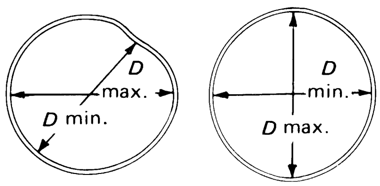
$$\frac{D + 50}{200} \text{ and } \frac{D}{100}$$

(SI Units)

$$\frac{D + 1250}{200} \text{ and } \frac{D}{100}$$

where D is the nominal inside diameter, in. (mm), 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 Figure NB-4221.1-1). When the cross section passes through an opening, the permissible difference in

Figure NB-4221.1-1
Maximum Difference in Cross-Sectional Diameters



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

NB-4221.2 Maximum Deviation From True Theoretical Form for External Pressure. Vessels designed for external pressure shall meet the tolerances given in (a) through (c) below.

(a) The maximum plus or minus deviation from the true circular form of cylinders or the theoretical form of other shapes, measured radially on the outside or inside of the component, shall not exceed the maximum permissible deviation obtained from Figure NB-4221.2(a)-1. Measurements shall be made from a segmental circular template having the design inside or outside radius depending on where the measurements are taken and a chord length equal to twice the arc length obtained from Figure NB-4221.2(a)-2. For Figure NB-4221.2(a)-1, the maximum permissible deviation e need not be less than $0.3t$. For Figure NB-4221.2(a)-2, the arc length need not be greater than $0.30D_o$. Measurements shall not be taken on welds or other raised parts.

(b) The value of t, in. (mm), at any cross section is the nominal plate thickness less corrosion allowance for sections of constant thickness and the nominal thickness of the thinnest plate less corrosion allowance for sections having plates of more than one thickness.

(c) The value of L in Figures NB-4221.2(a)-1 and NB-4221.2(a)-2 is determined by (1) through (3) below.

(1) For cylinders, L is as given in NB-3133.2.

(2) For cones, L is the axial length of the conical section if no stiffener rings are used or, if stiffener rings are used, the axial length from the head bend line at the large end of the cone to the first stiffener ring, with D_o taken as the outside diameter in inches of the cylinder at the large end of the cone.

(3) For spheres, L is one-half of the outside diameter D_o, in.

Figure NB-4221.2(a)-1
Maximum Permissible Deviation e From a True Circular Form

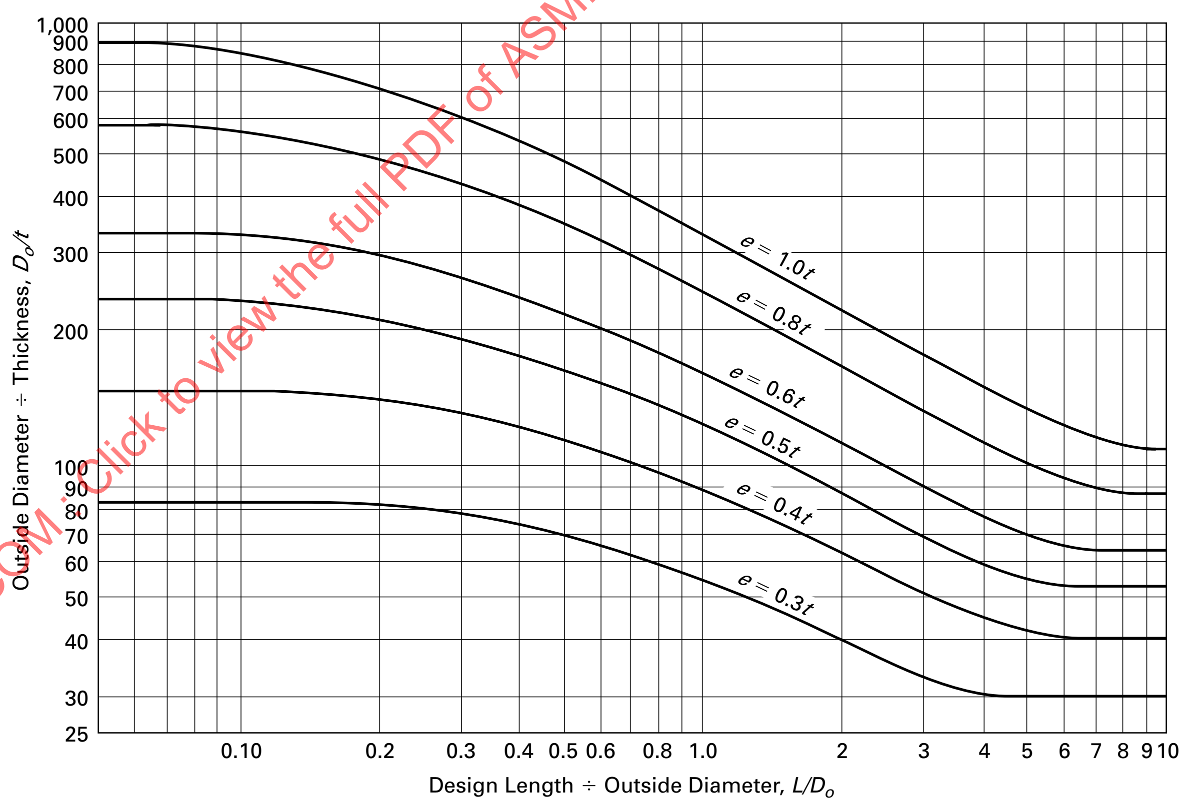
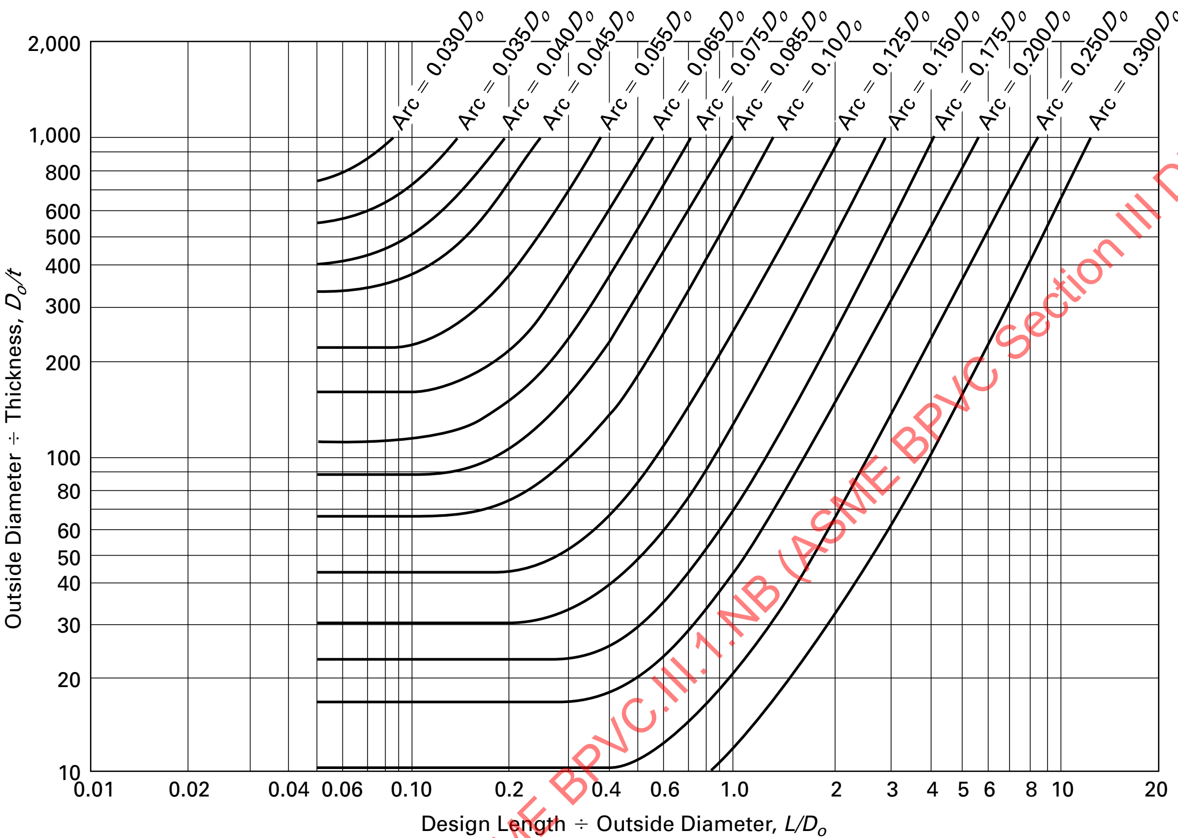


Figure NB-4221.2(a)-2
Maximum Arc Length for Determining Plus or Minus Deviation



NB-4221.3 Deviations From Tolerances. Deviations from the tolerance requirements stipulated in NB-4221.1 and NB-4221.2 are permitted, provided the drawings are modified and reconciled with the Design Report (NCA-3211.40) and provided the modifications are certified by a Certifying Engineer in an addendum to the Design Report.

NB-4221.4 Tolerance Deviations for Vessel Parts Fabricated From Pipe. Vessel parts subjected to either internal or external pressure and fabricated from pipe, meeting all other requirements of this Subsection, may have variations of diameter and deviations from circularity permitted by the specification for such pipe.

NB-4222 Tolerances for Formed Vessel Heads

The tolerance for formed vessel heads shall be as set forth in the following subparagraphs.

NB-4222.1 Maximum Difference in Cross-Sectional Diameters. The skirt or cylindrical end of a formed head shall be circular to the extent that the difference in inches between the maximum and minimum diameters does not exceed the lesser of

(U.S. Customary Units)

$$\frac{D + 50}{200} \text{ and } \frac{D + 12}{100}$$

(SI Units)

$$\frac{D + 1250}{200} \text{ and } \frac{D + 300}{100}$$

where D is the nominal inside diameter, in. (mm), and shall match the cylindrical edge of the adjoining part within the alignment tolerance specified in NB-4232.

NB-4222.2 Deviation From Specified Shape.

(a) The inner surface of a torispherical or ellipsoidal head shall not deviate outside the specified shape by more than $1\frac{1}{4}$% of D, inside the specified shape by more than $\frac{5}{8}$% of D, where D is the nominal inside diameter of the vessel. Such deviations shall be measured perpendicular to the specified shape and shall not be abrupt. The knuckle radius shall not be less than specified.

Table NB-4232-1
Maximum Allowable Offset in Final Welded Joints

Section Thickness, in. (mm)	Direction of Joints: Longitudinal	Direction of Joints: Circumferential
Up to $\frac{1}{2}$ (13), incl.	$\frac{1}{4}t$	$\frac{1}{4}t$
Over $\frac{1}{2}$ to $\frac{3}{4}$ (13 to 19), incl.	$\frac{1}{8}$ in. (3 mm)	$\frac{1}{4}t$
Over $\frac{3}{4}$ to $1\frac{1}{2}$ (19 to 38), incl.	$\frac{1}{8}$ in. (3 mm)	$\frac{3}{16}$ in. (5 mm)
Over $1\frac{1}{2}$ to 2 (38 to 50), incl.	$\frac{1}{8}$ in. (3 mm)	$\frac{1}{8}t$
Over 2 (50)	Lesser of $\frac{1}{16}t$ or $\frac{3}{8}$ in. (10 mm)	Lesser of $\frac{1}{8}t$ or $\frac{3}{4}$ in. (19 mm)

For 2:1 ellipsoidal heads, the knuckle radius may be considered to be 17% of the diameter of the vessel.

(b) Hemispherical heads and any spherical portion of a formed head shall meet the local tolerances for spheres as given in NB-4221.2, using L as the outside spherical radius, in., and D_o as two times L.

(c) Deviation measurements shall be taken on the surface of the base material and not on welds.

NB-4223 Tolerances for Formed or Bent Piping

The tolerances for formed or bent piping shall be as set forth in the following subparagraphs.

NB-4223.1 Minimum Wall Thickness. In order to ensure that the wall thickness requirements of the design calculations are met, the actual thickness shall be measured, or the process shall be qualified by demonstrating that it will maintain the required wall thickness.

NB-4223.2 Ovality Tolerance. Unless otherwise justified by the Design Report, the ovality of piping after bending shall not exceed 8% as determined by:

$$100 \times (D_{\max} - D_{\min})/D_o$$

where

D_o = nominal pipe outside diameter
$D_{\min}$ = minimum outside diameter after bending or forming
$D_{\max}$ = maximum outside diameter after bending or forming

NB-4230 FITTING AND ALIGNING

NB-4231 Fitting and Aligning Methods

Parts that are to be joined by welding may be fitted, aligned, and retained in position during the welding operation by the use of bars, jacks, clamps, tack welds, or temporary attachments.

NB-4231.1 Tack Welds. Tack welds 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. Tack welds shall be made by qualified welders using qualified welding procedures. When tack welds are to become part of the finished weld, they shall be visually examined and defective tack welds shall be removed.

NB-4232 Alignment Requirements When Components Are Welded From Two Sides

(a) Alignment of sections that are welded from two sides shall be such that the maximum offset of the finished weld will not be greater than the applicable amount listed in Table NB-4232-1, where t is the nominal thickness of the thinner section at the joint.

(b) Joints in spherical vessels, joints within heads, and joints between cylindrical shells and hemispherical heads shall meet the requirements in Table NB-4232-1 for longitudinal joints.

(c) In addition, offsets greater than those stated in Table NB-4232-1 are acceptable provided the requirements of NB-3200 are met.

NB-4232.1 Fairing of Offsets. Any offset within the allowable tolerance provided above shall be faired to at least a 3:1 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. In addition, single or multiple tapers or slopes more severe than 3:1 are acceptable, provided the requirements of NB-3200 are met.

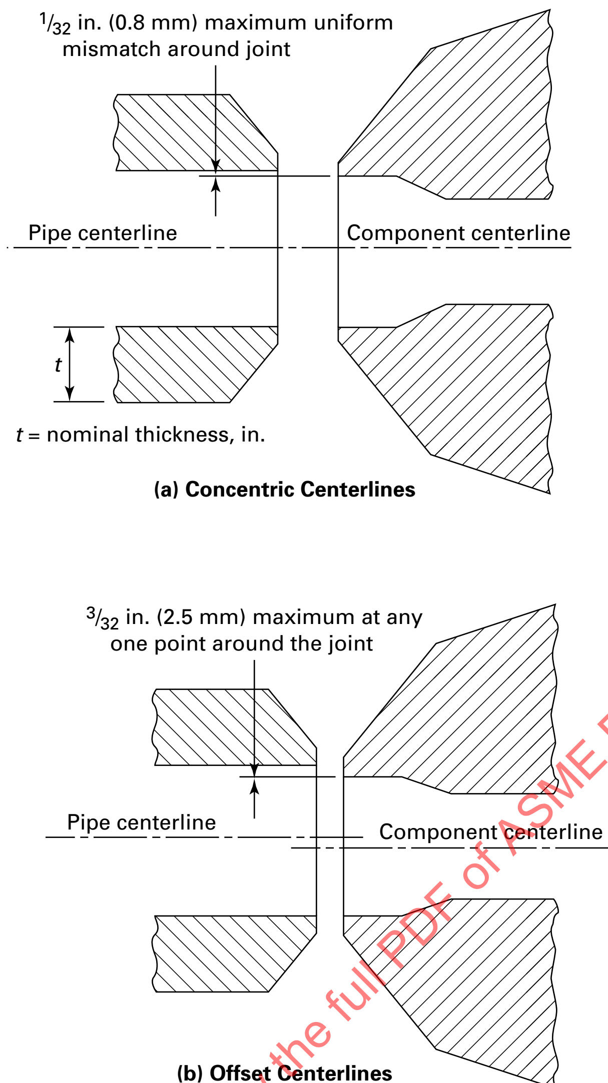
NB-4233 Alignment Requirements When Inside Surfaces Are Inaccessible

(a) When the inside surfaces of items are inaccessible for welding or fairing in accordance with NB-4232, alignment of sections shall meet the requirements of (1) and (2) below:

(1) See (-a) and (-b) below.

(-a) For circumferential joints the inside diameters shall match each other within $\frac{1}{16}$ in. (1.5 mm). When the items are aligned concentrically, a uniform mismatch of $\frac{1}{32}$ in. (0.8 mm) all around the joint can result as shown in Figure NB-4233(a)-1,

Figure NB-4233(a)-1
Butt Weld Alignment and Mismatch Tolerances for Unequal I.D. and O.D. When Components Are Welded From One Side and Fairing Is Not Performed



GENERAL NOTE: The weld end transitions are typical and are not intended as requirements. Refer to NB-4250 for weld end transition requirements.

sketch (a). However, other variables not associated with the diameter of the item often result in alignments that are offset rather than concentric. In these cases, the maximum misalignment at any one point around the joint shall not exceed $^{3}/_{32}$ in. (2.5 mm) as shown in Figure NB-4233(a)-1, sketch (b). Should tolerances on diameter, wall thickness, out-of-roundness, etc., result in inside diameter variations that do not meet these limits, the inside diameters shall be counterbored, sized, or ground to produce a bore within these limits, provided the requirements of NB-4250 are met.

(-b) Offset of outside surfaces shall be faired to at least a 3:1 taper over the width of the finished weld or, if necessary, by adding additional weld metal.

(2) For longitudinal joints the misalignment of inside surfaces shall not exceed $^{3}/_{32}$ in. (2.5 mm) and the offset of outside surfaces shall be faired to at least a 3:1 taper over the width of the finished weld or, if necessary, by adding additional weld metal.

(b) Single-welded joints may meet the alignment requirements of (a)(1) and (a)(2) above in lieu of the requirements of NB-4232.

(c) In addition, misalignments and offsets greater than those stated in Figure NB-4233(a)-1 and single or multiple tapers or slopes more severe than 3:1 are acceptable provided the requirements of NB-3200 are met.

NB-4240 REQUIREMENTS FOR WELD JOINTS IN COMPONENTS

NB-4241 Category A Weld Joints in Vessels and Longitudinal Weld Joints in Other Components

Category A weld joints in vessels and longitudinal weld joints in other components shall be full penetration butt joints. Joints that have been welded from one side with backing that has been removed and those welded from one side without backing are acceptable as full penetration welds provided the weld root side of the joints meets the requirements of NB-4424.

NB-4242 Category B Weld Joints in Vessels and Circumferential Weld Joints in Other Components

Category B weld joints in vessels and circumferential weld joints in other components shall be full penetration butt joints, except that piping NPS 2 (DN 50) and smaller may be socket welded. When used, backing strips shall be continuous in cross section. Joints prepared with opposing lips to form an integral backing strip and joints with backing strips that are not later removed are acceptable provided the requirements of NB-3352.2 are met.

NB-4243 Category C Weld Joints in Vessels and Similar Weld Joints in Other Components

Category C weld joints in vessels and similar weld joints in other components shall be full penetration joints, except that NPS 2 (DN 50) and smaller socket welded joints may be used on component nozzles and in piping. Joints that have been welded from one side with backing that has been removed and those welded from one side without backing are acceptable as full penetration welds provided the weld root side of the joints meets the requirements of NB-4424. Either a butt-welded joint or a full penetration corner joint as shown in Figure NB-4243-1 shall be used.

NB-4244 Category D Weld Joints in Vessels and Similar Weld Joints in Other Components

Category D weld joints in vessels and similar weld joints in other components shall be full or partial penetration weld joints using one of the details of (a) through (e) below.

(a) Butt-Welded Nozzles. Nozzles shall be attached by full penetration butt welds through the wall of the component, nozzle, or branch as shown in Figure NB-4244(a)-1. Backing strips, if used, shall be removed.

(b) Corner-Welded Nozzles. Nozzles shall be joined to the component by full penetration welds through the wall of the component, nozzle, or branch similar to those shown in Figure NB-4244(b)-1. Backing strips, if used, shall be removed.

(c) Deposited Weld Metal of Openings for Nozzles. Nozzles shall be joined to the component by full penetration welds to built-up weld deposits applied to the component or nozzle as shown in Figure NB-4244(c)-1. Backing strips, if used, shall be removed. Fillet welds shall be used only to provide a transition between the parts joined or to provide a seal. The fillet welds, when used, shall be finished by grinding to provide a smooth surface having a transition radius at its intersection with either part being joined.

(d) Partial Penetration Welded Nozzles. Partial penetration welds in components shall meet the weld design requirements of NB-3352.4(d). Nozzles shall be attached as shown in Figures NB-4244(d)-1 and NB-4244(d)-2.

(e) Oblique Nozzles. Oblique nozzles shall be joined to the component by full penetration welds through the nozzle as shown in Figure NB-4244(e)-1. Backing rings, if used, shall be removed.

NB-4245 Complete Joint Penetration Welds

Complete joint penetration is considered to be achieved when the acceptance criteria for the examinations specified by this Subsection have been met. No other examination is required to assess that complete penetration has been achieved.

NB-4246 Piping Branch Connections

Piping branch connections shall be welded joints using the details of (a), (b), or (c).

(a) Full Penetration Welded Branch Connections. Branch connections shall be joined by full penetration welds as shown in Figure NB-4246(a)-1 meeting the following requirements:

(1) Backing strips if used shall be removed.

(2) The requirements of NB-3683.8(a) shall be met.

(b) Fillet and Partial Penetration Welded Branch Connections. Fillet and partial penetration welded branch connections shall meet the requirements of NB-3661.3. Branch connections shall be attached as shown in Figure NB-4246(b)-1.

(c) Welded Branch Connections per NB-4244. Welded connections per NB-4244 are permitted; however, the stress indices of NB-3683.8 are not applicable to all configurations.

NB-4250 WELDING END TRANSITIONS — MAXIMUM ENVELOPE (23)

The welding ends of items shall provide a gradual change in thickness from the item to the adjoining item. Any welding end transition that lies entirely within the envelope shown in Figure NB-4250-1 is acceptable, provided

(a) the wall thickness in the transition region is not less than the minimum wall thickness of the adjoining pipe;

(b) sharp reentrant angles and abrupt changes in slope in the transition region are avoided. When the included angle between any two adjoining surfaces of a taper transition is less than 150 deg, the intersection or corner (except for the weld reinforcement) shall be provided with a radius of at least $0.05t_{min}$;

(c) if the weld is subject to preservice inspection and if counterboring is performed, the length of the counterbore shall be a minimum of $2t_{min}$ for pipe and a minimum of t_{min} for components and fittings, as shown in Figure NB-4250-2 or Figure NB-4250-3.

(d) Items subject to preservice MANDE (Section XI, Division 2) shall be configured in such a manner that all requirements for MANDE in the Design Specification can be met.

(e) Transitions more severe than those stated herein are acceptable provided the requirements of NB-3200 are met.

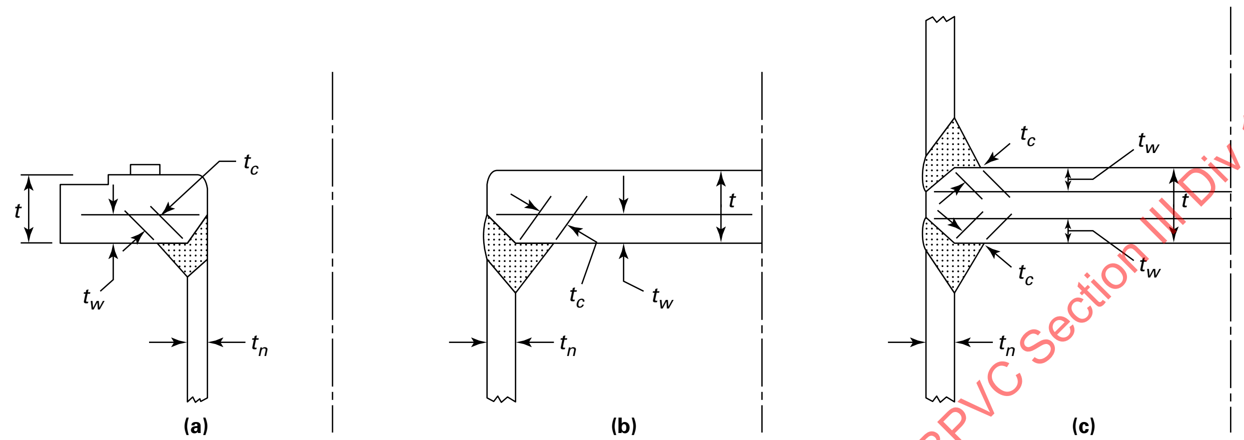
NB-4300 WELDING QUALIFICATIONS

NB-4310 GENERAL REQUIREMENTS

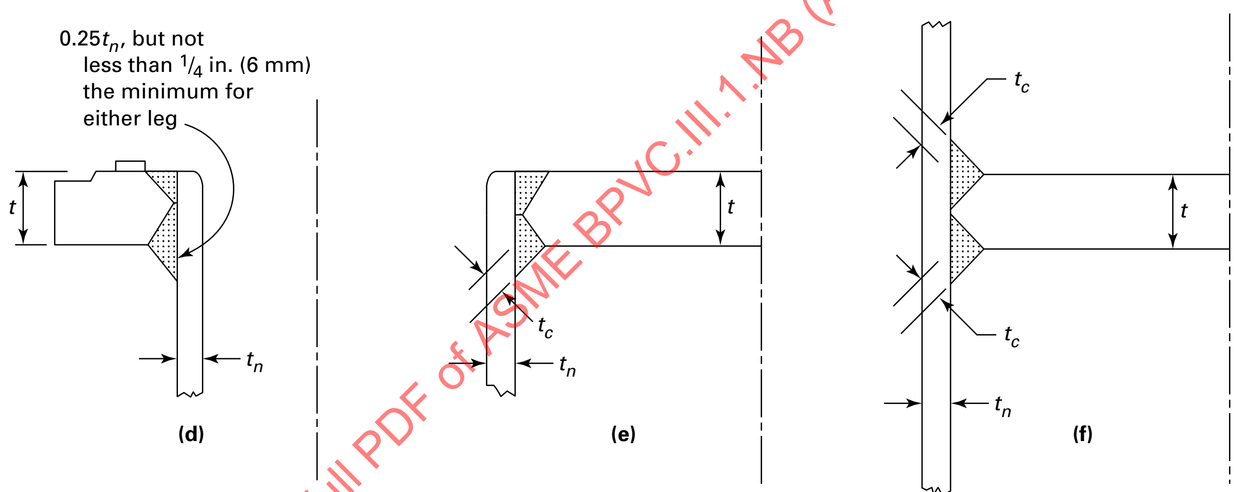
NB-4311 Types of Processes Permitted

Only those welding processes that are capable of producing welds in accordance with the welding procedure qualification requirements of Section IX and this

Figure NB-4243-1
Acceptable Full Penetration Weld Details for Category C Joints (NB-3352.3)

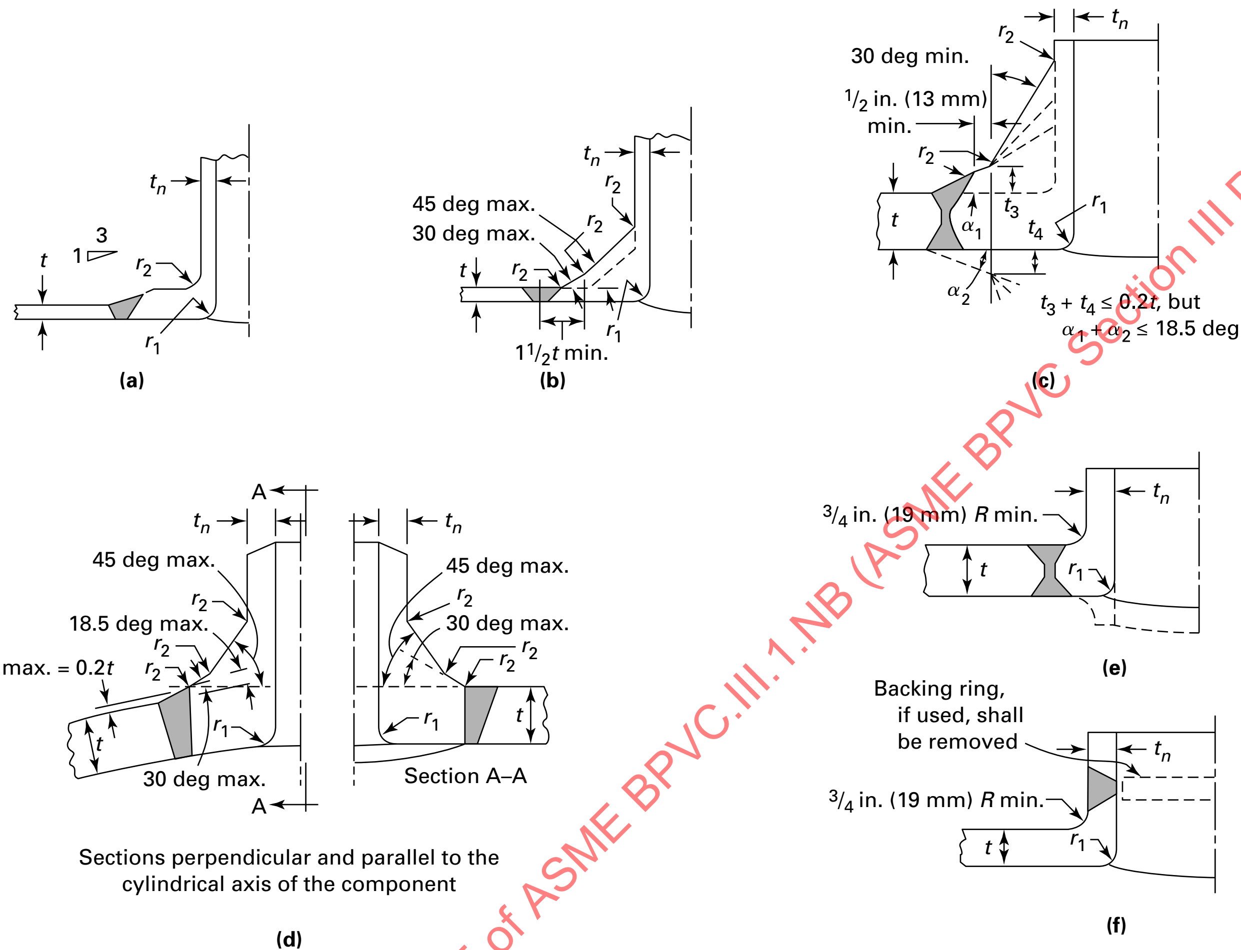


Type 1 Corner Welds



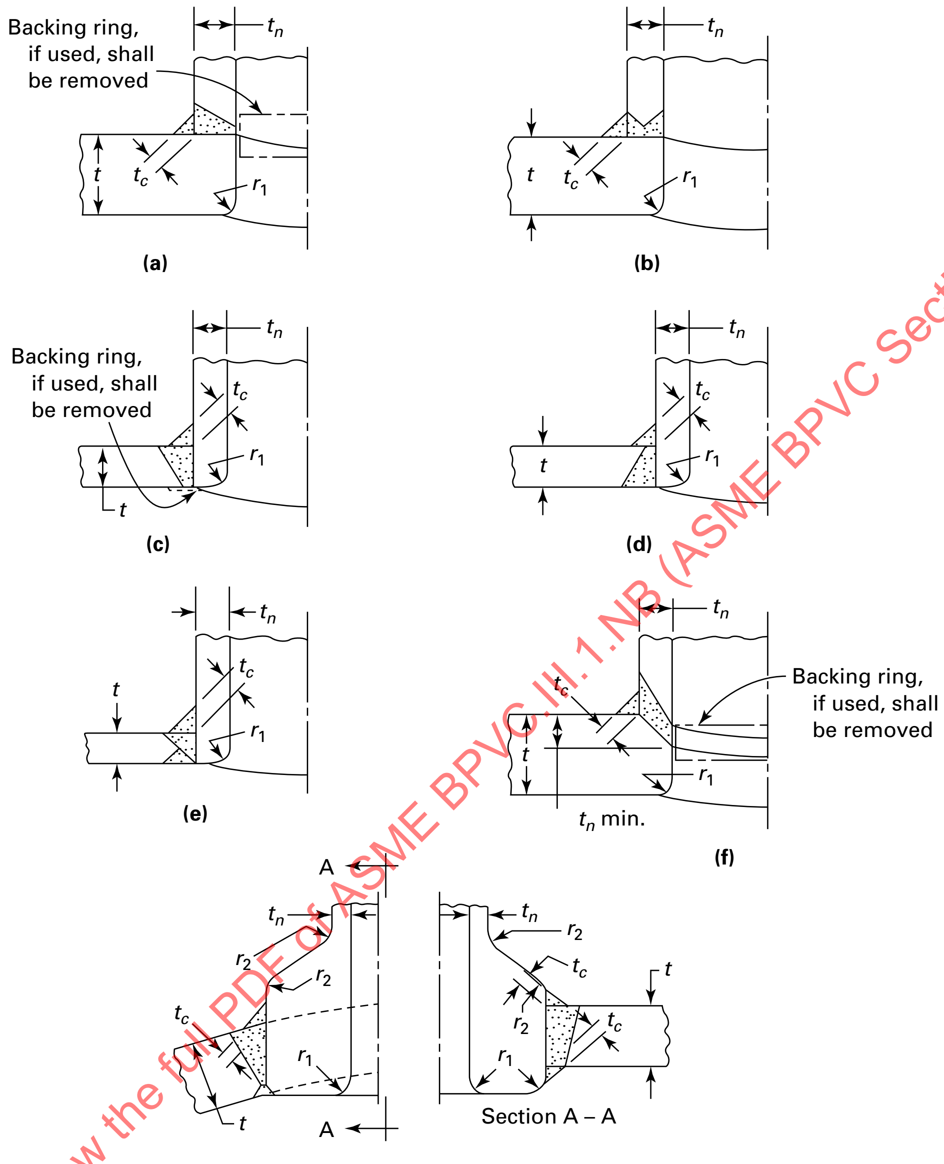
Type 2 Corner Welds

Figure NB-4244(a)-1
Nozzles Joined by Full Penetration Butt Welds



GENERAL NOTES:
(a) For definitions of symbols, see NB-3352.4(a).
(b) Reinforcement may be distributed within the limits prescribed by the Code.

Figure NB-4244(b)-1
Nozzles Joined by Full Penetration Corner Welds

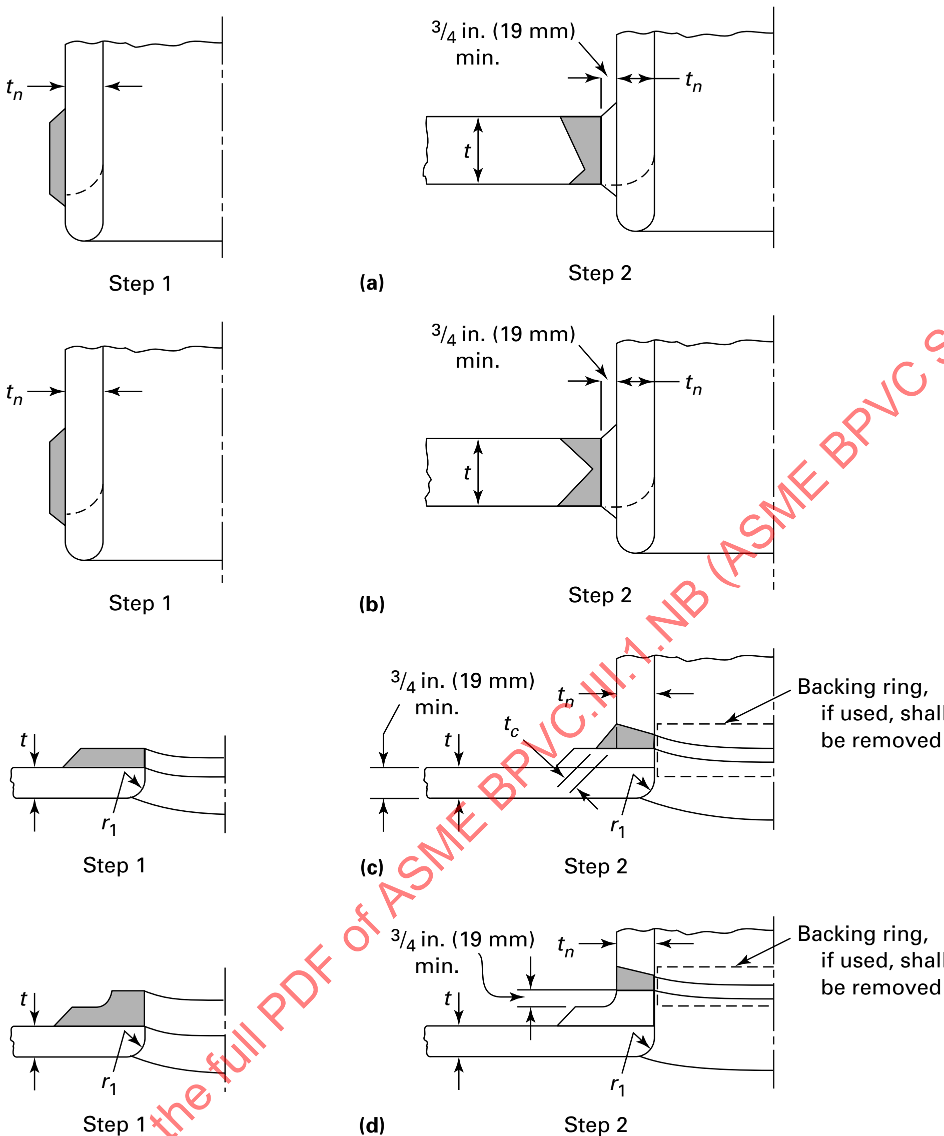


Sections perpendicular and parallel to the cylindrical axis of the component

(g)

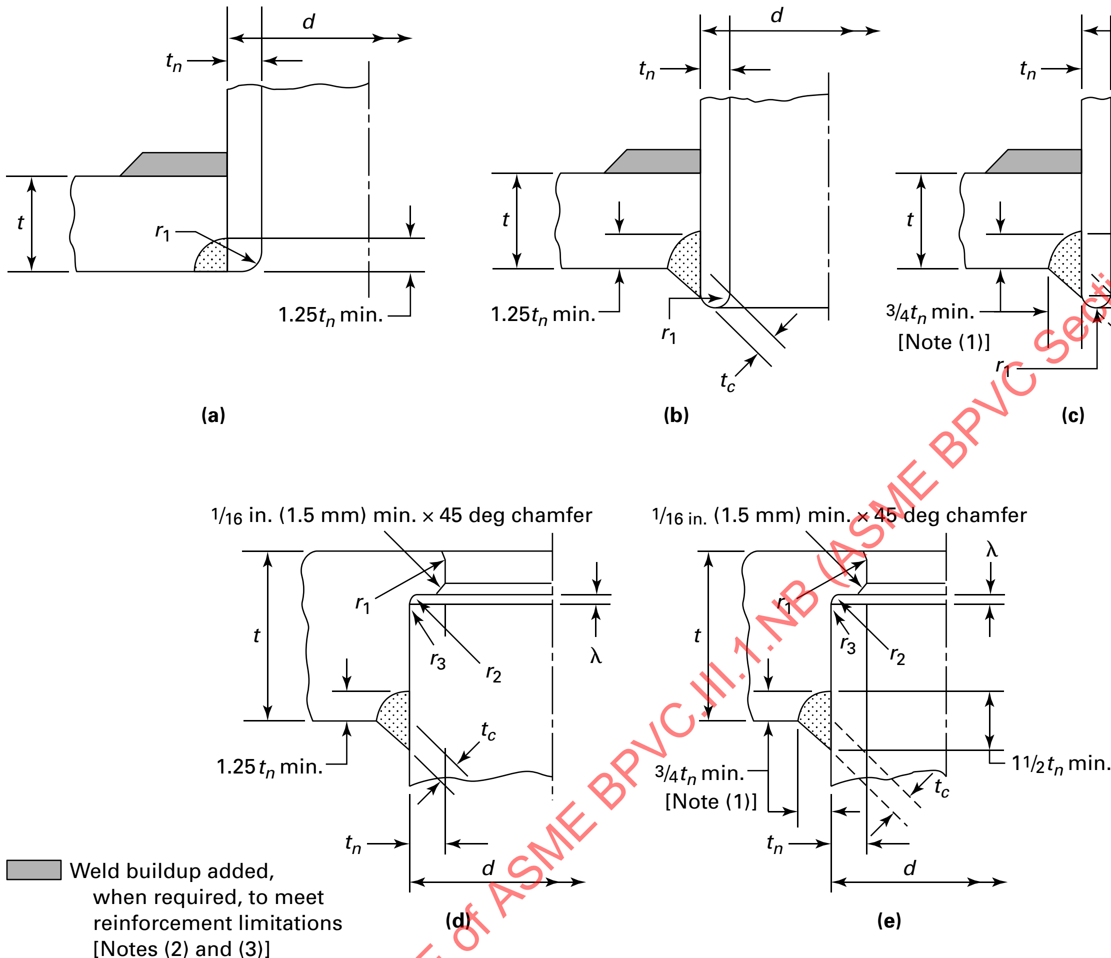
GENERAL NOTE: For definitions of symbols, see NB-3352.4(b).

Figure NB-4244(c)-1
Deposited Weld Metal Used as Reinforcement of Openings for Nozzles



GENERAL NOTES:
(a) For definitions of symbols, see NB-3352.4(c).
(b) At Step 1 examination (see NB-5244) required before assembly.

Figure NB-4244(d)-1
Partial Penetration Nozzles



GENERAL NOTE: For definitions of symbols and other related requirements, see NB-3352.4(d).

NOTES:
(1) The $\frac{3}{4}t_n$ min. dimension applies to the fillet leg and the J-groove depth.
(2) Weld buildup, if used, shall be examined as required in NB-5244.
(3) Weld buildups are not attached to the nozzle.

Figure NB-4244(d)-2
Partial Penetration Nozzle for Coaxial Cylinders

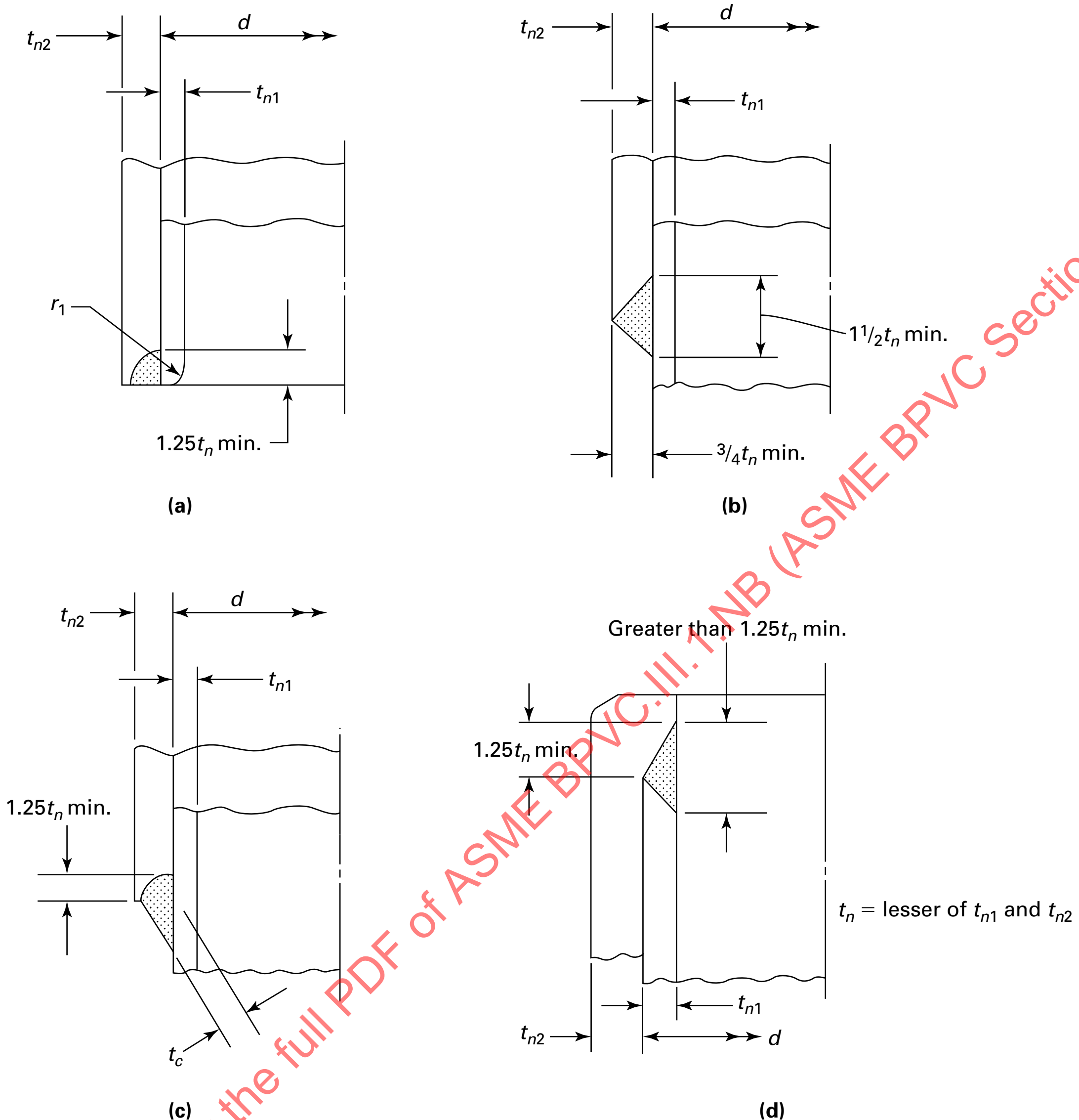
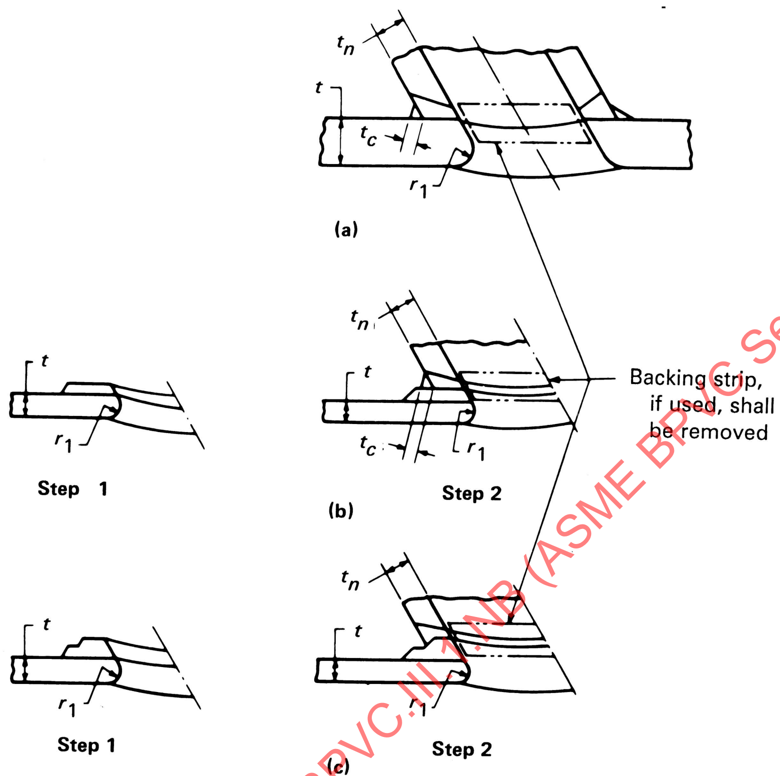
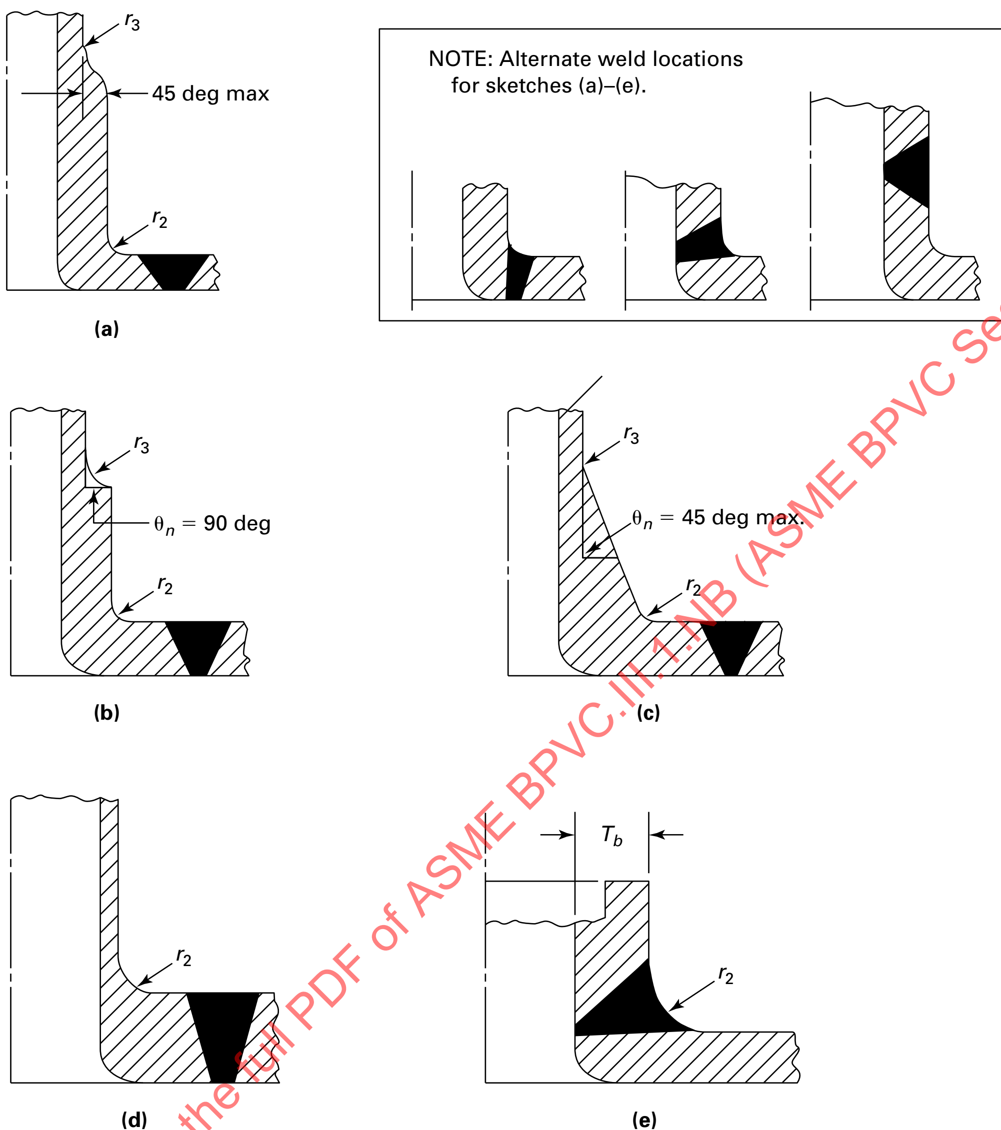


Figure NB-4244(e)-1
Oblique Connections



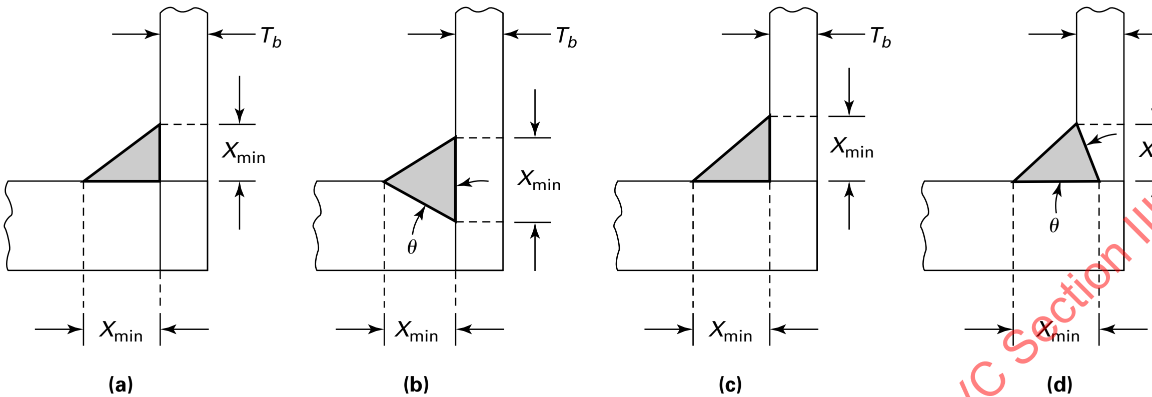
GENERAL NOTES:
(a) Step 1 examination required before assembly.
(b) For definitions of symbols, see NB-3352.4(e).

Figure NB-4246(a)-1
Typical Piping Branch Connections Joined by Full Penetration Welds



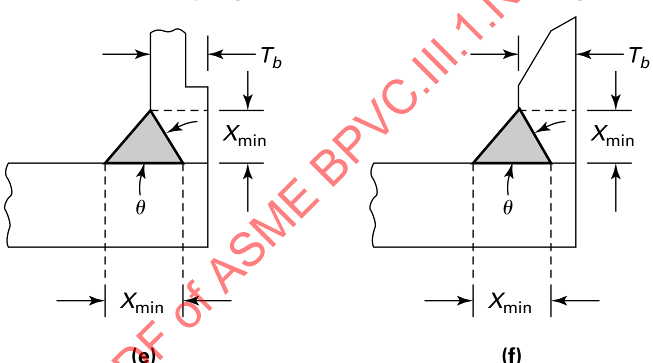
GENERAL NOTE: Welds may be made from one or both sides in any of the locations shown.

Figure NB-4246(b)-1
Typical Piping Branch Connections Joined by a Fillet Weld or a Partial Penetration Weld



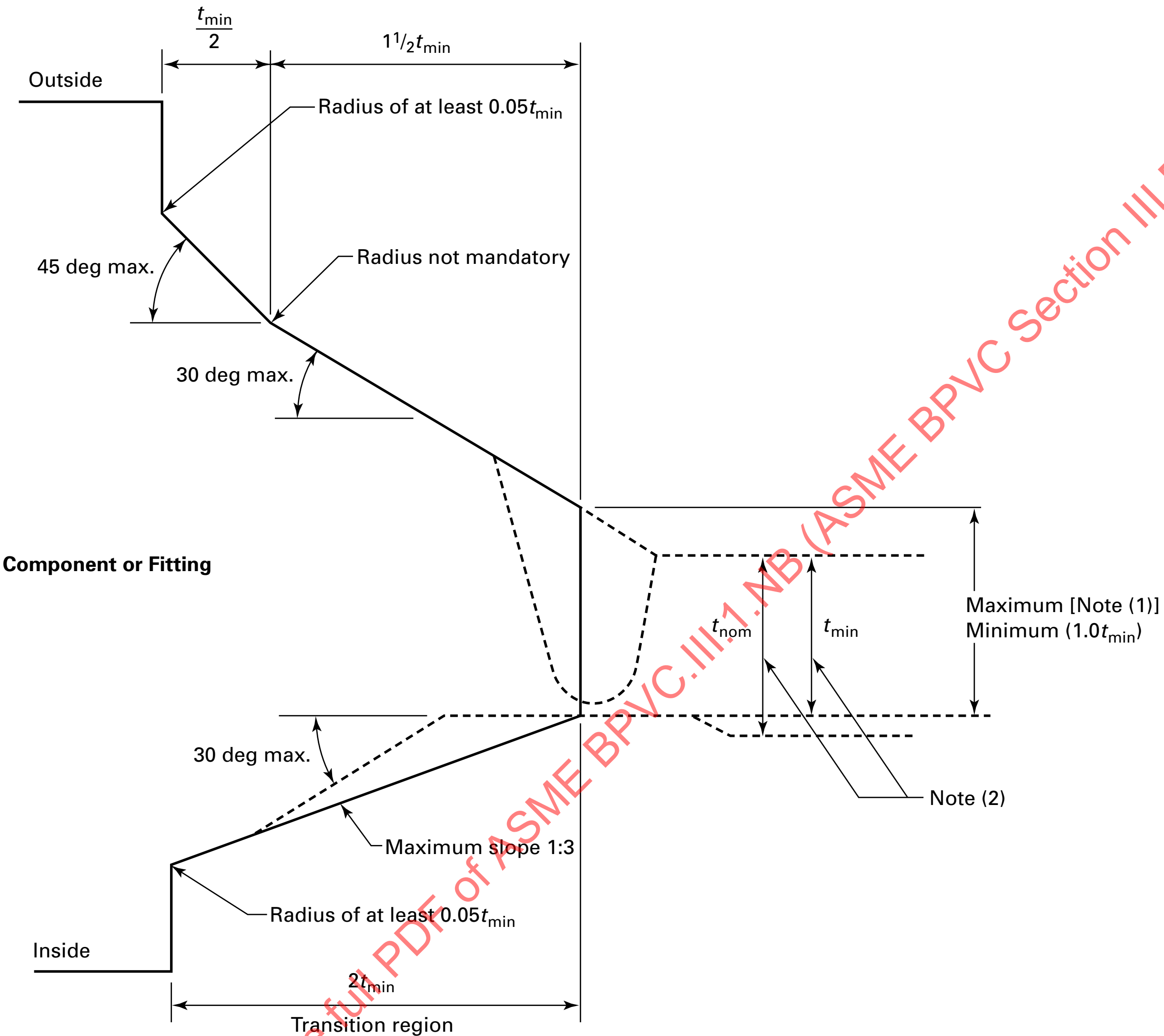
T_b = Nominal branch pipe wall thickness
X_{min} = $1^1/_4 T_b$
θ = Partial penetration weld groove angle ≥ 45 deg

ASME B16.11 Coupling **Welded Outlet Fitting**



T_b = Fitting wall thickness in the reinforcement zone (when the fitting is tapered in the reinforcement zone, use average wall thickness)
X_{min} = $1^1/_4 T_b$
θ = Partial penetration weld groove angle ≥ 45 deg; θ = 90 deg (fillet weld) is permitted

Figure NB-4250-1
Welding End Transitions — Maximum Envelope

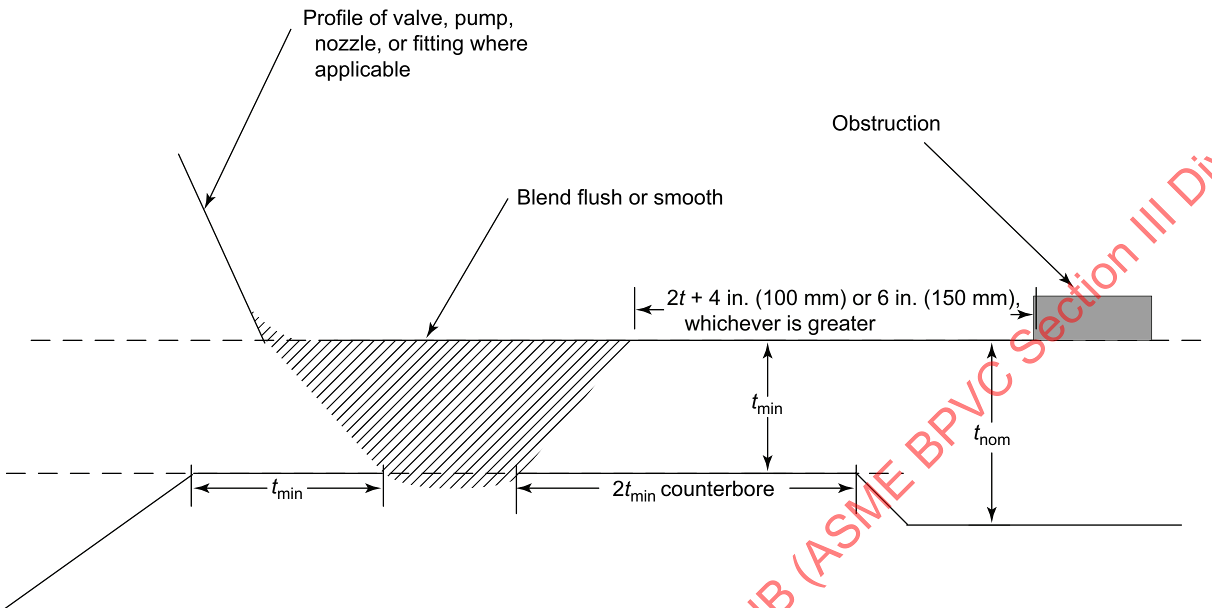


GENERAL NOTES:
(a) Weld bevel is shown for illustration only.
(b) The weld reinforcement permitted by NB-4426 may lie outside the maximum envelope.

NOTES:
(1) The maximum thickness at the end of the component is:
 (a) the greater of t_{min} + 0.15 in. (3.8 mm) or $1.15t_{min}$ when ordered on a minimum wall basis;
 (b) the greater of t_{min} + 0.15 in. (3.8 mm) or $1.0t_{nom}$ when ordered on a nominal wall basis.
(2) The value of t_{min} is whichever of the following is applicable:
 (a) the minimum ordered wall thickness of the pipe;
 (b) 0.875 times the nominal wall thickness of pipe ordered to a pipe schedule wall thickness that has an under tolerance of 12.5%;
 (c) the minimum ordered wall thickness of the cylindrical welding end of a component or fitting (or the thinner of the two) when the joint is between two components.

Figure NB-4250-2
Component to Pipe Weld

(23)



GENERAL NOTE:
(a) The counterbore is not required to be parallel to the pipe O.D., provided that all other requirements of Figure NB-4250-2 are met.
(b) The wall thickness in the counterbore area shall be a minimum of t_{min} as defined in Figure NB-4250-1.
(c) The counterbore length shown is a minimum requirement.
(d) Cross-hatched area represents allowable weld profile after grinding/weld conditioning.
(e) Obstruction refers to hangers, lugs, trunnions, welded attachments, branch connections, or any other item that could interfere with UT coverage of the weld required for PSI. Distances indicated are from the edge of the weld to the closer edge of the obstruction.

Subsection may be used for welding pressure-retaining material or attachments thereto. Any process used shall be such that the records required by NB-4320 can be prepared, except that records for stud welds shall be traceable to the welders and welding operators and not necessarily to each specific weld.

NB-4311.1 Stud Welding Restrictions. Stud welding is acceptable only for nonstructural and temporary attachments (see NB-4435). Studs shall be limited to 1 in. (25 mm) maximum diameter for round studs and an equivalent cross-sectional area for studs of other shapes when welding in the flat position and $^3/_4$ in. (19 mm) diameter for all other welding positions. Postweld heat treatment shall comply with NB-4600, except that time at temperature need not exceed $^1/_2$ hr regardless of base material thickness. Welding procedure and performance qualification shall comply with the requirements of Section IX.

NB-4311.2 Capacitor Discharge Welding. Capacitor discharge welding may be used for welding temporary attachments and permanent nonstructural attachments provided:

(a) temporary attachments are removed in accordance with the provisions of NB-4435(b); and

(b) the energy output for permanent nonstructural attachments such as strain gages and thermocouples is limited to 125 W-sec, and the minimum thickness of the material to which the attachment is made is greater than 0.09 in. (2.3 mm); and

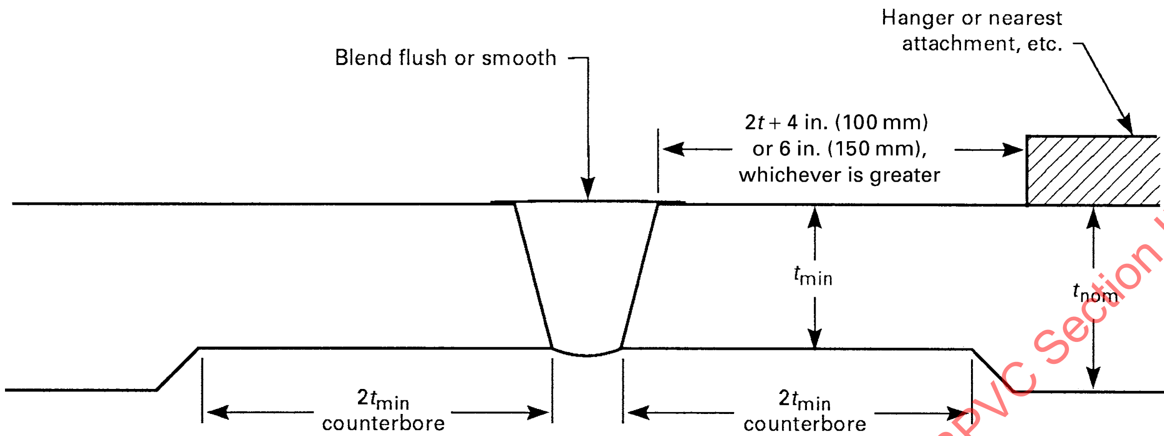
(c) a Welding Procedure Specification is prepared describing the capacitor discharge equipment, the combination of materials to be joined, and the technique of application; qualification of the welding procedure is not required.

NB-4311.4 Inertia and Continuous Drive Friction Welding.

(a) Inertia and continuous drive friction welding shall not be used for the fabrication of vessels and piping.

(b) The weld between the two members shall be a full penetration weld.

Figure NB-4250-3
Pipe to Pipe Weld



GENERAL NOTES:

(a) The counterbore is not required to be parallel to the pipe O.D., provided that all other requirements of Figure NB-4250-3 are met.

(b) The wall thickness in the counterbore area shall be a minimum of t_{min} as defined in Figure NB-4250-1.

(c) The counterbore length shown is a minimum requirement.

NB-4320 WELDING QUALIFICATIONS, RECORDS, AND IDENTIFYING STAMPS

NB-4321 Required Qualifications

(a) Each Certificate Holder is responsible for the welding done by its organization, and each Certificate Holder shall establish the procedure and conduct the tests required by this Article and by Section IX in order to qualify both the welding procedures and the performance of welders and welding operators who apply these procedures.

(b) Procedures, welders, and welding operators used to join permanent or temporary attachments to pressure parts and to make permanent or temporary tack welds used in such welding shall also meet the qualification requirements of this Article.

(c) When making procedure test plates for butt welds, consideration shall be given to the effect of angular, lateral, and end restraint on the weldment. This applies particularly to material and weld metal of 80.0 ksi (550 MPa) tensile strength or higher and heavy sections of both low and high tensile strength material. The addition of restraint during welding may result in cracking difficulties that otherwise might not occur.

(d) NCA-3131 provides specific additional requirements when welding services are subcontracted to or through organizations not holding an appropriate Certificate of Authorization.

NB-4322 Maintenance and Certification of Records

The Certificate Holder shall maintain a record of the qualified welding procedures and of the welders and welding operators it qualified, showing the date and results of tests and the identification mark assigned to each welder. These records shall be reviewed, verified, and certified by the Certificate Holder by signature or some other method of control in accordance with the Certificate Holder's Quality Assurance program and shall be available to the Authorized Nuclear Inspector.

NB-4322.1 Identification of Joints by Welder or Welding Operator.

(a) Each welder or welding operator shall apply the identification mark assigned by the Certificate Holder on or adjacent to all permanent welded joints or series of joints on which that person welds. The marking shall be at intervals of 3 ft (1 m) or less and shall be done with either blunt nose continuous or blunt nose interrupted dot die stamps. As an alternative, the

Certificate Holder shall keep a record of permanent welded joints in each item and of the welders and welding operators used in making each of the joints.

(b) When a multiple number of permanent structural attachment welds, nonstructural welds, fillet welds, socket welds, welds of specially designed seals, weld metal cladding, hard surfacing, and tube-to-tube sheet welds are made on an item, the Certificate Holder need not identify the welder or welding operator who welded each individual joint, provided:

(1) the Certificate Holder maintains a system that will identify the welders or welding operators who made such welds on each item so that the Inspector can verify that the welders or welding operators were all properly qualified;

(2) the welds in each category are all of the same type and configuration and are welded with the same Welding Procedure Specification.

(c) The identification of welder or welding operator is not required for tack welds.

NB-4323 Welding Prior to Qualifications

No welding shall be undertaken until after the welding procedures that are to be used have been qualified. Only welders and welding operators who are qualified in accordance with NB-4320 and Section IX shall be used.

NB-4324 Transferring Qualifications

The welding procedure qualifications and the performance qualification tests for welders and welding operators conducted by one Certificate Holder shall not qualify welding procedures and shall not qualify welders or welding operators to weld for any other Certificate Holder, except as provided in Section IX.

NB-4330 GENERAL REQUIREMENTS FOR WELDING PROCEDURE QUALIFICATION TESTS

NB-4331 Conformance to Section IX Requirements

All welding procedure qualification tests shall be in accordance with the requirements of Section IX as supplemented or modified by the requirements of this Article.

NB-4333 Heat Treatment of Qualification Welds for Ferritic Materials

Postweld heat treatment of procedure qualification welds shall conform to the applicable requirements of NB-4620 and Section IX. The postweld heat treatment time at temperature shall be at least 80% of the maximum time to be applied to the component weld material. The postweld heat treatment total time may be applied in one heating cycle.

NB-4334 Preparation of Test Coupons and Specimens

(a) Removal of test coupons from the test weld and the dimensions of specimens made from them shall conform to the requirements of Section IX, except that the removal of impact test coupons and the dimensions of impact test specimens shall be in accordance with (b) below.

(b) Weld deposit of each process in a multiple process weld shall, where possible, be included in the impact test specimens. When each process cannot be included in the full-size impact test specimen at the $\frac{1}{4}t$ location required by this Section, additional full-size specimens shall be obtained from locations in the test weld that will ensure that at least a portion of each process has been included in full-size test specimens. As an alternative, additional test welds can be made with each process so that full-size specimens can be tested for each process.

NB-4334.1 Coupons Representing the Weld Deposit. Impact test specimens and testing methods shall conform to NB-2321. The impact specimen shall be located so that the longitudinal axis of the specimen is at least $0.25t$ and, where the thickness of the test assembly permits, not less than $\frac{3}{8}$ in. (10 mm) from the weld surface of the test assembly. In addition, when the postweld heat treatment temperature exceeds the maximum temperature specified in NB-4620 and the test assembly is cooled at an accelerated rate, the longitudinal axis of the specimen shall be a minimum of t from the edge of the test assembly. The specimen shall be transverse to the longitudinal axis of the weld with the area of the notch located in the weld. The length of the notch of the Charpy V-notch specimen shall be normal to the surface of the weld. Where drop weight specimens are required, the tension surface of the specimen shall be oriented parallel to the surface of the test weld assembly.

NB-4334.2 Coupons Representing the Heat-Affected Zone. Where impact tests of the heat-affected zone are required by NB-4335.2, specimens shall be taken from the welding procedure qualification test assemblies in accordance with (a) through (c) below.

(a) If the qualification test material is in the form of a plate or a forging, the axis of the weld shall be oriented in the direction parallel to the principal direction of rolling or forging.

(b) The heat-affected zone impact test specimens and testing methods shall conform to the requirements of NB-2321.2. The specimens shall be removed from a location as near as practical to a depth midway between the surface and center thickness. The coupons for heat-affected zone impact specimens shall be taken transverse to the axis of the weld and etched to define the heat-affected zone. The notch of the Charpy V-notch specimen shall be cut approximately normal to the material surface in such a manner as to include as much heat-affected zone as possible in the resulting fracture. Where the material

thickness permits, the axis of a specimen may be inclined to allow the root of the notch to align parallel to the fusion line. When a grain refining heat treatment is not performed on welds made by the electroslag or electrogas welding process, the notch for the impact specimens shall be located in the grain coarsened region.

(c) For the comparison of heat-affected zone values with base material values [see NB-4335.2(b)], Charpy V-notch specimens shall be removed from the unaffected base material at approximately the same distance from the base material surface as the heat-affected zone specimens. The axis of the unaffected base material specimens shall be parallel to the axis of the heat-affected zone specimens, and the axis of the notch shall be normal to the surface of the base material. When required by NB-4335.2(b), drop-weight specimens shall be removed from a depth as near as practical to midway between the surface and center thickness of the unaffected base material and shall be tested in accordance with the requirements of NB-2321.1.

NB-4335 Impact Test Requirements

When materials are required to be impact tested per NB-2300, impact tests of the weld metal and heat-affected zone shall be performed in accordance with the following subparagraphs. The weld procedure qualification impact test specimens shall be prepared and tested in accordance with the applicable requirements of NB-2330 and NB-4334. Retests in accordance with the provisions of NB-2350 are permitted.

NB-4335.1 Impact Tests of Weld Metal.

(a) Impact tests of the weld metal shall be required for welding procedure qualification tests for production weld joints exceeding $^5\!/_8$ in. (16 mm) in thickness when the weld will be made on the surface or penetrate base material that requires impact testing in accordance with NB-2310. In addition, such testing of the weld metal is required for the welding procedure qualification tests for any weld repair to base material that requires impact testing in accordance with NB-2310, regardless of the depth of the repair.

(b) The impact test requirements and acceptance standards for welding procedure qualification weld metal shall be the same as specified in NB-2330 for the base material to be welded or repaired. Where two materials are to be joined by welding and have different fracture toughness requirements, the test requirements and acceptance standards of either material may be used for the weld metal except where this is otherwise specified by NCA-1280 or other parts of this Subsection.

NB-4335.2 Impact Tests of Heat-Affected Zone.

(a) Charpy V-notch tests of the heat-affected zone of the welding procedure qualification test assembly are required whenever the thickness of the weld exceeds $^5\!/_8$ in. (16 mm) and either of the base materials require impact testing in accordance with the rules of NB-2310. The only exceptions to the requirements are the following:

(1) the qualification for welds in P-Nos. 1 and 3 and SA-336 F12 materials that are postweld heat treated and are made by any process other than electroslag or electrogas.

(2) the qualification for weld deposit cladding or hard-facing on any base material.

(3) that portion of the heat-affected zone associated with GTAW root deposits with a maximum of two layers or $^3\!/_{16}$ in. (5 mm) thickness, whichever is less.

(b) The required testing shall be in accordance with (c) for base material tested under NB-2331 or NB-2332(b) and in accordance with (d) for base material tested under NB-2332(a).

(c) For heat-affected zones associated with base material tested under NB-2331 or NB-2332(b), the required testing shall be in accordance with (1) through (7).

(1) Determine the T_{NDT} of the unaffected base material to be used in the welding procedure qualification test assembly.

(2) Charpy V-notch test specimens representing both the heat-affected zone and the unaffected base material shall be tested. The unaffected base material specimens shall be tested at the (T_{NDT} + 60°F) [T_{NDT} + 33°C] temperature.

(3) The Charpy V-notch tests of the unaffected base material shall meet the applicable requirements of NB-2331(a) or additional testing shall be performed at higher temperatures until the requirements of NB-2331(a) are met.

(4) The heat-affected zone specimens shall be tested at the test temperature determined in (3). The average lateral expansion value of the specimens shall equal or exceed the average lateral expansion value of the unaffected base material. For this case the qualification test is acceptable for the essential and supplemental essential variables recorded on the welding procedure qualification record (PQR). If the heat-affected zone average lateral expansion value is less than the unaffected base material lateral expansion value, the adjustment given in (5) through (7) shall be determined and applied as provided in (e).

(5) Additional Charpy V-notch tests shall be performed on either the heat-affected zone or the unaffected base material, or both, at temperatures where the lateral expansion value of all three specimens tested is not less than 35 mils (0.89 mm). The average lateral expansion value for each test meeting this requirement shall be plotted on a lateral expansion versus temperature graph. The difference in temperature T_{HAZ} and T_{UBM} where the heat-affected zone and the unaffected base material average lateral expansion values are the same and not less than 35 mils (0.89 mm) shall be

used to determine the adjustment temperature T_{ADJ} where:

$$T_{ADJ} = T_{HAZ} - T_{UBM}$$

If $T_{ADJ} \leq 0$, then $T_{ADJ} = 0$.

(6) As an alternative to (5), if the average lateral expansion value of the heat-affected zone specimens is no less than 35 mils (0.89 mm) and the average of the heat-affected zone specimens is not less than 5 mils (0.13 mm) below the average lateral expansion value of the unaffected base material specimens, T_{ADJ} may be taken as 15°F (8°C).

(7) As a second alternative to (5), if the average lateral expansion value of the heat-affected zone specimens is no less than 35 mils (0.89 mm), the difference between the average lateral expansion of the heat-affected zone and the unaffected base material specimens shall be calculated and used as described in (e)(3).

(d) For heat-affected zones associated with base materials tested under NB-2332(a), the required testing shall be in accordance with (1) through (5).

(1) Three Charpy V-notch specimens shall be removed from both the unaffected base material and the heat-affected zone. The unaffected base material specimens shall be tested at a test temperature established in the design specification or additional testing shall be performed at higher temperatures until the applicable requirements of Table NB-2332(a)-1 are met for the thickness of material to be welded in production.

(2) The heat-affected zone specimens shall be tested at the test temperature determined in (1). The average lateral expansion value of the specimens shall equal or exceed the average lateral expansion value of the unaffected base material. For this case the qualification test is acceptable for the essential and supplemental essential variables recorded on the weld procedure qualification record. If the heat-affected zone average lateral expansion value is less than the unaffected base material lateral expansion value, the adjustment given in (3) through (5) shall be determined and applied as provided in (e). Alternatively, another test coupon may be welded and tested.

(3) Additional Charpy V-notch tests shall be performed on either the heat-affected zone or the unaffected base material, or both, at temperatures where the lateral expansion value of all three specimens tested is not less than the values shown in Table NB-2332(a)-1 for the thickness of base material to be welded in production. The average lateral expansion value for each test meeting this requirement shall be plotted on a lateral expansion versus temperature graph. The difference in temperature T_{HAZ} and T_{UBM} where the heat-affected zone and the unaffected base material average lateral expansion values are the same shall be used to determine the adjustment temperature where:

$$T_{ADJ} = T_{HAZ} - T_{UBM}$$

If $T_{ADJ} \leq 0$, then $T_{ADJ} = 0$.

(4) As an alternative to (3), if the average lateral expansion value of the heat-affected zone is no less than 35 mils (0.89 mm) and the average of the heat-affected zone specimens is not less than 5 mils (0.13 mm) below the average lateral expansion value of the unaffected base material, T_{ADJ} may be taken as 15°F (8°C).

(5) As a second alternative to (3), if the average lateral expansion value of the heat-affected zone specimens is no less than 35 mils (0.89 mm), the difference between the average lateral expansion of the heat-affected zone and unaffected base material specimens shall be calculated and used as described in (e)(3).

(e) At least one of the following methods shall be used to compensate for the heat-affected zone toughness decrease due to the welding procedure.

(1) The RT_{NDT} temperature established in NB-2331 or NB-2332(b) or the lowest service temperature specified in the Design Specification [see NB-2332(a)] for all of the material to be welded in production welding procedure specifications (WPSs) supported by this PQR shall be increased by the adjustment temperature T_{ADJ}.

(2) The specified testing temperature for the production material may be reduced by T_{ADJ}.

(3) The materials to be welded may be welded using the WPS provided they exhibit Charpy V-notch values that are no less than the minimum required lateral expansion value required by NB-2300 plus the difference in average lateral expansion values established in (c)(7) or (d)(5).

(f) The Charpy V-notch testing results shall be recorded on the welding PQR and any offsetting T_{ADJ} or increased toughness requirements shall be noted on the welding PQR and on the WPS. More than one compensation method may be used on a par basis.

NB-4336 Qualification Requirements for Built-Up Weld Deposits

Built-up weld deposits for base metal reinforcement shall be qualified in accordance with the requirements of NB-4331 through NB-4335.

NB-4337 Welding of Instrument Tubing

Welding of P-No. 8 material instrument tubing may be performed without the prescribed radiographic examination of Article NB-5000, provided all of the additional rules of (a) through (j) are met.

(a) Nominal tube size shall not exceed $\frac{1}{2}$ in. (13 mm), and wall thickness shall not exceed 0.065 in. (1.6 mm).

(b) Automatic welding equipment shall be used.

(c) Welding shall be limited to the gas tungsten-arc welding process.

(d) The welding procedures and welding operators shall be qualified in accordance with Sections III and IX. In addition, one sample weld shall be prepared for