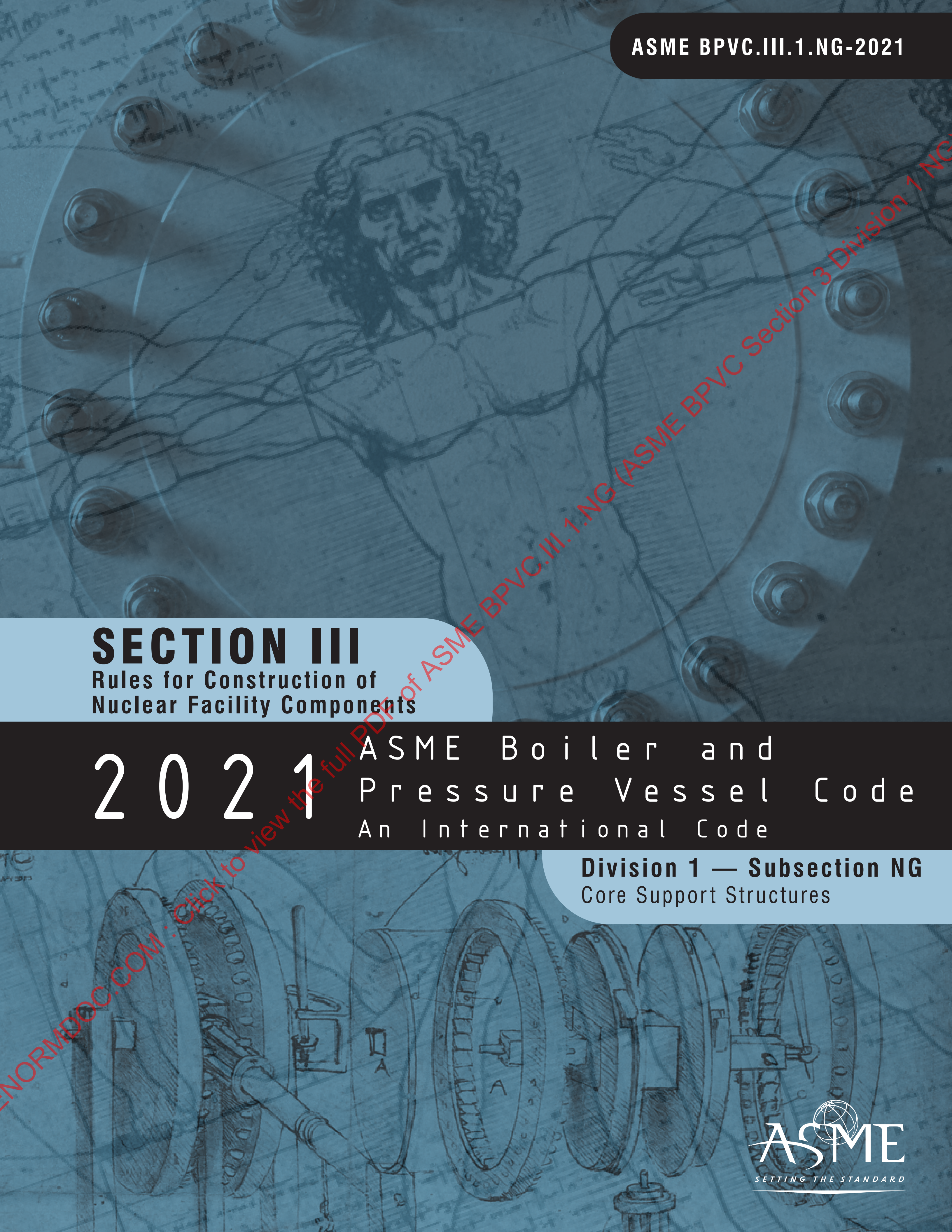


ASME BPVC.III.1.NG-2021

SECTION III

Rules for Construction of Nuclear Facility Components

2021 ASME Boiler and Pressure Vessel Code

An International Code

Division 1 — Subsection NG

Core Support Structures

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 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

2021 ASME Boiler & Pressure Vessel Code

2021 Edition July 1, 2021

III

RULES FOR CONSTRUCTION OF NUCLEAR FACILITY COMPONENTS

Division 1 - Subsection NG

Core Support Structures

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, 2021

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 assure that individuals from competent and concerned interests have had an opportunity to participate. The proposed code or standard was made available for public review and comment that provides 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 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 representative(s) or person(s) 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
Printed in the United States of America

Adopted by the Council of The American Society of Mechanical Engineers, 1914; latest edition 2021.

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

TABLE OF CONTENTS

Figures

Tables

LIST OF SECTIONS

(21)

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 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 Power Plant 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 Power Plants

XII Rules for Construction and Continued Service of Transport Tanks

XIII Rules for Overpressure Protection

* In the 2021 Edition, Subsections NC and ND have been incorporated into one publication, Subsection NCD (BPVC.III.1.NCD), Class 2 and Class 3 Components.

INTERPRETATIONS

Interpretations are issued in real time in ASME's Interpretations Database at http://go.asme.org/Interpretations. Historical BPVC interpretations may also be found in the Database.

CODE CASES

The Boiler and Pressure Vessel Code committees meet regularly to consider proposed additions and revisions to the Code and to formulate Cases to clarify the intent of existing requirements or provide, when the need is urgent, rules for materials or constructions not covered by existing Code rules. Those Cases that have been adopted will appear in the appropriate 2021 Code Cases book: "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 up to the publication of the 2023 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. Code Case users can check the current status of any Code Case at http://go.asme.org/BPVCCDatabase. Code Case users can also view an index of the complete list of Boiler and Pressure Vessel Code Cases and Nuclear Code Cases at http://go.asme.org/BPVCC.

FOREWORD[*]

(21)

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.

(21) # SUBMITTAL OF TECHNICAL INQUIRIES TO THE BOILER AND PRESSURE VESSEL STANDARDS COMMITTEES

1 INTRODUCTION

(a) The following information provides guidance to Code users for submitting technical inquiries to the applicable Boiler and Pressure Vessel (BPV) Standards Committee (hereinafter referred to as the Committee). See the guidelines on approval of new materials under the ASME Boiler and Pressure Vessel Code in Section II, Part D for requirements for requests that involve adding new materials to the Code. See the guidelines on approval of new welding and brazing materials in Section II, Part C for requirements for requests that involve adding new welding and brazing materials ("consumables") to the Code.

Technical inquiries can include requests for revisions or additions to the Code requirements, requests for Code Cases, or requests for Code Interpretations, as described below:

(1) Code Revisions. Code revisions are considered to accommodate technological developments, to address administrative requirements, to incorporate Code Cases, or to clarify Code intent.

(2) Code Cases. Code Cases represent alternatives or additions to existing Code requirements. Code Cases are written as a Question and Reply, and are usually intended to be incorporated into the Code at a later date. When used, Code Cases prescribe mandatory requirements in the same sense as the text of the Code. However, users are cautioned that not all regulators, jurisdictions, or Owners automatically accept Code Cases. The most common applications for Code Cases are as follows:

(-a) to permit early implementation of an approved Code revision based on an urgent need

(-b) to permit use of a new material for Code construction

(-c) to gain experience with new materials or alternative requirements prior to incorporation directly into the Code

(3) Code Interpretations

(-a) Code Interpretations provide clarification of the meaning of existing requirements in the Code and are presented in Inquiry and Reply format. Interpretations do not introduce new requirements.

(-b) Interpretations will be issued only if existing Code text is ambiguous or conveys conflicting requirements. If a revision of the requirements is required to support the Interpretation, an Intent Interpretation will be issued in parallel with a revision to the Code.

(b) Code requirements, Code Cases, and Code Interpretations established by the Committee 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 requirements.

(c) Inquiries that do not comply with the following guidance or that do not provide sufficient information for the Committee's full understanding may result in the request being returned to the Inquirer with no action.

2 INQUIRY FORMAT

Submittals to the Committee should include the following information:

(a) Purpose. Specify one of the following:

(1) request for revision of present Code requirements

(2) request for new or additional Code requirements

(3) request for Code Case

(4) request for Code Interpretation

(b) Background. The Inquirer should provide the information needed for the Committee's understanding of the Inquiry, being sure to include reference to the applicable Code Section, Division, Edition, Addenda (if applicable), paragraphs, figures, and tables. This information should include a statement indicating why the included paragraphs, figures, or tables are ambiguous or convey conflicting requirements. Preferably, the Inquirer should provide a copy of, or relevant extracts from, the specific referenced portions of the Code.

(c) Presentations. The Inquirer may desire to attend or be asked to attend a meeting of the Committee to make a formal presentation or to answer questions from the Committee members with regard to the Inquiry. Attendance at a BPV Standards Committee meeting shall be at the expense of the Inquirer. The Inquirer's attendance or lack of attendance at a meeting will not be used by the Committee as a basis for acceptance or rejection of the Inquiry by the Committee. However, if the Inquirer's request is unclear, attendance by the Inquirer or a representative may be necessary for the Committee to understand the request sufficiently to be able to provide an Interpretation. If the Inquirer desires to make a presentation at a Committee meeting, the Inquirer should provide advance notice to the Committee Secretary, to ensure time will be allotted for the presentation in the meeting agenda. The Inquirer should consider the need for additional audiovisual equipment that might not otherwise be provided by the Committee. With sufficient advance notice to the Committee Secretary, such equipment may be made available.

3 CODE REVISIONS OR ADDITIONS

Requests for Code revisions or additions should include the following information:

(a) Requested Revisions or Additions. For requested revisions, the Inquirer should identify those requirements of the Code that they believe should be revised, and should submit a copy of, or relevant extracts from, the appropriate requirements as they appear in the Code, marked up with the requested revision. For requested additions to the Code, the Inquirer should provide the recommended wording and should clearly indicate where they believe the additions should be located in the Code requirements.

(b) Statement of Need. The Inquirer should provide a brief explanation of the need for the revision or addition.

(c) Background Information. The Inquirer should provide background information to support the revision or addition, including any data or changes in technology that form the basis for the request, that will allow the Committee to adequately evaluate the requested revision or addition. Sketches, tables, figures, and graphs should be submitted, as appropriate. The Inquirer should identify any pertinent portions of the Code that would be affected by the revision or addition and any portions of the Code that reference the requested revised or added paragraphs.

4 CODE CASES

Requests for Code Cases should be accompanied by a statement of need and background information similar to that described in 3(b) and 3(c), respectively, for Code revisions or additions. The urgency of the Code Case (e.g., project underway or imminent, new procedure) should be described. In addition, it is important that the request is in connection with equipment that will bear the ASME Single Certification Mark, with the exception of Section XI applications. The proposed Code Case should identify the Code Section and Division, and should be written as a Question and a Reply, in the same format as existing Code Cases. Requests for Code Cases should also indicate the applicable Code Editions and Addenda (if applicable) to which the requested Code Case applies.

5 CODE INTERPRETATIONS

(a) Requests for Code Interpretations should be accompanied by the following information:

(1) Inquiry. The Inquirer should propose a condensed and precise Inquiry, omitting superfluous background information and, when possible, composing the Inquiry in such a way that a "yes" or a "no" Reply, with brief limitations or conditions, if needed, can be provided by the Committee. The proposed question should be technically and editorially correct.

(2) Reply. The Inquirer should propose a Reply that clearly and concisely answers the proposed Inquiry question. Preferably, the Reply should be "yes" or "no," with brief limitations or conditions, if needed.

(3) Background Information. The Inquirer should include a statement indicating why the included paragraphs, figures, or tables are ambiguous or convey conflicting requirements. The Inquirer should provide any need or background information, such as described in 3(b) and 3(c), respectively, for Code revisions or additions, that will assist the Committee in understanding the proposed Inquiry and Reply.

If the Inquirer believes a revision of the Code requirements would be helpful to support the Interpretation, the Inquirer may propose such a revision for consideration by the Committee. In most cases, such a proposal is not necessary.

(b) Requests for Code Interpretations should be limited to an Interpretation of a particular requirement in the Code or in a Code Case. Except with regard to interpreting a specific Code requirement, the Committee is not permitted to consider consulting-type requests such as the following:

(1) a review of calculations, design drawings, welding qualifications, or descriptions of equipment or parts to determine compliance with Code requirements

(2) a request for assistance in performing any Code-prescribed functions relating to, but not limited to, material selection, designs, calculations, fabrication, inspection, pressure testing, or installation

(3) a request seeking the rationale for Code requirements

6 SUBMITTALS

(a) Submittal. Requests for Code Interpretation should preferably be submitted through the online Interpretation Submittal Form. The form is accessible at http://go.asme.org/InterpretationRequest. Upon submittal of the form, the Inquirer will receive an automatic e-mail confirming receipt. If the Inquirer is unable to use the online form, the Inquirer may mail the request to the following address:

Secretary
ASME Boiler and Pressure Vessel Committee
Two Park Avenue
New York, NY 10016-5990

All other Inquiries should be mailed to the Secretary of the BPV Committee at the address above. Inquiries are unlikely to receive a response if they are not written in clear, legible English. They must also include the name of the Inquirer and the company they represent or are employed by, if applicable, and the Inquirer's address, telephone number, fax number, and e-mail address, if available.

(b) Response. The Secretary of the appropriate Committee will provide a written response, via letter or e-mail, as appropriate, to the Inquirer, upon completion of the requested action by the Committee. Inquirers may track the status of their Interpretation Request at http://go.asme.org/Interpretations.

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

(21)

January 1, 2021

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
D. A. Bowers
C. Brown
D. B. DeMichael
R. P. Deubler
P. D. Edwards
J. G. Feldstein
G. W. Galanes
J. A. Hall
T. E. Hansen
G. W. Hembree
J. F. Henry
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
M. Wadkinson
J. E. Batey, *Contributing Member*

Subgroup on Research and Development (TOMC)

S. C. Roberts, *Chair*
S. J. Rossi, *Staff Secretary*
R. W. Barnes
N. A. Finney
J. F. Henry
W. Hoffelner
B. Hrubala
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
J. F. Henry
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*
P. Lang, *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
J. F. Henry
R. I. Jetter
P. Smith

ADMINISTRATIVE COMMITTEE

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

MARINE CONFERENCE GROUP

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

CONFERENCE COMMITTEE

C. B. Cantrell — Nebraska, *Chair*
J. T. Amato — Ohio, *Secretary*
W. Anderson — Mississippi
P. Bearden — Minnesota
R. Becker — Colorado
T. D. Boggs — Missouri
R. A. Boillard — Indiana
R. J. Bunte — Iowa
J. H. Burpee — Maine
S. Chapman — Tennessee
T. G. Clark — Oregon
B. J. Crawford — Georgia
E. L. Creaser — New Brunswick, Canada
J. J. Dacanay — Hawaii
R. DeLury — Manitoba, Canada
C. Dinic — Ontario, Canada
D. Eastman — Newfoundland and Labrador, Canada
D. A. Ehler — Nova Scotia, Canada
S. D. Frazier — Washington
T. J. Granneman II — Oklahoma
S. Harder — Arizona
E. G. Hilton — Virginia
M. L. Jordan — Kentucky
R. Kamboj — British Columbia, Canada
E. Kawa, Jr. — Massachusetts
A. Khssassi — Quebec, Canada
D. Kinney — North Carolina
J. Klug — City of Milwaukee, Wisconsin
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
A. K. Oda — Washington
B. S. Oliver — New Hampshire
J. L. Oliver — Nevada
M. Poehlmann — Alberta, Canada
P. B. Polick — Illinois
J. F. Porcella — West Virginia
C. F. Reyes — California
W. J. Ross — Pennsylvania
M. J. Ryan — City of Chicago, Illinois
M. H. Sansone — New York
T. S. Seime — North Dakota
C. S. Selinger — Saskatchewan, Canada
J. E. Sharier — Ohio
R. Spiker — North Carolina
D. J. Stenrose — Michigan
R. J. Stimson II — Kansas
R. K. Sturm — Utah
D. K. Sullivan — Arkansas
J. Taveras — Rhode Island
G. Teel — California
S. R. Townsend — Prince Edward Island, Canada
R. D. Troutt — Texas
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
P. D. Edwards
J. G. Feldstein
S. Fincher
G. W. Galanes
T. E. Hansen
J. F. Henry
J. S. Hunter
M. Ishikawa
G. B. Komora
F. Massi
L. Moedinger
P. A. Molvie
Y. Oishi
D. E. Tompkins
D. E. Tuttle
J. Vattappilly
M. Wadkinson
R. V. Wielgoszinski
F. Zeller
H. Michael, *Delegate*
D. L. Berger, *Honorary Member*
D. N. French, *Honorary Member*
J. Hainsworth, *Honorary Member*
W. L. Lowry, *Honorary Member*
J. R. MacKay, *Honorary Member*
T. C. McGough, *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

Subgroup on Design (BPV I)

D. I. Anderson, *Chair*
L. S. Tsai, *Secretary*
P. Becker
D. Dewees
G. B. Komora
L. Krupp
P. A. Molvie
N. Ranck
J. Vattappilly
M. Wadkinson
J. P. Glaspie, *Contributing Member*

Subgroup on Fabrication and Examination (BPV I)

J. L. Arnold, *Chair*
P. F. Gilston, *Vice Chair*
P. Becker, *Secretary*
A. Biesecker
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)

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

Subgroup on Locomotive Boilers (BPV I)

J. R. Braun, *Chair*
S. M. Butler, *Secretary*
A. Biesecker
C. Cross
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. F. Henry
J. S. Hunter
E. Liebl
F. Masuyama
M. Ortolani
D. W. Rahoi
J. Vattappilly
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
F. Massi
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
J. F. Henry
R. E. McLaughlin
P. A. Molvie
E. M. Ortman
D. E. Tuttle
J. Vattappilly

Germany International Working Group (BPV I)

A. Spangenberg, *Chair*
P. Chavdarov, *Secretary*
B. Daume
J. Fleischfresser
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*
P. Paluszkiewicz, *Contributing Member*
R. Uebel, *Contributing Member*

India International Working Group (BPV I)

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

COMMITTEE ON MATERIALS (BPV II)

J. Cameron, *Chair*
J. F. Grubb, *Vice Chair*
C. E. O'Brien, *Staff Secretary*
A. Appleton
P. Chavdarov
J. R. Foulds
D. W. Gandy
J. A. Hall
J. F. Henry
K. M. Hottle
M. Ishikawa
K. Kimura
F. Masuyama
K. E. Orie
D. W. Rahoi
W. Ren
E. Shapiro
R. C. Sutherlin
F. Zeller
O. Oldani, *Delegate*
F. Abe, *Contributing Member*
A. Chaudouet, *Contributing Member*
D. B. Denis, *Contributing Member*
J. D. Fritz, *Contributing Member*
W. Hoffelner, *Contributing Member*
M. Katcher, *Contributing Member*
R. K. Nanstad, *Contributing Member*
M. L. Nayyar, *Contributing Member*
D. T. Peters, *Contributing Member*
B. W. Roberts, *Contributing Member*
J. J. Sanchez-Hanton, *Contributing Member*
R. W. Swindeman, *Contributing Member*
J. M. Tanzosh, *Contributing Member*
E. Upitis, *Contributing Member*
R. G. Young, *Contributing Member*
T. M. Cullen, *Honorary Member*
W. D. Edsall, *Honorary Member*
G. C. Hsu, *Honorary Member*
C. E. Spaeder, Jr., *Honorary Member*
A. W. Zeuthen, *Honorary Member*

Executive Committee (BPV II)

J. Cameron, *Chair*
C. E. O'Brien, *Staff Secretary*
A. Appleton
G. W. Galanes
J. F. Grubb
J. F. Henry
M. Ishikawa
D. L. Kurle
R. W. Mikitka
E. Shapiro
R. C. Sutherlin

Subgroup on External Pressure (BPV II)

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

Subgroup on Ferrous Specifications (BPV II)

A. Appleton, *Chair*
K. M. Hottle, *Vice Chair*
C. Hyde, *Secretary*
B. M. Dingman
M. J. Dosdourian
O. Elkadim
D. Fialkowski
J. F. Grubb
J. Gundlach
D. S. Janikowski
S. G. Lee
W. C. Mack
K. E. Orie
D. Poweleit
E. Upitis
J. D. Fritz, *Contributing Member*

Subgroup on International Material Specifications (BPV II)

M. Ishikawa, *Chair*
A. R. Nywening, *Vice Chair*
B. Mruk, *Secretary*
A. Chaudouet
P. Chavdarov
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*
S. Yem, *Vice Chair*
J. Robertson, *Secretary*
R. M. Beldyk
J. M. Downs
J. F. Grubb
W. MacDonald
D. Maitra
J. A. McMaster
D. W. Rahoi
W. Ren
R. C. Sutherlin
J. Weritz
A. Williams
R. Wright
D. B. Denis, *Contributing Member*
M. Katcher, *Contributing Member*
D. T. Peters, *Contributing Member*

Subgroup on Physical Properties (BPV II)

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

Subgroup on Strength, Ferrous Alloys (BPV II)

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

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

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

Working Group on Materials Database (BPV II)

W. Hoffelner, *Vice Chair*
C. E. O'Brien, *Staff Secretary*
F. Abe
J. R. Foulds
J. F. Henry
R. C. Sutherlin
D. Andrei, *Contributing Member*
J. L. Arnold, *Contributing Member*
D. T. Peters, *Contributing Member*
W. Ren, *Contributing Member*
B. W. Roberts, *Contributing Member*
R. W. Swindeman, *Contributing Member*

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

M. Ortolani, *Chair*
G. W. Galanes, *Vice Chair*
S. H. Bowes
K. K. Coleman
J. R. Foulds
J. F. Henry
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*
G. Cumino, *Contributing Member*
P. D. Flenner, *Contributing Member*
R. W. Swindeman, *Contributing Member*
J. M. Tanzosh, *Contributing Member*

Working Group on Data Analysis (BPV II)

J. F. Grubb, *Chair*
J. R. Foulds, *Vice Chair*
J. F. Henry
F. Masuyama
M. Ortolani
W. Ren
M. Subanovic
M. J. Swindeman
F. Abe, *Contributing Member*
W. Hoffelner, *Contributing Member*
M. Katcher, *Contributing Member*
D. T. Peters, *Contributing Member*
B. W. Roberts, *Contributing Member*
R. W. Swindeman, *Contributing Member*

China International Working Group (BPV II)

S. Liu, *Chair*
Yong Zhang, *Vice Chair*
A. T. Xu, *Secretary*
W. Fang
Q. C. Feng
S. Huo
F. Kong
H. Li
J. Li
S. Li
Z. Rongcan
S. Tan
C. Wang
J. Wang
Q.-J. Wang
X. Wang
F. Yang
G. Yang
H.-C. Yang
J. Yang
R. Ye
L. Yin
H. Zhang
X.-H. Zhang
Yingkai Zhang
Q. Zhao
S. Zhao

COMMITTEE ON CONSTRUCTION OF NUCLEAR FACILITY COMPONENTS (BPV III)

R. B. Keating, *Chair*
T. M. Adams, *Vice Chair*
D. E. Matthews, *Vice Chair*
K. Verderber, *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
V. Kostarev
M. A. Lockwood
K. A. Manoly
K. Matsunaga
B. McGlone
S. McKillop
J. C. Minichiello
M. N. Mitchell
T. Nagata
J. B. Ossmann
S. Pellet
E. L. Pleins
S. Sham
W. J. Sperko
C. T. Smith, *Contributing Member*
W. K. Sowder, Jr., *Contributing Member*
M. Zhou, *Contributing Member*
D. K. Morton, *Honorary Member*
R. F. Reedy, Sr., *Honorary Member*

Executive Committee (BPV III)

R. B. Keating, *Chair*
K. Verderber, *Staff Secretary*
T. M. Adams
P. R. Donavin
J. V. Gardiner
J. Grimm
D. E. Matthews
S. McKillop
J. A. Munshi
S. Sham
W. K. Sowder, Jr.

Subcommittee on Design (BPV III)

P. R. Donavin, *Chair*
R. P. Deubler
M. A. Gray
R. I. Jetter
R. B. Keating
K. A. Manoly
D. E. Matthews
S. McKillop
M. N. Mitchell
S. Sham
W. F. Weitze
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
S. Asada
J. F. Ball
C. Basavaraju
D. Chowdhury
R. P. Deubler
P. Hirschberg
M. Kassar
R. B. Keating
D. Keck
O.-S. Kim
T. R. Liszkai
K. A. Manoly
R. J. Masterson
J. C. Minichiello
T. Mitsuhashi
D. Murphy
T. M. Musto
T. Nagata
J. R. Stinson
G. Z. Tokarski
J. P. Tucker
S. Willoughby-Braun
C. Wilson
A. A. Dermenjian, *Contributing Member*
I. Saito, *Contributing Member*
K. R. Wichman, *Honorary Member*

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
H. S. Mehta
M. Nakajima
M. D. Snyder
R. Vollmer
T. M. Wiger
C. Wilson
Y. Wong
A. Tsirigotis, *Alternate*
J. F. Kielb, *Contributing Member*

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

D. J. Ammerman, *Chair*
S. Klein, *Secretary*
V. Broz
D. W. Lewis
A. Rigato
D. Siromani
X. Zhai
X. Zhang
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
M. Martin
D. P. Munson
F. J. Schaaf, Jr.
R. Stakenborghs
J. Wright
M. T. Audrain, *Alternate*
D. Burwell, *Contributing Member*
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. Farrell
R. G. Gilada
N. M. Graham
M. A. Gray
R. W. Haupt
A. Hirano
P. Hirschberg
M. Kassar
J. Kawahata
V. Kostarev
D. Lieb
T. B. Littleton
J. F. McCabe
I.-K. Nam
J. O'Callaghan
K. E. Reid II
N. C. Sutherland
D. Vlaicu
S. Weindorf
C.-I. Wu
T. M. Adams, *Contributing Member*
R. J. Gurdal, *Contributing Member*
R. B. Keating, *Contributing Member*
Y. Liu, *Contributing Member*
J. C. Minichiello, *Contributing Member*
A. N. Nguyen, *Contributing Member*
M. S. Sills, *Contributing Member*
E. A. Wais, *Contributing Member*

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

J. F. Ball, *Chair*
K. R. May, *Vice Chair*
R. Krithivasan, *Secretary*
J. W. Dickson
S. Jones
R. Lack
D. Miller
T. Patel
K. Shores
I. H. Tseng
J. Yu
N. J. Hansing, *Alternate*
J. M. Levy, *Alternate*
B. J. Yonsky, *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*
M. D. Eftychiou
R. A. Fleming
S. Hughes
J. Kikushima
K. J. Noel
J. Sulley
A. G. Washburn
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)

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

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

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

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

D. Murphy, *Chair*
S. Willoughby-Braun, *Secretary*
J. Arthur
C. Basavaraju
D. Keck
J. I. Kim
O.-S. Kim
D. E. Matthews
T. Mitsuhashi
T. J. Schriefer
M. C. Scott
P. K. Shah
C. Turylo
D. Vlaicu
C. Wilson
T. Yamazaki
R. Z. Ziegler
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
R. Farrell
S. R. Gosselin
M. A. Gray
J. V. Gregg, Jr.
K. Hsu
R. Kalnas
D. Keck
J. I. Kim
W. J. O'Donnell, Sr.
W. D. Reinhardt
P. Smith
S. D. Snow
R. Vollmer
W. F. Weitze
T. M. Adams, *Contributing Member*
C. W. Bruny, *Contributing Member*
H. T. Harrison III, *Contributing Member*
K. Wright, *Contributing Member*

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

R. Farrell, *Chair*
R. Vollmer, *Secretary*
K. Avrithi
C. Basavaraju
C. M. Faidy
C. F. Heberling II
M. Kassar
J. I. Kim
T. R. Liszkai
K. Matsunaga
S. McKillop
B. Pellereau
S. Ranganath
W. D. Reinhardt
P. K. Shah
S. D. Snow
S. Wang
W. F. Weitze
J. Wen
T. M. Wiger
G. Banyay, *Contributing Member*
D. S. 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*
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
T. D. Gilman
S. R. Gosselin
Y. He
A. Hirano
P. Hirschberg
H. S. Mehta
J.-S. Park
B. Pellereau
G. L. Stevens
D. Vlaicu
K. Wang
R. Z. Ziegler
S. Cuvilliez, *Contributing Member*
K. Wright, *Contributing Member*

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

P. R. Donavin, *Chair*
M. S. Shelton, *Secretary*
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
H. S. Mehta
B. Pellereau
S. Ranganath
G. L. Stevens
Y. Wang
W. F. Weitze
Y. Zou
D. Dewees, *Contributing Member*
S. Majumdar, *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*
T. Asayama
K. Avrithi
G. Brouette
J. Hakii
D. O. Henry
A. Hirano
A. Martin
P. J. O'Regan
B. Pellereau
R. S. Hill III, *Contributing Member*

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

D. J. Ammerman, *Vice Chair*
V. Broz, *Secretary*
J. M. Jordan
S. Kuehner
D. Molitoris
W. D. Reinhardt
P. Y.-K. Shih
S. D. Snow
C.-F. Tso
M. C. Yaksh
U. Zencker

Working Group on Allowable Stress Criteria (SG-HTR) (BPV III)

R. Wright, *Chair*
M. McMurtrey, *Secretary*
K. Kimura
D. Maitra
R. J. McReynolds
M. C. Messner
W. Ren
R. Rupp
S. Sham
Y. Wang
X. Wei
J. R. Foulds, *Contributing Member*
R. W. Swindeman, *Contributing Member*

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

M. C. Messner, *Chair*
R. W. Barnes
J. A. Blanco
P. Carter
M. E. Cohen
R. I. Jetter
G. H. Koo
H. Qian
S. Sham
X. Wei
S. X. Xu
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)

S. Sham, *Chair*
Y. Wang, *Secretary*
M. Ando
F. W. Brust
P. Carter
M. E. Cohen
R. I. Jetter
G. H. Koo
M. McMurtrey
M. C. Messner
J. C. Poehler
H. Qian
X. Wei

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

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

Subgroup on General Requirements (BPV III)

J. V. Gardiner, *Chair*
N. DeSantis, *Secretary*
V. Apostolescu
A. Appleton
S. Bell
J. R. Berry
G. Brouette
G. C. Deleanu
J. W. Highlands
E. V. Imbro
K. A. Kavanagh
Y.-S. Kim
B. McGlone
E. C. Renaud
T. N. Rezk
J. Rogers
D. J. Roszman
R. Spuhl
G. E. Szabatura
D. M. Vickery
J. DeKleine, *Contributing Member*
H. Michael, *Contributing Member*
C. T. Smith, *Contributing Member*
W. K. Sowder, Jr., *Contributing Member*

Working Group on General Requirements (SG-GR) (BPV III)

B. McGlone, *Chair*
J. Grimm, *Secretary*
V. Apostolescu
A. Appleton
S. Bell
J. R. Berry
G. Brouette
J. Carter
P. J. Coco
N. DeSantis
Y. Diaz-Castillo
O. Elkadim
J. V. Gardiner
S. M. Goodwin
J. Harris
J. W. Highlands
E. V. Imbro
K. A. Kavanagh
Y.-S. Kim
D. T. Meisch
R. B. Patel
E. C. Renaud
T. N. Rezk
J. Rogers
D. J. Roszman
B. S. Sandhu
R. Spuhl
J. F. Strunk
G. E. Szabatura
D. M. Vickery
J. L. Williams
J. DeKleine, *Contributing Member*
S. F. Harrison, Jr., *Contributing Member*

Special Working Group on General Requirements Consolidation (SG-GR) (BPV III)

J. V. Gardiner, *Chair*
J. Grimm, *Vice Chair*
C. T. Smith, *Vice Chair*
Y. Diaz-Castillo
R. B. Patel
E. C. Renaud
R. Spuhl
J. L. Williams

Working Group on General Requirements for Graphite and Ceramic Composite Core Components and Assemblies (SG-GR) (BPV III)

A. Appleton, *Chair*
W. J. Geringer, *Secretary*
J. R. Berry
Y. Diaz-Castillo
M. N. Mitchell
E. C. Renaud
W. Windes

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

J. Grimm, *Chair*
S. Hunter, *Secretary*
W. H. Borter
G. R. Cannell
S. Cho
P. J. Coco
R. H. Davis
B. D. Frew
D. W. Gandy
S. E. Gingrich
M. Golliet
L. S. Harbison
R. M. Jessee
J. Johnston, Jr.
C. C. Kim
M. Kris
M. Lashley
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*
R. W. Barnes, *Contributing Member*
D. B. Denis, *Contributing Member*

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

G. Brouette, *Chair*
M. A. Martin, *Secretary*
M. C. Buckley
M. Golliet
J. Johnston, Jr.
P. Krishnaswamy
M. Kuntz
B. Lin
D. P. Munson
T. M. Musto
S. Patterson
S. Schuessler
R. Stakenborghs
M. Troughton
J. Wright
B. Hauger, *Contributing Member*

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

J. A. Munshi, *Chair*
J. McLean, *Vice Chair*
J. Cassamassino, *Staff Secretary*
C. J. Bang
L. J. Colarusso
A. C. Eberhardt
F. Farzam
P. S. Ghosal
B. D. Hovis
T. C. Inman
C. Jones
O. Jovall
T. Kang
N.-H. Lee
T. Muraki
N. Orbovic
J. F. Strunk
G. Thomas
S. Wang
A. Adediran, *Contributing Member*
J. F. Artuso, *Contributing Member*
S. Bae, *Contributing Member*
J.-B. Domage, *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*

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
F. Farzam
P. S. Ghosal
B. D. Hovis
T. C. Inman
C. Jones
O. Jovall
J. A. Munshi
T. Muraki
N. Orbovic
J. S. Saini
G. Thomas
A. Istar, *Contributing Member*
S.-Y. Kim, *Contributing Member*
J. Kwon, *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*
M. Allam
C. J. Bang
B. Birch
J.-B. Domage
P. S. Ghosal
T. Kang
N.-H. Lee
Z. Shang
J. F. Strunk
I. Zivanovic
A. A. Aboelmagd, *Contributing Member*
J. F. Artuso, *Contributing Member*
B. B. Scott, *Contributing Member*

Special Working Group on Modernization (BPV III-2)

N. Orbovic, *Chair*
J. McLean, *Vice Chair*
A. Adediran
O. Jovall
N. Stoeva
A. Varma
S. Wang
I. Zivanovic
J.-B. Domage, *Contributing Member*
F. Lin, *Contributing Member*
M. A. Ugalde, *Contributing Member*

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

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

Subgroup on Fusion Energy Devices (BPV III)

W. K. Sowder, Jr., *Chair*
D. Andrei, *Staff Secretary*
D. J. Roszman, *Secretary*
M. Bashir
J. P. Blanchard
L. C. Cadwallader
T. P. Davis
B. R. Doshi
L. El-Guebaly
G. Holtmeier
D. Johnson
K. A. Kavanagh
K. Kim
I. Kimihiro
S. Lee
G. Li
X. Li
P. Mokaria
T. R. Muldoon
M. Porton
F. J. Schaaf, Jr.
P. Smith
Y. Song
M. Trosen
C. Waldon
I. J. Zatz
R. W. Barnes, *Contributing Member*

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)

S. Lee, *Chair*
K. Kim, *Vice Chair*

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

Subgroup on High Temperature Reactors (BPV III)

S. Sham, *Chair*
M. Ando
N. Broom
F. W. Brust
P. Carter
M. E. Cohen
W. J. Geringer
B. F. Hantz
M. H. Jawad
R. I. Jetter
K. Kimura
G. H. Koo
A. Mann
M. C. Messner
X. Wei
W. Windes
R. Wright
A. Yeshnik
G. L. Zeng
A. Tsirigotis, *Alternate*
D. S. Griffin, *Contributing Member*
X. Li, *Contributing Member*
S. Majumdar, *Contributing Member*
D. L. Marriott, *Contributing Member*
M. Morishita, *Contributing Member*
W. O'Donnell, Sr., *Contributing Member*
L. Shi, *Contributing Member*
R. W. Swindeman, *Contributing Member*

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

W. Windes, *Chair*
W. J. Geringer, *Vice Chair*
A. Appleton
T. D. Burchell
S.-H. Chi
V. Chugh
S. T. Gonczy
K. Harris
M. G. Jenkins
Y. Katoh
J. Lang
M. N. Mitchell
J. B. Ossmann
A. Yeshnik
G. L. Zeng

Special Working Group on High Temperature Reactor Stakeholders (SG-HTR) (BPV III)

M. E. Cohen, *Chair*
M. Arcaro
R. W. Barnes
N. Broom
V. Chugh
R. A. Fleming
K. Harris
R. I. Jetter
Y. W. Kim
G. H. Koo
K. J. Noel
S. Sham
B. Song
X. Wei
A. Yeshnik
G. L. Zeng
T. Asayama, *Contributing Member*
X. Li, *Contributing Member*
M. Morishita, *Contributing Member*
L. Shi, *Contributing Member*
G. Wu, *Contributing Member*

Seismic Design Steering Committee (BPV III)

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

Argentina International Working Group (BPV III)

J. Fernández, *Chair*
A. Politi, *Vice Chair*
O. Martinez, *Staff Secretary*
A. Gomez, *Secretary*
A. Acrogliano
W. Agrelo
G. O. Anteri
M. Anticoli
C. A. Araya
J. P. Balbiani
A. A. Betervide
D. O. Bordato
G. Bourguigne
M. L. Cappella
A. Claus
R. G. Cocco
A. Coleff
A. J. Dall'Osto
L. M. De Barberis
D. P. Delfino
D. N. Dell'Erba
F. G. Diez
A. Dominguez
S. A. Echeverria
E. P. Fresquet
M. M. Gamizo
I. M. Guerreiro
I. A. Knorr
M. F. Liendo
D. E. Matthews
L. R. Miño
J. Monte
R. L. Morard
A. E. Pastor
E. Pizzichini
J. L. Racamato
H. C. Sanzi
G. J. Scian
G. G. Sebastian
M. E. Szarko
P. N. Torano
A. Turrin
O. A. Verastegui
M. D. Vigliano
P. Yamamoto
M. Zunino

China International Working Group (BPV III)

J. Yan, *Chair*
W. Tang, *Vice Chair*
Y. He, *Secretary*
L. Guo
Y. Jing
D. Kang
Y. Li
B. Liang
H. Lin
S. Liu
W. Liu
J. Ma
K. Mao
D. E. Matthews
W. Pei
C. Peiyin
Z. Sun
G. Tang
L. Ting
Y. Tu
Y. Wang
H. Wu
S. Xue
Z. Yin
D. Yuangang
G. Zhang
W. Zhang
Y. Zhong
Z. Zhong

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. Sybert
I. Tewes
R. Tiete
R. Trieglaff
F. Wille
S. Zickler

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
D. Kulkarni
R. Kumar
D. Narain
E. L. Pleins
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
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
J.-S. Park
Y. S. Pyun
T. Shin
S. Song
W. J. Sperko
J. S. Yang
O. Yoo

United Kingdom International Working Group (BPV III)

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

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)

M. Brandes, *Chair*
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
J. Wright
C. Lin, *Alternate*
D. Burwell, *Contributing Member*

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 Industry Experience for New Plants (BPV III & BPV XI)

J. T. Lindberg, *Chair*
J. B. Ossmann, *Chair*
M. C. Buckley, *Secretary*
A. Cardillo
T. L. Chan
P. J. Hennessey
D. O. Henry
J. Honcharik
C. G. Kim
O.-S. Kim
K. Matsunaga
D. E. Matthews
R. E. McLaughlin
D. W. Sandusky
R. M. Wilson
S. M. Yee
A. Tsirigotis, *Alternate*

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

D. E. Matthews, *Chair*
K. Verderber, *Staff Secretary*
T. M. Adams
R. W. Barnes
T. D. Burchell
R. L. Crane
P. R. Donavin
E. L. Pleins
W. J. Sperko

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

E. L. Pleins, *Chair*
M. C. Scott, *Secretary*
A. Cardillo
P. J. Coco
J. Honcharik
O.-S. Kim
M. Kris
D. W. Sandusky
R. R. Stevenson
M. L. Wilson
H. Xu
J. Yan
N. J. Hansing, *Alternate*
J. C. Minichiello, *Contributing Member*
K. Verderber, *Contributing Member*

COMMITTEE ON HEATING BOILERS (BPV IV)

J. A. Hall, *Chair*
T. L. Bedeaux, *Vice Chair*
C. R. Ramcharran, *Staff Secretary*
L. Badziagowski
B. Calderon
J. P. Chicoine
J. M. Downs
J. L. Kleiss
J. Klug
M. Mengon
P. A. Molvie
R. D. Troutt
M. Wadkinson
R. V. Wielgoszinski
H. Michael, *Delegate*
D. Picart, *Delegate*
D. Nelson, *Alternate*
S. V. Voorhees, *Contributing Member*

Subgroup on Care and Operation of Heating Boilers (BPV IV)

R. D. Troutt, *Chair*
C. R. Ramcharran, *Staff Secretary*
B. Ahee
T. L. Bedeaux
J. M. Downs
J. A. Hall
J. L. Kleiss
P. A. Molvie
M. Wadkinson

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)

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

Subgroup on Water Heaters (BPV IV)

L. Badziagowski, *Chair*
J. L. Kleiss, *Vice Chair*
C. R. Ramcharran, *Staff Secretary*
B. Ahee
J. P. Chicoine
C. Dinic
B. J. Iske
P. A. Molvie
T. E. Trant
R. D. Troutt

Subgroup on Welded Boilers (BPV IV)

T. L. Bedeaux, *Chair*
J. L. Kleiss, *Vice Chair*
C. R. Ramcharran, *Staff Secretary*
B. Ahee
L. Badziagowski
B. Calderon
C. Dinic
M. Mengon
P. A. Molvie
R. D. Troutt
M. Wadkinson
R. V. Wielgoszinski
D. Nelson, *Alternate*

COMMITTEE ON NONDESTRUCTIVE EXAMINATION (BPV V)

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

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

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

Subgroup on Surface Examination Methods (BPV V)

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

Subgroup on Volumetric Methods (BPV V)

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

Special Working Group on Advanced Ultrasonic Testing Techniques (BPV V)

L. E. Mullins, *Chair*
K. Krueger, *Vice Chair*
D. Adkins
D. Bajula
N. A. Finney
J. L. Garner
J. F. Halley
P. T. Hayes
M. Lozev
E. Peloquin
M. Sens
D. Tompkins
C. Wassink

Working Group on Full Matrix Capture (FMC) (BPV V)

P. T. Hayes, *Chair*
E. Peloquin, *Vice Chair*
D. Adkins
D. Bajula
D. Bellistri
J. Catty
N. A. Finney
J. L. Garner
V. F. Godinez-Azcuaga
R. T. Grotenhuis
J. F. Halley
K. Hayes
G. W. Hembree
K. Krueger
M. Lozev
L. E. Mullins
D. Richard
M. Sens
D. Tompkins
O. Volf
C. Wassink

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

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

Working Group on Computed Tomography (BPV V)

C. May, *Chair*
T. L. Clifford
R. W. Hardy
G. W. Hembree
F. B. Kovacs
R. J. Mills
T. L. Plasek
C. Vorwald
B. White
L. E. Mullins, *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
C. May
R. J. Mills
T. L. Plasek
T. Vidimos
B. White
S. J. Akrin, *Contributing Member*
J. E. Batey, *Contributing Member*
N. Y. Faransso, *Contributing Member*
R. W. Kruzic, *Contributing Member*

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

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

Italy International Working Group (BPV V)

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

COMMITTEE ON PRESSURE VESSELS (BPV VIII)

S. C. Roberts, *Chair*
M. D. Lower, *Vice Chair*
J. Oh, *Staff Secretary*
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*
X. Tang, *Delegate*
A. Chaudouet, *Contributing Member*
J. P. Glaspie, *Contributing Member*
W. S. Jacobs, *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.
M. Kowalczyk
S. A. Marks
P. Matkovics
F. L. Richter
S. C. Roberts
J. C. Sowinski
K. Subramanian
A. Viet
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. 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*
W. S. Jacobs, *Contributing Member*
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*
Z. Wang, *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*
D. L. Marriott, *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
E. A. Whittle
K. Oyamada, *Delegate*
W. J. Bees, *Contributing Member*
L. F. Campbell, *Contributing Member*
J. Lee, *Contributing Member*
J. Si, *Contributing Member*
R. Uebel, *Contributing Member*
X. Xue, *Contributing Member*
B. Yang, *Contributing Member*

Subgroup on General Requirements (BPV VIII)

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

Task Group on Fired Heater Pressure Vessels (BPV VIII)

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

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
J. R. Sims
M. P. Vaclavik
R. Cordes, *Contributing Member*
S. Krishna, *Contributing Member*
D. T. Peters, *Contributing Member*

Task Group on UG-20(f) (BPV VIII)

S. Krishnamurthy, *Chair*
T. L. Anderson
K. E. Bagnoli
R. P. Deubler
B. F. Hantz
B. R. Macejko
J. Penso
M. Prager
M. D. Rana

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
I. G. Campbell, *Contributing Member*
G. G. Karcher, *Contributing Member*
J. Pasek, *Contributing Member*
D. Srnic, *Contributing Member*
Z. Tong, *Contributing Member*

Working Group on Plate Heat Exchangers (BPV VIII)

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

Subgroup on High Pressure Vessels (BPV VIII)

K. Subramanian, *Chair*
M. Sarzynski, *Vice Chair*
A. P. Maslowski, *Staff Secretary*
L. P. Antalffy
R. C. Biel
P. N. Chaku
L. Fridlund
R. T. Hallman
K. Karpanan
J. Keltjens
A. K. Khare
G. M. Mital
G. T. Nelson
M. Parr
D. T. Peters
E. A. Rodriguez
E. D. Roll
J. R. Sims
E. Smith
F. W. Tatar
S. Terada
C. Tipple
R. Wink
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*
D. Fuenmayor, *Contributing Member*
R. M. Hoshman, *Contributing Member*
Y. Huang, *Contributing Member*
F. Kirkemo, *Contributing Member*
R. A. Leishear, *Contributing Member*
C. Romero, *Contributing Member*
K.-J. Young, *Contributing Member*
D. J. Burns, *Honorary Member*
D. M. Fryer, *Honorary Member*
G. J. Mraz, *Honorary Member*
E. H. Perez, *Honorary Member*

Subgroup on Materials (BPV VIII)

M. Kowalczyk, *Chair*
J. Cameron, *Vice Chair*
S. Kilambi, *Secretary*
P. Chavdarov
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. A. McMaster, *Contributing Member*
J. Penso, *Contributing Member*
B. Pletcher, *Contributing Member*
P. G. Wittenbach, *Contributing Member*
X. Wu, *Contributing Member*

Subgroup on Toughness (BPV VIII)

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

Subgroup on Graphite Pressure Equipment (BPV VIII)

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

Argentina International Working Group (BPV VIII)

A. Dominguez, *Chair*
F. P. Larrosa, *Secretary*
M. M. Acosta
R. A. Barey
C. Alderetes
F. A. Andres
L. F. Boccanera
O. S. Bretones
A. Burgueno
G. Casanas
D. H. Da Rold
J. I. Duo
M. Favareto
M. D. Kuhn
L. M. Leccese
C. Meinl
M. A. Mendez
J. J. Monaco
M. A. A. Pipponzi
D. Rizzo
R. Robles
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
Z. Chen
J. Cui
R. Duan
W. Guo
B. Han
J. Hu
Q. Hu
H. Hui
D. Luo
Y. Luo
C. Miao
X. Qian
L. Sun
B. Wang
C. Wu
F. Xu
F.-Z. Xuan
Y. Yang
K. Zhang
Yanfeng Zhang
Yijun Zhang
S. Zhao
J. Zheng
G. Zhu

Germany International Working Group (BPV VIII)

P. Chavdarov, *Chair*
M. Sykora, *Vice Chair*
B. Daume
A. Emrich
J. Fleischfresser
R. Helmholdt
R. Kauer
D. Koelbl
S. Krebs
T. Ludwig
R. A. Meyers
H. Michael
S. Reich
A. Spangenberg
G. Naumann, *Contributing Member*
P. Paluszkiewicz, *Contributing Member*
R. Uebel, *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
S. K. Goyal
V. Jayabalan
A. Kakumanu
V. V. P. Kumar
T. Mukherjee
P. C. Pathak
S. B. Patil
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*
D. D. Raimander, *Secretary*
B. G. Alborali
P. Aliprandi
A. Avogadri
A. Camanni
M. Colombo
P. Conti
D. Cortassa
P. L. Dinelli
F. Finco
M. Guglielmetti
A. F. Magri
P. Mantovani
M. Millefanti
L. Moracchioli
P. Pacor
G. Pontiggia
S. Sarti
A. Veroni
G. Gobbi, *Contributing Member*

Special Working Group on Bolted Flanged Joints (BPV VIII)

R. W. Mikitka, *Chair*
G. Aurioles, Sr.
D. Bankston, Jr.
W. Brown
H. Chen
A. Mann
W. McDaniel
M. Osterfoss
J. R. Payne
G. B. Rawls, Jr.
R. Wacker

Subgroup on Interpretations (BPV VIII)

G. Aurioles, Sr., *Chair*
J. Oh, *Staff Secretary*
S. R. Babka
J. Cameron
N. Carter
C. W. Cary
B. F. Hantz
M. Kowalczyk
D. L. Kurle
M. D. Lower
A. Mann
S. A. Marks
P. Matkovics
G. M. Mital
D. I. Morris
D. T. Peters
F. L. Richter
S. C. Roberts
C. D. Rodery
T. G. Seipp
J. C. Sowinski
D. B. Stewart
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)

D. A. Bowers, *Chair*
M. J. Pischke, *Vice Chair*
E. Lawson, *Staff Secretary*
M. Bernasek
M. A. Boring
J. G. Feldstein
P. D. Flenner
S. E. Gingrich
K. L. Hayes
R. M. Jessee
J. S. Lee
W. M. Lundy
S. A. Marks
T. Melfi
W. F. Newell, Jr.
D. K. Peetz
E. G. Reichelt
M. J. Rice
M. B. Sims
W. J. Sperko
P. L. Sturgill
J. P. Swezy, Jr.
E. W. Woelfel
D. Pojatar, *Delegate*
A. Roza, *Delegate*
M. Consonni, *Contributing Member*
S. A. Jones, *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
A. R. Nywening
M. J. Pischke
J. P. Swezy, Jr.

Subgroup on General Requirements (BPV IX)

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

Subgroup on Materials (BPV IX)

M. Bernasek, *Chair*
T. Anderson
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)

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

Subgroup on Strength of Weldments (BPV II and IX)

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

Subgroup on Welding Qualifications (BPV IX)

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

Argentina International Working Group (BPV IX)

A. Burgueno, *Chair*
E. Lawson, *Staff Secretary*
B. Bardott
L. F. Boccanera
M. Favareto
C. A. Garibotti
J. A. Herrera
M. D. Kuhn
M. A. Mendez
A. E. Pastor
G. Telleria
M. M. C. Tocco

Germany International Working Group (BPV IX)

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

Italy International Working Group (BPV IX)

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

Spain International Working Group (BPV IX)

F. J. Q. Pandelo, *Chair*
F. L. Villabrille, *Vice Chair*
E. Lawson, *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*
B. F. Shelley, *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
D. Eisberg
M. R. Gorman
B. Hebb
L. E. Hunt
D. L. Keeler
D. H. McCauley
N. L. Newhouse
G. Ramirez
J. R. Richter
S. L. Wagner
D. O. Yancey, Jr.
P. H. Ziehl
D. H. Hodgkinson, *Contributing Member*

COMMITTEE ON NUCLEAR INSERVICE INSPECTION (BPV XI)

R. W. Swayne, *Chair*
S. D. Kulat, *Vice Chair*
D. W. Lamond, *Vice Chair*
D. Miro-Quesada, *Staff Secretary*
J. F. Ball
W. H. Bamford
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
P. D. Fisher
T. J. Griesbach
J. Hakii
M. L. Hall
D. O. Henry
W. C. Holston
J. T. Lindberg
G. A. Lofthus
H. Malikowski
S. L. McCracken
S. A. Norman
C. A. Nove
T. Nuoffer
J. Nygaard
J. E. O'Sullivan
N. A. Palm
G. C. Park
A. T. Roberts III
D. A. Scarth
F. J. Schaaf, Jr.
S. Takaya
D. Vetter
T. V. Vo
D. E. Waskey
J. G. Weicks
M. Weis
Y.-K. Chung, *Delegate*
C. Ye, *Delegate*
M. L. Benson, *Alternate*
J. K. Loy, *Alternate*
R. O. McGill, *Alternate*
D. J. Shim, *Alternate*
A. Udyawar, *Alternate*
E. B. Gerlach, *Contributing Member*
B. R. Newton, *Contributing Member*
C. D. Cowfer, *Honorary Member*
D. D. Davis, *Honorary Member*
R. E. Gimple, *Honorary Member*
F. E. Gregor, *Honorary Member*
O. F. Hedden, *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)

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

Argentina International Working Group (BPV XI)

F. M. Schroeter, *Chair*
O. Martinez, *Staff Secretary*
D. A. Cipolla
A. Claus
D. Costa
D. P. Delfino
D. N. Dell'Erba
A. Dominguez
S. A. Echeverria
E. P. Fresquet
M. M. Gamizo
I. M. Guerreiro
F. Llorente
R. J. Lopez
M. Magliocchi
L. R. Miño
J. Monte
M. D. Pereda
A. Politi
C. G. Real
F. J. Schaaf, Jr.
G. J. Scian
M. J. Solari
P. N. Torano
P. Yamamoto

China International Working Group (BPV XI)

J. H. Liu, *Chair*
Y. Nie, *Vice Chair*
C. Ye, *Vice Chair*
M. W. Zhou, *Secretary*
J. F. Cai
H. Chen
H. D. Chen
Y. Cheng
Y. B. Guo
Y. Hongqi
D. R. Horn
Y. Hou
S. X. Lin
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

German International Working Group (BPV XI)

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

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*
M. Orihuela
K. R. Rao

Task Group on Inspectability (BPV XI)

J. T. Lindberg, *Chair*
E. Henry, *Secretary*
A. Cardillo
D. R. Cordes
M. J. Ferlisi
P. Gionta
D. O. Henry
J. Honcharik
R. Klein
C. Latiolais
G. A. Lofthus
S. Matsumoto
D. E. Matthews
P. J. O'Regan
J. B. Ossmann
S. A. Sabo
P. Sullivan
C. Thomas
J. Tucker

Task Group on ISI of Spent Nuclear Fuel Storage and Transportation Containment Systems (BPV XI)

K. Hunter, *Chair*
M. Orihuela, *Secretary*
D. J. Ammerman
W. H. Borter
J. Broussard
S. Brown
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
B. L. Montgomery
R. M. Pace
E. L. Pleins
M. A. Richter
B. Sarno
R. Sindelar
M. Staley
J. Wellwood
X. J. Zhai
P.-S. Lam, *Alternate*
G. White, *Alternate*
J. Wise, *Alternate*
H. Smith, *Contributing Member*

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

W. H. Bamford, *Chair*
N. A. Palm, *Secretary*
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
H. S. Mehta
K. Miyazaki
R. M. Pace
J. C. Poehler
S. Ranganath
D. A. Scarth
D. J. Shim
G. L. Stevens
A. Udyawar
T. V. Vo
G. M. Wilkowski
S. X. Xu
M. L. Benson, *Alternate*

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
H. S. Mehta
T. V. Vo
G. M. Wilkowski
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
M. A. Erickson
C. M. Faidy
M. M. Farooq
B. R. Ganta
R. G. Gilada
F. D. Hayes
P. H. Hoang
K. Hojo
D. N. Hopkins
S. Kalyanam
Y. Kim
V. Lacroix
D. R. Lee
Y. S. Li
C. Liu
M. Liu
H. S. Mehta
G. A. A. Miessi
K. Miyazaki
S. Noronha
R. K. Qashu
S. Ranganath
P. J. Rush
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

Working Group on Flaw Evaluation Reference Curves (BPV XI)

G. L. Stevens, *Chair*
A. Udyawar, *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
R. Janowiak
A. Jenks
V. Lacroix
H. S. Mehta
K. Miyazaki
B. Pellereau
S. Ranganath
D. A. Scarth
D. J. Shim
S. Smith
T. V. Vo
S. X. Xu

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

N. A. Palm, *Chair*
A. E. Freed, *Secretary*
K. R. Baker
W. H. Bamford
M. Brumovsky
M. A. Erickson
T. J. Griesbach
M. Hayashi
R. Janowiak
M. Kirk
S. A. Kleinsmith
H. Kobayashi
H. S. Mehta
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

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

N. Glunt, *Chair*
R. M. Pace, *Secretary*
A. E. Freed
M. A. Gray
T. J. Griesbach
H. Nam
A. Nana
A. D. Odell
C.-S. Oh
H. Park
S. Ranganath
D. J. Shim
S. Smith
G. L. Stevens
A. Udyawar

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

D. A. Scarth, *Chair*
G. M. Wilkowski, *Secretary*
K. Azuma
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
S. R. Gosselin
C. E. Guzman-Leong
K. Hasegawa
P. H. Hoang
K. Hojo
D. N. Hopkins
E. J. Houston
R. Janowiak
S. Kalyanam
K. Kashima
V. Lacroix
Y. S. Li
R. O. McGill
H. S. Mehta
G. A. A. Miessi
K. Miyazaki
S. H. Pellet
P. J. Rush
C. J. Sallaberry
W. L. Server
D. J. Shim
S. Smith
M. F. Uddin
A. Udyawar
T. V. Vo
K. Wang
B. Wasiluk
S. X. Xu

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

R. O. McGill, *Chair*
E. J. Houston, *Secretary*
G. A. Antaki
R. C. Cipolla
M. M. Farooq
R. Janowiak
S. M. Parker
D. Rudland
P. J. Rush
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
P. J. Rush
D. A. Scarth

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

P. J. Rush, *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. R. Cordes, *Secretary*
M. Briley
C. Brown
T. L. Chan
T. Cinson
S. E. Cumblidge
K. J. Hacker
J. Harrison
D. O. Henry
G. A. Lofthus
S. A. Sabo
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*
T. Cinson, *Secretary*
J. E. Aycock
J. Bennett
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)

G. A. Lofthus, *Chair*
J. Harrison, *Secretary*
M. Briley
A. Bushmire
D. R. Cordes
S. R. Doctor
K. J. Hacker
W. A. Jensen
D. A. Kull
C. Latiolais
C. A. Nove
S. A. Sabo
R. V. Swain
D. Van Allen
D. K. Zimmerman
B. Lin, *Alternate*

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
P. D. Fisher
M. L. Hall
W. C. Holston
J. Honcharik
A. B. Meichler
B. R. Newton
S. A. Norman
J. E. O'Sullivan
G. C. Park
R. R. Stevenson
R. W. Swayne
D. J. Tilly
D. E. Waskey
J. G. Weicks
B. Lin, *Alternate*
J. K. Loy, *Alternate*

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

J. G. Weicks, *Chair*
D. Barborak
S. J. Findlan
P. D. Fisher
R. C. Folley
M. L. Hall
W. C. Holston
J. Honcharik
C. C. Kim
M. Kris
S. E. Marlette
S. L. McCracken
B. R. Newton
J. E. O'Sullivan
D. J. Tilly
D. E. Waskey
J. K. Loy, *Alternate*

Task Group on Temper Bead Welding (BPV XI)

S. J. Findlan, *Chair*
D. Barborak
M. L. Hall
S. L. McCracken
N. Mohr
B. R. Newton
G. Olson
J. E. O'Sullivan
A. Patel
J. Tatman
D. J. Tilly
D. E. Waskey
J. G. Weicks

Task Group on Weld Overlay (BPV XI)

S. L. McCracken, *Chair*
D. Barborak
S. J. Findlan
M. L. Hall
W. C. Holston
S. Hunter
C. Lohse
S. E. Marlette
B. R. Newton
G. Olson
A. Patel
P. Raynaud
D. W. Sandusky
D. E. Waskey
J. G. Weicks

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

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

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 (WGN-MRR) (BPV XI)

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

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

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

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

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

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

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

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

H. Malikowski, *Chair*
K. Dietrich, *Secretary*
W. H. Bamford
T. Cinson
P. R. Donavin
K. M. Hoffman
H. Kobayashi
C. Lohse
S. E. Marlette
B. L. Montgomery
G. C. Park
W. Sims
D. E. Waskey
C. Wax
K. A. Whitney

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

M. J. Ferlisi, *Chair*
R. Thames, *Secretary*
P. S. Ghosal
H. T. Hill
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*
R. W. Blyde
K. Caver
C. Cueto-Felgueroso
M. J. Ferlisi
M. L. Garcia Heras
K. W. Hall
K. M. Hoffman
J. Howard
A. Keller
S. D. Kulat
E. Lantz
A. Maekawa
T. Nomura
J. C. Nygaard
S. Orita

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

J. M. Boughman, *Chair*
S. A. Norman, *Secretary*
T. Anselmi
B. Casey
Y.-K. Chung
M. J. Homiack
A. E. Keyser
D. W. Lamond
J. K. McClanahan
T. P. McClure
B. L. Montgomery
M. Moenssens
R. A. Nettles
C. Thomas

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
G. J. Navratil
P. J. O'Regan
N. A. Palm
D. Vetter
J. C. Younger

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
T. N. Rezk
A. T. Roberts III
S. R. Scott
D. Vetter
S. E. Woolf
M. T. Audrain, *Alternate*
R. S. Spencer, *Alternate*

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

A. T. Roberts III, *Chair*
D. Vetter, *Secretary*
T. Anselmi
N. Broom
V. Chugh
S. R. Doctor
J. D. Fletcher
J. T. Fong
J. Grimm
K. Harris
P. J. Hennessey
D. M. Jones
D. R. Lee
T. Lupold
M. Orihuela
F. J. Schaaf, Jr.
H. M. Stephens, Jr.
R. W. Swayne
S. Takaya
R. Vayda

Working Group on MANDE (BPV XI)

H. M. Stephens, Jr., *Chair*
S. R. Doctor, *Vice Chair*
M. Turnbow, *Secretary*
T. Anselmi
N. A. Finney
J. T. Fong
D. O. Henry
T. Lupold
L. E. Mullins
M. Orihuela

JSME/ASME Joint Task Group for System-Based Code (SWG-RIM) (BPV XI)

S. Takaya, *Chair*
T. Asayama
S. R. Doctor
K. Dozaki
J. T. Fong
J. Hakii
K. Harris
M. Hayashi
Y. Kamishima
D. R. Lee
H. Machida
T. Muraki
A. T. Roberts III
F. J. Schaaf, Jr.
R. Vayda
D. Watanabe
M. Morishita, *Contributing Member*

COMMITTEE ON TRANSPORT TANKS (BPV XII)

N. J. Paulick, *Chair*
M. D. Rana, *Vice Chair*
J. Oh, *Staff Secretary*
A. N. Antoniou
P. Chilukuri
W. L. Garfield
M. Pitts
J. Roberts
T. A. Rogers
R. C. Sallash
M. Shah
S. Staniszewski
A. P. Varghese
Y. Doron, *Contributing Member*
R. Meyers, *Contributing Member*
M. R. Ward, *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
P. Chilukuri
Y. Doron
S. L. McWilliams
N. J. Paulick
M. D. Rana
T. A. Rogers
M. Shah
S. Staniszewski
A. P. Varghese
K. Xu
A. T. Duggleby, *Contributing Member*
R. D. Hayworth, *Contributing Member*
G. G. Karcher, *Contributing Member*
B. E. Spencer, *Contributing Member*
M. R. Ward, *Contributing Member*
J. Zheng, *Contributing Member*

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

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

Subgroup on General Requirements (BPV XII)

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

Subgroup on Nonmandatory Appendices (BPV XII)

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

COMMITTEE ON OVERPRESSURE PROTECTION (BPV XIII)

D. B. DeMichael, *Chair*
D. Miller, *Vice Chair*
C. E. O'Brien, *Staff Secretary*
J. F. Ball
J. Burgess
B. Calderon
J. W. Dickson
A. Donaldson
S. F. Harrison, Jr.
B. K. Nutter
T. Patel
M. Poehlmann
T. R. Tarbay
D. E. Tompkins
Z. Wang
J. A. West
A. Wilson
H. Aguilar, *Contributing Member*
R. W. Barnes, *Contributing Member*
R. D. Danzy, *Contributing Member*
M. Elias, *Contributing Member*
D. Felix, *Contributing Member*
A. Frigerio, *Contributing Member*
J. P. Glaspie, *Contributing Member*
A. Hassan, *Contributing Member*
P. K. Lam, *Contributing Member*
J. M. Levy, *Contributing Member*
M. Mengon, *Contributing Member*
J. Mize, *Contributing Member*
M. Mullavey, *Contributing Member*
S. K. Parimi, *Contributing Member*
R. Raman, *Contributing Member*
M. Reddy, *Contributing Member*
S. Ruesenberg, *Contributing Member*
K. Shores, *Contributing Member*
D. E. Tezzo, *Contributing Member*

Executive Committee (BPV XIII)

D. Miller, *Chair*
D. B. DeMichael, *Vice Chair*
C. E. O'Brien, *Staff Secretary*
J. F. Ball
A. Donaldson
B. K. Nutter
J. A. West

Subgroup on Design and Materials (BPV XIII)

D. Miller, *Chair*
T. Patel, *Vice Chair*
B. Mruk, *Secretary*
C. E. Beair
A. Biesecker
W. E. Chapin
J. L. Freiler
B. Joergensen
V. Kalyanasundaram
B. J. Mollitor
A. Swearingin
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*
D. J. Azukas
J. F. Ball
M. Z. Brown
J. Burgess
D. B. DeMichael
M. Elias
S. T. French
J. Gillham
R. Klimas, Jr.
Z. E. Kumana
P. K. Lam
K. R. May
J. Mize
L. Moedinger
M. Mullavey
M. Poehlmann
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*
C. Haldiman, *Contributing Member*
J. Horne, *Contributing Member*
B. Joergensen, *Contributing Member*
C. Lasarte, *Contributing Member*
D. Mainiero-Cessna, *Contributing Member*
M. Mengon, *Contributing Member*
D. E. Miller, *Contributing Member*
R. Miyata, *Contributing Member*
B. Mruk, *Contributing Member*
R. Raman, *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)

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

Subgroup on Testing (BPV XIII)

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

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

D. Miller, *Chair*
C. E. O'Brien, *Staff Secretary*
J. F. Ball
T. J. Bevilacqua
D. B. DeMichael
J. W. Dickson
B. K. Nutter
T. Patel
J. R. Thomas, Jr.
J. A. West
J. F. White

COMMITTEE ON BOILER AND PRESSURE VESSEL CONFORMITY ASSESSMENT (CBPVCA)

R. V. Wielgoszinski, *Chair*
G. Scribner, *Vice Chair*
P. Murray, *Staff Secretary*
J. P. Chicoine
P. D. Edwards
T. E. Hansen
B. L. Krasiun
P. F. Martin
L. E. McDonald
D. Miller
I. Powell
L. Skarin
R. Uebel
E. A. Whittle
P. Williams
T. P. Beirne, *Alternate*
M. Blankinship, *Alternate*
J. W. Dickson, *Alternate*
J. M. Downs, *Alternate*
B. J. Hackett, *Alternate*
W. Hibdon, *Alternate*
Y.-S. Kim, *Alternate*
B. Morelock, *Alternate*
M. Poehlmann, *Alternate*
R. Rockwood, *Alternate*
B. C. Turczynski, *Alternate*
D. E. Tuttle, *Alternate*
S. V. Voorhees, *Alternate*
D. Cheetham, *Contributing Member*
A. J. Spencer, *Honorary Member*

COMMITTEE ON NUCLEAR CERTIFICATION (CNC)

R. R. Stevenson, *Chair*
J. DeKleine, *Vice Chair*
Z. McLucas, *Staff Secretary*
J. F. Ball
G. Claffey
G. Gobbi
S. M. Goodwin
J. W. Highlands
K. A. Kavanagh
J. C. Krane
M. A. Lockwood
T. McGee
E. L. Pleins
T. E. Quaka
T. N. Rezk
G. E. Szabatura
C. Turylo
D. M. Vickery
E. A. Whittle
T. Aldo, *Alternate*
M. Blankinship, *Alternate*
P. J. Coco, *Alternate*
N. DeSantis, *Alternate*
C. Dinic, *Alternate*
P. D. Edwards, *Alternate*
T. B. Franchuk, *Alternate*
K. M. Hottle, *Alternate*
P. Krane, *Alternate*
D. Nenstiel, *Alternate*
L. Ponce, *Alternate*
P. F. Prescott, *Alternate*
S. V. Voorhees, *Alternate*
M. Wilson, *Alternate*
S. Yang, *Alternate*
S. F. Harrison, Jr., *Contributing Member*

(21)

ORGANIZATION OF SECTION III

1 GENERAL

Section III consists of Division 1, Division 2, Division 3, 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, and by the letter "H" for Division 5. Each Subsection is published separately, with the exception of those listed for Divisions 2, 3, 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 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

* In the 2021 Edition, Subsections NC and ND have been incorporated into one publication, Subsection NCD (BPVC.III.1.NCD), Class 2 and Class 3 Components.

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

Errata to the BPV Code may be posted on the ASME website to provide corrections to incorrectly published items, or to correct typographical or grammatical errors in the BPV Code. Such Errata shall be used on the date posted.

Information regarding Special Notices and Errata is published by ASME at http://go.asme.org/BPVCerrata.

Changes given below are identified on the pages by a margin note, **(21)**, placed next to the affected area.

Page	***Location***	***Change***
v	List of Sections	(1) Listing for Section III updated (2) Section XIII added (3) Code Case information updated
vii	Foreword	(1) Subparagraph (k) added and subsequent subparagraph redesignated (2) Second footnote revised (3) Last paragraph added
x	Submittal of Technical Inquiries to the Boiler and Pressure Vessel Standards Committees	Paragraphs 1(a)(3)(-b), 2(b), and 5(a)(3) revised
xiii	Personnel	Updated
xxxiv	Organization of Section III	(1) In para. 1, Division 1 listing updated (2) In para. 9(c)(3), “MSS SP 89-2003” corrected by errata to “MSS SP-58-2009”
22	NG-2584.2	Revised
22	NG-2585.2	Revised
28	NG-3211	Subparagraph (c) revised
30	NG-3213.16	Revised
30	NG-3213.17	Revised
30	NG-3213.19	Added
30	NG-3213.20	Revised
30	NG-3213.21	Cross-reference updated
31	NG-3215	(1) First paragraph revised and second paragraph added (2) In subpara. (b)(1), cross-reference updated (3) Note deleted
31	NG-3216	Revised
31	NG-3216.1	In subpara. (c), penultimate sentence added
32	NG-3216.2	Subparagraph (e) revised
32	NG-3220	In NG-3221, NG-3221.1, and NG-3221.2, cross-references to figure updated
35	Figure NG-3222-1	In Note (5), S_a corrected by errata to S_{alt}
32	NG-3222.2	Revised
38	NG-3222.5	Revised
39	Figure NG-3224-1	Revised
39	NG-3224.1	Subparagraphs (c) and (c)(2) revised
40	NG-3225	Subparagraph (b) added and subsequent subparagraphs redesignated
42	NG-3228.1	Revised in its entirety
42	NG-3228.2	Revised in its entirety
42	NG-3228.3	(1) Revised (2) Former in-text table designated as Table NG-3228-1
43	NG-3229	Title revised
44	Figure NG-3232-1	Revised
43	NG-3232.1	Revised
44	NG-3232.2	Revised

Page	***Location***	***Change***
45	NG-3235	(1) In subparas. (a), (a)(3), and (b), last line revised (2) Subparagraph (c) deleted

LIST OF CHANGES IN RECORD NUMBER ORDER

DELETED

CROSS-REFERENCING AND STYLISTIC CHANGES IN THE BOILER AND PRESSURE VESSEL CODE

There have been structural and stylistic changes to BPVC, starting with the 2011 Addenda, that should be noted to aid navigating the contents. The following is an overview of the changes:

Subparagraph Breakdowns/Nested Lists Hierarchy

- First-level breakdowns are designated as (a), (b), (c), etc., as in the past.
- Second-level breakdowns are designated as (1), (2), (3), etc., as in the past.
- Third-level breakdowns are now designated as (-a), (-b), (-c), etc.
- Fourth-level breakdowns are now designated as (-1), (-2), (-3), etc.
- Fifth-level breakdowns are now designated as (+a), (+b), (+c), etc.
- Sixth-level breakdowns are now designated as (+1), (+2), etc.

Footnotes

With the exception of those included in the front matter (roman-numbered pages), all footnotes are treated as endnotes. The endnotes are referenced in numeric order and appear at the end of each BPVC section/subsection.

Submittal of Technical Inquiries to the Boiler and Pressure Vessel Standards Committees

Submittal of Technical Inquiries to the Boiler and Pressure Vessel Standards Committees has been moved to the front matter. This information now appears in all Boiler Code Sections (except for Code Case books).

Cross-References

It is our intention to establish cross-reference link functionality in the current edition and moving forward. To facilitate this, cross-reference style has changed. Cross-references within a subsection or subarticle will not include the designator/identifier of that subsection/subarticle. Examples follow:

- *(Sub-)Paragraph Cross-References.* The cross-references to subparagraph breakdowns will follow the hierarchy of the designators under which the breakdown appears.
  - If subparagraph (-a) appears in X.1(c)(1) and is referenced in X.1(c)(1), it will be referenced as (-a).
  - If subparagraph (-a) appears in X.1(c)(1) but is referenced in X.1(c)(2), it will be referenced as (1)(-a).
  - If subparagraph (-a) appears in X.1(c)(1) but is referenced in X.1(e)(1), it will be referenced as (c)(1)(-a).
  - If subparagraph (-a) appears in X.1(c)(1) but is referenced in X.2(c)(2), it will be referenced as X.1(c)(1)(-a).
- *Equation Cross-References.* The cross-references to equations will follow the same logic. For example, if eq. (1) appears in X.1(a)(1) but is referenced in X.1(b), it will be referenced as eq. (a)(1)(1). If eq. (1) appears in X.1(a)(1) but is referenced in a different subsection/subarticle/paragraph, it will be referenced as eq. X.1(a)(1)(1).

INTENTIONALLY LEFT BLANK

ARTICLE NG-1000 INTRODUCTION

NG-1100 SCOPE

NG-1110 ASPECTS OF CONSTRUCTION COVERED BY THESE RULES

Subsection NG establishes rules for materials, design, fabrication, examination, and preparation of reports required in the manufacture and installation of core support structures.[1, 2]

NG-1120 DEFINITION OF STRUCTURES AND APPLICATION OF THESE RULES TO THEM

NG-1121 Core Support Structures

Core support structures shall be constructed to the rules of this Subsection. Core support structures are those structures or parts of structures which are designed to provide direct support or restraint of the core (fuel and blanket assemblies) within the reactor pressure vessel. Structures which support or restrain the core only after the postulated failure of core support structures are considered to be internal structures (NG-1122).

NG-1122 Internal Structures

(a) Internal structures are *all* structures within the reactor pressure vessel other than core support structures, fuel[3] and blanket assemblies, control assemblies, and instrumentation.

(b) The rules of this Subsection apply to internal structures as defined in (a) above, only when so stipulated by the Certificate Holder manufacturing core supports, hereafter referred to in this Subsection as Certificate Holder.

(c) The Certificate Holder shall certify[2] that the construction of all internal structures is such as not to affect adversely the integrity of the core support structure.

NG-1123 Temporary Attachments

A temporary attachment is an element in contact with or connected to the core support structure, which is removed prior to operation. Temporary attachments include items such as alignment lug tie straps and braces.

NG-1130 BOUNDARIES OF JURISDICTION APPLICABLE TO THIS SUBSECTION

NG-1131 Boundary Between Core Support Structure and Reactor Pressure Vessel

The jurisdictional boundary between a core support structure and the reactor pressure vessel shall be the surface of the core support structure. The first connecting weld of a core support structure to the reactor pressure vessel shall be considered part of the reactor pressure vessel unless the weld is more than $2t$ from the pressure-retaining portion of the reactor pressure vessel, where t is the nominal thickness of the pressure-retaining material. Beyond the first connecting weld to the reactor pressure vessel, or beyond $2t$ from the pressure-retaining portion of the reactor pressure vessel, the first weld shall be considered part of the core support structure, unless otherwise specified in the Design Specification. Mechanical fasteners used to connect a core support structure to the reactor pressure vessel shall meet the requirements of this Subsection. Figure NG-1131-1 is provided as an aid in defining the boundary and construction requirements of this Subsection.

NG-1132 Boundary Between Core Support Structure and Internal Structure

(a) Internal structures may bear on or may be welded, cast, or fastened to core support structures.

(b) The jurisdictional boundary between a core support structure and an internal structure is the surface of the core support structure. The means by which the internal structure is connected to the core support structure shall be considered as follows:

(1) Attachment welds shall be considered as part of the core support structure.

(2) Mechanical connections (such as fasteners or pins) shall be considered as part of the internal structure.

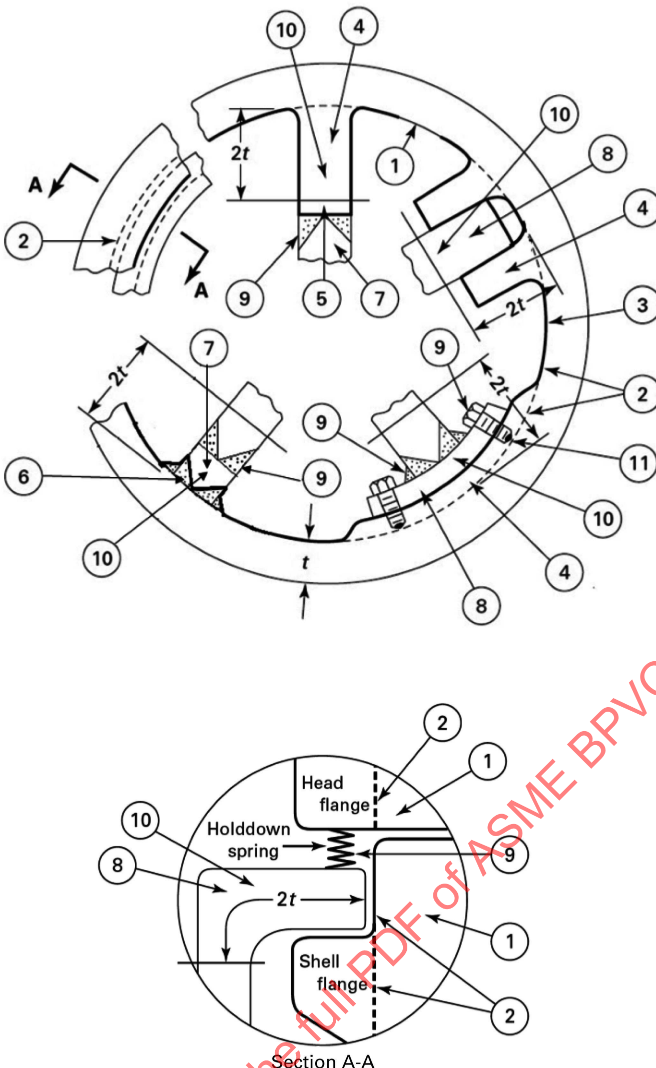
(c) One or more portions of a casting may be classified as core support structures and different portions of the same casting may be classified as internal structures. The portions of the casting so classified shall be defined by the Design Specification or on the drawing. The entire casting (core support and internal structural portions) shall meet the material property requirements of Article NG-2000 with the additional nondestructive examinations of the

internal structure portion sufficient to meet the requirement of NG-1122(c).

NG-1133 Boundary Between Core Support Structure and Temporary Attachment

The jurisdictional boundary between a core support structure and a temporary attachment shall be the surface of the core support structure.

Figure NG-1131-1
Jurisdictional Boundary Between Core Support Structure and Reactor Pressure Vessel



(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 NG-2000
MATERIAL

NG-2100 GENERAL REQUIREMENTS FOR MATERIAL

NG-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 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*: thickness, *t*, is defined as the largest nominal thickness of the load carrying portion of the casting.

NG-2120 MATERIAL FOR CORE SUPPORT STRUCTURES

NG-2121 Permitted Material Specifications

(a) Core support structural material, and material welded thereto, and threaded structural fasteners, with the exception of welding material (NG-2430), hard surfacing material (Section IX, QW-251.4), cladding which is 10% or less of the thickness of the base material (NG-3122), or the material excluded by NG-4430, shall conform to the requirements of the specifications for material given in Section II, Part D, Subpart 1, Tables 2A and 2B, including all applicable notes in the table, and to all of the special requirements of this Article which apply to the product form in which the material is used.

(b) The requirements of this Article apply to the internal structures (NG-1122) only as specifically stipulated by the Certificate Holder; however, the Certificate Holder shall certify that the material used for the internal structures shall not adversely affect the integrity of the core support structure.

(c) Welding material used in 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 materials used as backing rings or backing strips in welded joints.

NG-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 which 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 NG-2500. Any examination, repair, test, or treatment required by the material specification or this Article may be performed by the Material Organization or the Certificate Holder as provided in NG-4121.1. Any hydrostatic or pneumatic pressure test required by a material specification need not be performed provided the material is not used in a pressure-retaining function.

(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.

NG-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, mechanical properties, or both 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).

NG-2130 CERTIFICATION OF MATERIAL

All material used in the construction or installation of core support structures shall be certified as required in NCA-3862 and NCA-3861. Certified Material Test Reports are required for core support material except as provided by NCA-3862. A Certificate of Compliance may be provided in lieu of Certified Material Test Reports for all other material. Copies of all Certified Material Test Reports and Certificates of Compliance applicable to material used in a core support structure shall be furnished with the material.

NG-2140 WELDING MATERIAL

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

NG-2150 MATERIAL IDENTIFICATION

The identification of material for core support structures shall meet the requirements of NCA-4256. Material for small items shall be controlled during manufacture of the core support structures so that they are identifiable as acceptable material at all times. Welding material shall be controlled during the repair of material and the manufacture and installation of core support structures so that they are identifiable as acceptable material until the material is actually consumed in the process (NG-4122).

NG-2160 DETERIORATION OF MATERIAL IN SERVICE

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-3250), with specific attention being given to the effects of service conditions upon the properties of the material.

NG-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.

NG-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 -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.

NG-2190 TEMPORARY ATTACHMENT MATERIAL

Material used for temporary attachments need not comply with Article NG-2000 and may be welded to the core support structure provided the requirements of NG-4430 are met.

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

NG-2210 HEAT TREATMENT REQUIREMENTS

NG-2211 Test Coupon Heat Treatment for Ferritic Material[4]

Where ferritic steel material is subjected to heat treatment during construction, the material used for the tensile and impact test specimens shall be heat-treated in the same manner as the core support structures, except that test coupons and specimens for P-No. 1 Groups 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.

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

NG-2212.1 Cooling Rates. Where ferritic steel material is subjected to quenching from the austenitizing temperature, the test coupons representing those materials 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 (NG-2223.3 and NG-2226.4). This rule shall apply for coupons taken directly from the material as well as for separate test coupons representing the material, and one of the general procedures described in NG-2212.2 or one of the specific procedures described in NG-2220 shall be used for each product form.

NG-2212.2 General Procedures. One of the general procedures stipulated in (a) through (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 NG-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 which 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 NG-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

(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.

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

NG-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 this subarticle. References to dimensions signify nominal values.

NG-2222 Plates

NG-2222.1 Number of Tension Test Coupons. The number of tension test coupons required shall be in accordance with the material specification and 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.

NG-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.

NG-2222.3 Requirements for Separate Test Coupons. Where a separate test coupon is used to represent the core support structure 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 NG-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.

NG-2223 Forgings

NG-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 NG-2212.2(c) may be used to achieve these conditions, unless cooling rates applicable to the bulk forgings are simulated as otherwise provided in NG-2212.2.

NG-2223.2 Very Thick and Complex Forgings. Test coupons for forgings which are both very thick and complex, such as contour nozzles, flanges, nozzles, 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.

NG-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 the following:

(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-to-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 NG-2223.2.

NG-2224 Location of Coupons

(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) Threaded Structural Fastener Material. For threaded structural fastener material, the coupons shall be taken in conformance with the applicable material specification and with the midlength of the specimen at least one diameter or thickness from a heat-treated end. When the threaded structural fasteners, including studs and nuts, are not of sufficient length, the midlength of the specimen shall be at the midlength of the threaded structural fasteners. The threaded structural fasteners, including studs and nuts, 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 threaded structural fasteners.

NG-2225 Tubular Products and Fittings

NG-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.

NG-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 NG-2223.3 shall be met.

NG-2226 Castings

NG-2226.1 Castings With 2 in. (50 mm) Maximum Thickness and Less. For castings with a maximum thickness of 2 in. (50 mm) and less, the specimens shall be taken from either the standard separately cast coupons or the casting, in accordance with the material specification.

NG-2226.2 Castings With Thicknesses Exceeding 2 in. (50 mm) Maximum Thickness. For castings exceeding a thickness of 2 in. (50 mm), the coupons shall be taken from the casting (or an extension of it) so that specimens shall have their longitudinal axes at least $\frac{1}{4}t$ of the maximum heat-treated thickness from any surface and with the midlength of the specimens at least t from any second surface. A thermal buffer may be used [NG-2212.2(c)].

NG-2226.3 Separately Cast Test Coupons for Castings With Thicknesses Exceeding 2 in. (50 mm). In lieu of the requirements of NG-2226.2, separately cast test coupons may be used under the following conditions:

(a) The separate test coupon representing castings from one heat and one heat treatment lot shall be of the same heat of material and shall be subjected to substantially the same foundry practices as the production casting it represents.

(b) The separate test coupon shall be heat-treated in the same furnace charge and under the same conditions as the production casting, unless cooling rates applicable to the bulk castings are simulated in accordance with NG-2212.2.

(c) The separate test coupon shall be not less than $3t \times 3t \times t$, where t equals the nominal thickness of the casting. Test specimens shall be taken with 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 casting thickness.

NG-2226.4 Castings Machined or Cast to Finished Configuration Before Heat Treatment. In lieu of the requirements of NG-2226.1, NG-2226.2, or NG-2226.3, test coupons may be removed from prolongations or other stock provided on the product. 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 outside 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 be at least $^3/_4$ in. (19 mm) from 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. The Certificate Holder shall specify the surfaces of the finished product subjected to high tensile stresses in service.

NG-2300 FRACTURE TOUGHNESS REQUIREMENTS FOR MATERIAL

NG-2310 MATERIAL TO BE IMPACT TESTED

NG-2311 Components for Which Impact Testing of Material Is Required

(a) When the Design Specifications for core support structures require impact testing[5] they shall be impact tested in accordance with the requirements of NG-2300, except that the following materials are not to be impact tested as a requirement of this Subsection:

(1) material with a nominal section thickness of $^5/_8$ in. (16 mm) and less

(2) threaded structural fasteners, including studs and nuts, 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 materials for pipe, tube, and fittings with an NPS 6 (DN 150) diameter and smaller

(5) austenitic stainless steels, including precipitation-hardened austenitic Grade 660 (UNS S66286)

(6) nonferrous material

(b) Drop weight tests are not required for martensitic high alloy chromium (Series 4XX) steels and precipitation-hardening steels listed in Section II, Part D, Subpart 1, Tables 2A and 2B. The other requirements of NG-2331 and NG-2332 apply for these steels. For nominal wall thickness greater than 2 in. (50 mm), the required C_v value shall be 40 mils (1.00 mm) lateral expansion.

NG-2320 IMPACT TEST PROCEDURES

NG-2321 Types of Tests

NG-2321.1 Drop Weight Tests. The drop weight test, when required, shall be performed in accordance with ASTM E208. Specimen types P-1, P-2, or P-3 may be used. The orientations and locations of all test specimens and the results of all tests performed to meet the requirements of NG-2330 shall be reported in the Certified Material Test Report.

NG-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. The lateral expansion and absorbed energy, as applicable, and the test temperature, as well as the orientation and location of all tests performed to meet the requirements of NG-2330 shall be reported in the Certified Material Test Report.

NG-2322 Test Specimens

NG-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 NG-2220 for tensile test specimens. For material in other heat-treated conditions, impact test specimens shall be removed from the locations specified for tensile specimens in the material specification. For all other material, the number of tests shall be in accordance with NG-2340. For threaded structural fasteners, the C_v impact test specimens 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 threaded structural fasteners, including studs and nuts, are not of sufficient length, the midlength of the specimen shall be at the midlength of the threaded structural fasteners. The threaded structural fasteners, including studs and nuts, 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 threaded structural fasteners.

NG-2322.2 Orientation of Impact Test Specimens.

(a) Specimens for Charpy V-notch tests shall be oriented as follows:

(1) Specimens for forgings, other than threaded structural fasteners and bars, 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, shall be oriented in the axial direction.

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

(4) Specimens for all plate material, including those 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 (NG-2226).

(6) In cases (1) through (5) above, the length of 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.

Table NG-2331(a)-1
Required C_v Values for Core Structure Material With 2 in. (50 mm) Maximum Thickness (Other Than Threaded Structural Fasteners)

Nominal Wall Thickness, in. (mm)	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 (38 to 50), incl.	40 (1.00)

NG-2330 TEST REQUIREMENTS AND ACCEPTANCE STANDARDS[6]

NG-2331 Material for Core Support Structures Not Exceeding 2 in. (50 mm) Maximum Thickness

Material for core support structures (other than threaded structural fasteners) with nominal thickness 2 in. (50 mm) and less shall be tested as required in the following:

(a) Test three C_v specimens at a temperature lower than or equal to the lowest service temperature.[7] All three specimens shall meet the requirements of Table NG-2331(a)-1.

(b) Apply the procedures of (a) above to

(1) base material,[8]

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

(3) the weld metal of NG-2431.

NG-2332 Material With Thickness Exceeding 2 in. (50 mm)

Material for core support structures (other than threaded structural fasteners) with nominal wall thickness over 2 in. (50 mm) shall meet the following requirements:

(a) Establish a reference temperature RT_{NDT}; this shall be done as required in (1) through (5) below.

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

(2) At a temperature not greater than $[T_{NDT} + 60°F\ (33°C)]$, each specimen of the C_v test (NG-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 NG-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) are not met, conduct additional C_v tests in groups of three specimens (NG-2321.2) to determine the temperature T_{C_v} at which they are met. In this case, the reference temperature $RT_{NDT} = T_{C_v} - 60°F\ (33°C)$. Thus, the reference temperature RT_{NDT} is the higher of T_{NDT} or $[T_{C_v} - 60°F\ (33°C)]$.

(4) When a C_v test has not been performed at $[T_{NDT} + 60°F\ (33°C)]$ or when the C_v test at $[T_{NDT} + 60°F\ (33°C)]$ does not exhibit a minimum of 50 ft-lb (68 J) energy absorption and 35 mils (0.89 mm) lateral expansion, a temperature representing a minimum of 50 ft-lb (68 J) energy absorption 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) The lowest service temperature shall be not lower than RT_{NDT} + 100°F (55°C) unless a lower temperature is justified by using methods similar to those contained in Section III Appendices, Nonmandatory Appendix G, Article G-2000.

(b) Apply the procedures of (a) above to

(1) the base material

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

(3) the weld metal of NG-2431

(c) Product forms having dimensions which prohibit obtaining drop weight test specimens shall be tested in accordance with NG-2331.

(d) Consideration shall be given to the effects of irradiation on material toughness properties (such as core beltline region of reactor). The Design Specifications shall include additional requirements, as necessary, to assure adequate fracture toughness for the service lifetime of the core support structures. 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.

NG-2333 Threaded Structural Fasteners

For threaded structural fastener material, including studs and nuts, test three C_v specimens at a temperature no higher than the preload temperature or the lowest service temperature, whichever is the lesser. All three specimens shall meet the requirements of Table NG-2333-1.

Table NG-2333-1
Required C_v Values for Threaded Structural Fastener Material

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

NG-2340 NUMBER OF IMPACT TESTS REQUIRED

NG-2341 Plates

One test shall be made from each plate as heat-treated. Where plates are furnished in the nonheat-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.

NG-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 to 10,000 lb (450 kg to 4 500 kg) in weight.

(d) As an alternative to (c) above, 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 (NG-2226.3) may be used; one test shall be made for Charpy V-notch and one test for drop weight.

NG-2343 Bars

One test shall be made for each diameter or size having a nominal cross-sectional area greater than 1 in.^{2} in each lot, 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).

NG-2344 Tubular Products and Fittings

On products which are seamless or welded without filler metal, one test shall be made from each lot. On products which 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.

NG-2345 Threaded Structural Fastener 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 the following:

Diameter	Weight
$1^3/_4$ in. (45 mm) and less	1,500 lb (700 kg)
Over $1^3/_4$ in. to $2^1/_2$ in. (45 mm to 64 mm)	3,000 lb (1 350 kg)
Over $2^1/_2$ in. to 5 in. (64 mm to 125 mm)	6,000 lb (2 700 kg)
Over 5 in. (125 mm)	10,000 lb (4 500 kg)

NG-2346 Test Definition

Unless otherwise stated in NG-2341 through NG-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 (NG-2332) and only the C_v test when determination of RT_{NDT} is not required (NG-2331).

NG-2350 RETESTS

(a) For C_v tests required by NG-2330, one retest at the same temperature may be conducted, provided

(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 (13.6 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.

NG-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 specified in the following:

(a) Temperature instruments used to control 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 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).

NG-2400 WELDING MATERIAL

NG-2410 GENERAL REQUIREMENTS

(a) All welding material used in the construction and repair of components or material, except welding material used for hard surfacing, shall conform to the requirements of the 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 NG-2150.

(b) The Certificate Holder shall provide the organization performing the testing with the following information, as applicable:

(1) welding process

(2) SFA Specification and classification

(3) other identification if no SFA Specification applies

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

(5) drop weight test for material as-welded or heat-treated or both (NG-2332)

(6) Charpy V-notch test for material as-welded or heat-treated or both (NG-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 [NG-2431.1(c)]

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

(9) elements for which chemical analysis is required per the SFA Specification or WPS, and NG-2432

(10) minimum delta ferrite (NG-2433)

NG-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 NG-4000 and this subarticle are made and the results conform to the requirements of this Article.

NG-2430 WELD METAL TESTS

NG-2431 Mechanical Properties Test

Tensile and impact tests shall be made, in accordance with this paragraph, of welding material used to join P-Nos. 1, 3 through 7, 9, and 11 base materials in any combination, with the following exceptions:

(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 NG-2300 shall likewise be exempted from the impact testing required by this paragraph

NG-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 with 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 which 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[4] 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 that are tested in the as-welded condition, or following a postweld heat treatment within the holding temperature ranges of Table NG-4622.1-1 or Table NG-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 NG-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 NG-2321.1 and NG-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 requirements of NG-2330 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.

NG-2431.2 Standard Test Requirements. In lieu of the use of the General Test Requirements specified in NG-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 NG-2431, shall apply for this Standard Test Requirements option. The limitations and testing under this Standard Test option shall be in accordance with the following:

(a) Testing to the requirements of this subparagraph shall be limited to electrode classifications included in Specification 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 NG-2330, 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 postweld heat treatment temperatures shall be in accordance with Table NG-4622.1-1 for the applicable P-Number equivalent. The time at postweld heat treatment temperature shall be 8 hr (this qualifies postweld heat treatments of 10 hr or less). Where the postweld heat treatment of the production weld exceeds 10 hr or the PWHT temperature is other than that required above, the general test of NG-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 NG-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 NG-2431.1(f) shall be applicable to the impact testing of this option.

Table NG-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

NG-2432 Chemical Analysis Test

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

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

(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) below. As an alternative, the deposit shall be made in accordance with (d) below 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 either the filler metal analysis or the undiluted weld deposit analysis or for *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[9] 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 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 which does not have a Mechanical Properties Test requirement, a chemical analysis test coupon shall be prepared as required by NG-2431.1(c), except that heat treatment of the coupon is not required and the weld coupon thickness requirements of NG-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 QW-453 for the minimum thickness for which the Welding Procedure Specification is qualified.

NG-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 the following:

(a) All welding material shall be analyzed for the elements listed in Table NG-2432.2-1 and for other elements specified either in the welding material specification referenced by the Welding Procedure Specification or in the Welding Procedure Specification.

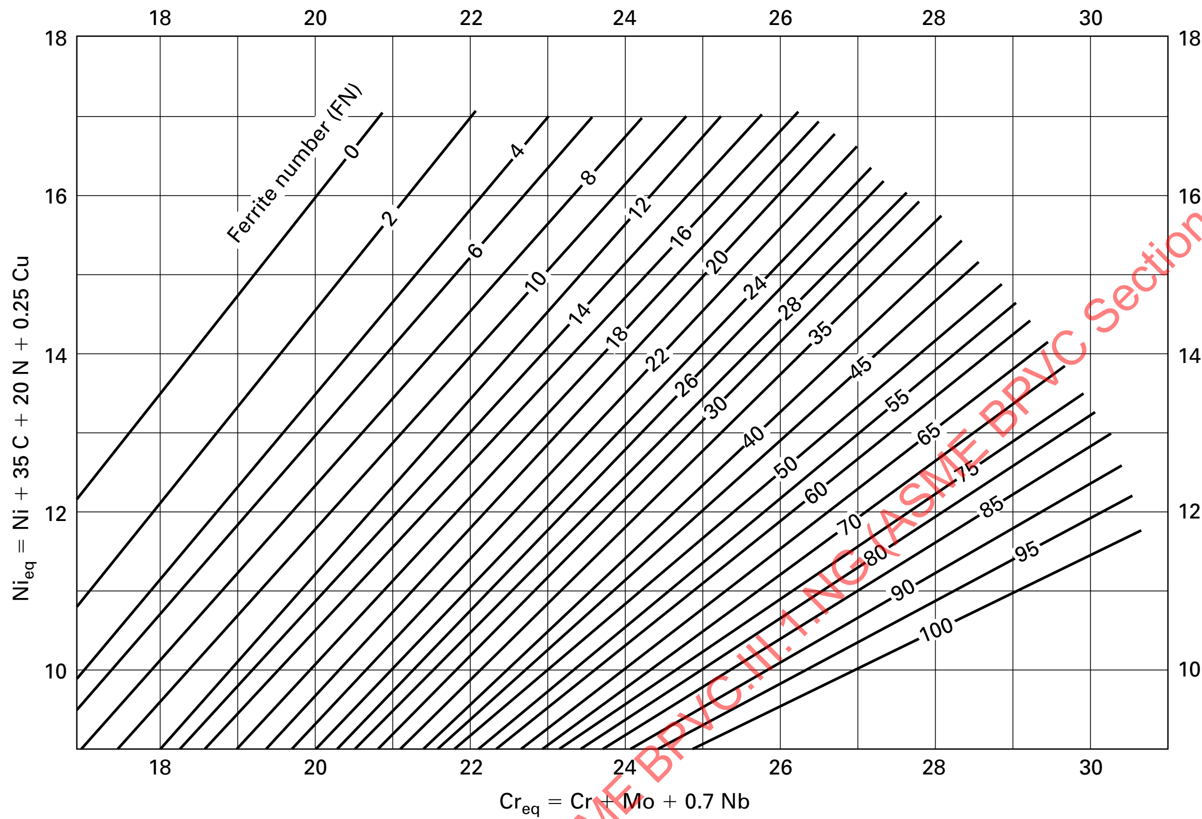
(b) The chemical composition of the weld metal or filler metal shall conform to the welding material specification for elements having specified percentage composition limits. Where the Welding Procedure Specification contains a modification of the composition limits of SFA or other referenced welding 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-3862.1. Elements listed in Table NG-2432.2-1 but not specified in the welding material specification shall be reported for information only.

Table NG-2432.2-1
Welding Material Chemical Analysis

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
Nickel and Ni-alloy materials	C, Cr, Mo, Ni, Mn, Si, S, Cb + Ta, Cu, Fe, Co

Figure NG-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.

NG-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-5.4, Type 16-8-2, or A-No. 8 weld filler metal to be used for weld metal cladding.

NG-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 NG-2432 in conjunction with Figure NG-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 NG-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).

NG-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 NG-2130 or NG-4120.

NG-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.

NG-2500 EXAMINATION AND REPAIR OF CORE SUPPORT STRUCTURE MATERIAL

NG-2510 EXAMINATION OF CORE SUPPORT STRUCTURE MATERIAL

Material for core support structures shall be examined by nondestructive methods applicable to the material and product form as required by the rules of this subarticle.

NG-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.

NG-2530 EXAMINATION AND REPAIR OF PLATE

NG-2531 Required Examination

All plates for core support structures greater than $^3/_4$ in. (19 mm) thickness shall be examined by the straight beam ultrasonic method in accordance with NG-2532.1.

NG-2532 Examination Procedures

NG-2532.1 Straight Beam Examination. The requirements for straight beam examination shall be in accordance with SA-578, as shown in Section V, except that the extent of examination and the acceptance standards to be applied are given in the following:

(a) Extent of Examination. 100% 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.

NG-2532.2 Angle Beam Examination. The requirements for angle beam examination shall be in accordance with SA-577, Specification for Ultrasonic Shear Wave Inspection of Steel Plates, as shown in Section V, as supplemented by this subparagraph. The calibration notch, extent of examination, and the acceptance standards to be applied are given in the following:

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

(b) Extent of Examination. 100% 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 which shows one or more imperfections which produce indications exceeding in amplitude the indication from the calibration notch is unacceptable.

NG-2537 Time of Examination

Acceptance examinations shall be performed at the time of manufacture as required in the following:

(a) Ultrasonic examination shall be performed after rolling to size and after heat treatment, except 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 in ferritic material 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. All repair welds in austenitic and nonferrous material may be liquid penetrant examined prior to any required postweld heat treatment.

NG-2538 Elimination of Surface Defects

Surface defects shall be removed by grinding or machining, provided the following requirements are met:

(a) The depression, after defect elimination, is blended uniformly into the surrounding surface with not less than a 3:1 taper.

(b) After defect elimination, the area is examined by the magnetic particle method in accordance with NG-2545 or the liquid penetrant method in accordance with NG-2546 to assure that the defect has been removed or reduced to an imperfection of an 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) If the elimination of the defect reduces the thickness of the section below the minimum required to satisfy the rules of Article NG-3000, the product shall be repaired in accordance with NG-2539.

NG-2539 Repair by Welding

Material from which defects have been removed may be repaired by welding, provided the requirements of the following subparagraphs are met. Prior approval of the Certificate Holder shall be obtained for any repair of plates to be used in the manufacture of core support structures.

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

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

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

NG-2539.4 Examination of Repair Welds. Each repair weld shall be examined by the magnetic particle method (NG-2545) or by the liquid penetrant method (NG-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 in accordance with Article NG-5000 and to the acceptance standards of NG-5320 or shall be ultrasonically examined after repair in accordance with NG-2532.2 or NG-2532.1.

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

NG-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 and, in addition, all repair welds exceeding an accumulated area of 20% of the area of the part or 15 in.^{2} (9 700 mm^2), whichever is less, shall be described in the Certified Material Test Report. The Certified Material Test Report for each piece shall include a chart which 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.

NG-2540 EXAMINATION AND REPAIR OF FORGINGS AND BARS

NG-2541 Required Examinations

(a) Forgings and bars except as noted in NG-2551 shall be examined by the ultrasonic method in accordance with NG-2542, except that forgings or sections of forgings which have coarse grains or configurations which do not yield meaningful examination results by ultrasonic methods shall be examined by radiographic methods in accordance with Section V, Article 2, and the acceptance standards of NG-5320. In addition, selected surfaces, as designated by the Certificate Holder, shall be liquid penetrant examined in accordance with NG-2546 or magnetic particle examined in accordance with NG-2545.

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

(c) Bar material used for threaded structural fasteners shall be examined in accordance with NG-2580.

NG-2542 Ultrasonic Examination

NG-2542.1 Examination Procedure. All forgings in the rough forged or finished condition, and bars, shall be examined in accordance with one of the following specifications: SA-745, Standard Practice for Ultrasonic Examination of Austenitic Steel Forgings; or SA-388, Recommended Practice for Ultrasonic Testing and Inspection of Heavy Steel Forgings, as shown in Section V, Article 23. Contact, immersion, or water column coupling is permissible. The following techniques are required, as applicable:

(a) All forgings and bars shall be examined by the ultrasonic method using the straight beam technique.

(b) Ring forgings and other hollow forgings shall, in addition, be examined using the angle beam technique in two circumferential directions, unless wall thickness or geometric configuration makes angle beam examination impractical.

(c) Forgings may be examined by the use of alternative ultrasonic methods which utilize distance amplitude corrections provided the acceptance standards are shown to be equivalent to those listed in NG-2542.2.

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

NG-2545 Magnetic Particle Examination

NG-2545.1 Examination Procedure. The procedure for magnetic particle examination shall be in accordance with the methods of Section V, Article 7.

NG-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 which are not relevant.

(b) Any indication in excess of the NG-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 which would mask defects are unacceptable.

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

NG-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

NG-2546 Liquid Penetrant Examination

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

NG-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 or surface conditions may produce similar indications which are not relevant.

(b) Any indication in excess of the NG-2546.3 acceptance standards that 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 which result from imperfections. Linear indications are indications in which the length is more than three times the width. Rounded indications are indications which are circular or elliptical with the length equal to or less than three times the width.

NG-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 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 relevant indications in a line separated by $^1/_{16}$ in. (1.6 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

NG-2547 Time of Examination

Acceptance examinations, including those for repair welds, shall be performed at the time of manufacture as required in the following:

(a) Ultrasonic examination may be performed at any time after forging, and the maximum practical volume 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.

NG-2548 Elimination of Surface Defects

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

NG-2549 Repair by Welding

Repair by welding shall be in accordance with NG-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 methods in accordance with the requirements of NG-2542 in lieu of radiography.

NG-2550 EXAMINATION AND REPAIR OF SEAMLESS AND WELDED TUBULAR PRODUCTS AND FITTINGS

NG-2551 Required Examination

(a) The examination performed shall be practical and yield meaningful pertinent information for the product form being examined. Certain examination methods are ineffective for some material conditions and product configuration. Some examples are

(1) it may not be practical or meaningful to examine irregular shapes such as welding flanges and fittings by ultrasonic methods

(2) ultrasonic examination employing special techniques is required on coarse-grained austenitic stainless steel or coarse-grained, nickel-base alloy materials

(b) Welded tubular products and fittings, including flanges and fittings, made from plate material greater than $^3/_4$ in. (19 mm) in thickness shall be ultrasonically or radiographically examined in accordance with NG-2552 or NG-2553.

(c) All welds in welded tubular products and fittings, including flanges and fittings, shall be ultrasonically or radiographically examined in accordance with NG-2552 or NG-2553. In addition, all welds shall be magnetic particle or liquid penetrant examined on all accessible surfaces in accordance with NG-2555 or NG-2556.

(d) Wrought seamless tubular products and fittings, including flanges and fittings machined from forgings and bars, greater than $^3/_8$ in. (10 mm) thickness shall be ultrasonically or radiographically examined in accordance with NG-2552 or NG-2553.

NG-2552 Ultrasonic Examination

NG-2552.1 Examination Procedure. The procedure for ultrasonic examination shall provide a sensitivity which will consistently detect defects that produce indications equal to and greater than the indication produced by standard defects included in the reference specimen specified in NG-2552.2. Products with defects that produce indications in excess of the indications produced by the standard defects in the reference specimens are unacceptable unless the defects are eliminated or repaired in accordance with NG-2558 or NG-2559, as applicable.

NG-2552.2 Reference Specimens.

(a) 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 which is being examined. The standard defects shall be axial notches or grooves on the outside and the 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), and a depth not greater than the larger of 0.004 in. (0.10 mm) or 5% of the nominal wall thickness. The reference specimen may be the product being examined.

(b) 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.

NG-2552.3 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

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

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

(c) at the end of the production run

(d) at any time that malfunctioning is suspected

If during any check it is determined that the testing equipment is not functioning properly, all of the product that has been tested since the last valid equipment calibration shall be reexamined.

NG-2553 Radiographic Examination

The radiographic examination shall be performed in accordance with Section V, Article 2, as modified by NG-5111, using the acceptance requirements of NG-5320.

NG-2555 Magnetic Particle Examination

The magnetic particle examination shall be performed in accordance with the requirements of NG-2545.

NG-2556 Liquid Penetrant Examination

The liquid penetrant examination shall be performed in accordance with the requirements of NG-2546.

NG-2557 Time of Examination

Time of acceptance examination, including that of repair welds, shall be in accordance with NG-2537.

NG-2558 Elimination of Surface Defects

Surface defects shall be removed by grinding or machining provided the following requirements 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 method which originally disclosed the defect to assure 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 NG-3000, the product shall be repaired in accordance with NG-2559.

NG-2559 Repair by Welding

Repair welding of base material defects shall be in accordance with NG-2539. Repair welding of seam defects shall be made in accordance with NG-4450.

NG-2570 EXAMINATION AND REPAIR OF STATICALLY AND CENTRIFUGALLY CAST PRODUCTS

NG-2571 Required Examinations

NG-2571.1 General Requirements. The portion of castings, as specified by the Design Specifications or drawings, used for core support structures shall be examined over the maximum feasible volume by radiographic methods, or ultrasonic methods, or a combination of both methods. Castings or sections of castings which have coarse grains or configurations which do not yield meaningful examination results by ultrasonic methods shall be examined by radiographic methods. In addition, the portion of castings used for core support structures shall be examined on accessible surfaces by either magnetic particle or liquid penetrant methods. Accessible machined surfaces, except threaded surfaces, of a cast product shall be examined by either liquid penetrant or magnetic particle methods after machining.

NG-2571.2 Alternative General Requirements. The portion of castings 2 in. (50 mm) thick and less, which are specified by the Design Specifications or drawings to be used for core support structures, may be utilized when the following requirements are met:

(a) The design stress intensity values in Section II, Part D, Subpart 1, Tables 2A and 2B are reduced by applying a quality factor of 0.75.

(b) A fatigue strength reduction factor of 2.0 is applied to the allowable S_a values when peak stresses are considered.

(c) The portions of castings used as core support structures are magnetic particle or liquid penetrant examined per NG-2575 or NG-2576 on all accessible as-cast or, if machined, machine-finished surfaces. The acceptance criteria of NG-2575 or NG-2576 shall be utilized except that no linear indications greater than $^1/_{16}$ in. (1.5 mm) are permitted.

(d) Five pilot castings[10] made from a new or altered design of a production run[11] shall be radiographically examined over the maximum feasible volume to the requirements of NG-2573.1. If all five pilot castings meet the radiographic acceptance criteria, a production run may be poured. The production run shall be examined using either of the sampling plans specified in (1) or (2) below. The five pilot castings, having passed examination, are not to be included in the following sampling examination programs:

(1) The production run shall be considered a single lot. Twenty castings shall be randomly selected from the production run and examined to the requirements of the pilot castings. The production run is accepted if all 20 castings meet the examination requirements and it is rejected if any one of the 20 castings does not meet the examination requirements. Acceptable castings may be retrieved from a rejected production run by examining all castings from that production run.

(2) The production run castings shall, in order of manufacture, be grouped into sublots with a maximum of 25 castings each. Five castings shall be randomly selected from each sublot and examined to the requirements of the pilot castings. The sublot is accepted if all five castings meet the examination requirements and it is rejected if any one of the five castings does not meet the examination requirements. In the event two sublots are rejected by the sampling examination, succeeding sublots shall have eight castings randomly selected for examination to the requirements of the pilot castings. In any event, acceptable castings may be retrieved from a rejected sublot by examining all castings from that sublot.

NG-2572 Ultrasonic Examination of Castings

The requirements for ultrasonic examination of statically and centrifugally cast products are given in the following subparagraphs.

NG-2572.1 Straight Beam Method. When castings are to be examined ultrasonically, all sections, regardless of thickness, shall be examined in accordance with SA-609, Standard Method and Specification for Longitudinal Beam Ultrasonic Inspection of Carbon and Low Alloy Castings, as shown in Section V; however, supplementary angle beam examination in accordance with NG-2572.2 or radiographic examination in accordance with NG-2573 shall be performed in areas where a back reflection cannot be maintained during the straight beam examination, or where the angle between the two surfaces of the casting is more than 15 deg.

NG-2572.2 Angle Beam Method. Examination shall be conducted in accordance with Section V, Article 5, T-571.4, except that the acceptance standards in Section V do not apply.

NG-2572.3 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. to 4 in. (50 mm to 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), the requirements in (1) through (5) shall apply for both straight beam and angle beam examination.

(1) Area imperfections producing 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 [Notes (1)–(3)]
1	1.5 in. (38 mm)
2	2.0 in. (50 mm)
3	2.5 in. (64 mm)
4	3.0 in. (75 mm)

NOTES:

(1) The areas for the Ultrasonic Quality Levels in SA-609 as shown in Section V refer to the surface area on the casting over which a 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 which 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) Imperfections indicated to have a change in depth equal to or greater than one-half the wall thickness or 1 in., whichever is less, are unacceptable.

(4) Two or more imperfections in the same plane with indication amplitudes exceeding the Amplitude Reference Line and separated by a distance less than the longest dimension of the larger of the adjacent imperfections 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 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 thickness 2 in. through 4 in. (50 mm to 100 mm), and greater than permitted for Quality Level 3 for thickness greater than 4 in. (100 mm), separated by a distance less than the longest dimension of the larger of the adjacent imperfections, are unacceptable if they cannot be encompassed in an area less than that of the Quality Level requirements stated in (a) above.

NG-2573 Radiographic Examination

NG-2573.1 Extent, Methods, and Acceptance Standards. Radiographic examination, where required, shall be performed on castings used for core support structures. The radiographic methods shall be in accordance with ASTM E94, Recommended Practice for Radiographic Testing, and ASTM E142, Controlling Quality of Radiographic Testing, and shall meet the acceptance requirements of Severity Level 3 for Category A and B defects and Severity Level 2 for Category C defects of ASTM E446,[12] Reference Radiographs for Steel Castings Up To 2 in. (50 mm) In Thickness, ASTM E186,[12] Reference Radiographs for Heavy-Walled [2 to 4½ in. (50 mm to 114 mm)] Steel Castings, or ASTM E280,[12] Reference Radiographs for Heavy-Walled [4½ 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. ASTM E280[12] shall also apply for castings over 12 in. (300 mm) in thickness.

NG-2573.2 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 technique, 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 NG-2573.1 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.

NG-2575 Magnetic Particle Examination

The magnetic particle examination, when required, shall be performed in accordance with the requirements of NG-2545.

NG-2576 Liquid Penetrant Examination

The liquid penetrant examination, when required, shall be performed in accordance with the requirements of NG-2546.

NG-2577 Time of Examination

Acceptance examinations, including those for weld repairs, shall be performed as stipulated in the following subparagraphs.

NG-2577.1 Ultrasonic Examination. Ultrasonic examination, if required, shall be performed at the stage of manufacture as required for radiography.

NG-2577.2 Radiographic Examination.

(a) Radiography shall be performed after final heat treatment as required by the material specification, except radiography may be performed prior to postweld heat treatment. The examination shall be performed at the stage of manufacture defined in this subparagraph.

(b) Castings prior to finish machining shall be radiographed at the limiting thicknesses stipulated in the following:

(1) For thicknesses less than 2 in. (50 mm), castings shall be radiographed within 50% of the finished thickness. The image quality indicator (IQI) shall be based on the final thickness.

(2) For thicknesses less than 6 in. (150 mm) but greater than 2 in. (50 mm), castings shall be radiographed within 20% of the finished thickness. The IQI shall be based on the final thickness.

(3) For thicknesses 6 in. (150 mm) and greater, castings shall be radiographed within 10% of the finished thickness. The IQI shall be based on the final thickness.

(4) Where casting practices for core support structure sections require thickness to exceed the finished machined thickness limits of (2) and (3) above, radiography of the as-cast thickness is acceptable provided the acceptance reference radiographs of the next lesser thickness are met in those areas; e.g., if the section being radiographed exceeds $4\frac{1}{2}$ in. (114 mm), use ASTM E186[12] reference radiographs. The IQI shall be based on the thickness of the section being radiographed.

NG-2577.3 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 material, 2 in. (50 mm) nominal thickness and less, may be examined prior to postweld heat treatment. For cast products with machined surfaces, all accessible finished machined surfaces, except threaded surfaces, shall also be examined by magnetic particle or liquid penetrant methods.

NG-2578 Elimination of Surface Defects

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

NG-2579 Repair by Welding

The Material Organization may repair castings by welding after removing the material containing 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 in accordance with the requirements of Article NG-4000 by a Certificate of Authorization Holder.

NG-2579.1 Defect Removal. The defect shall be removed or reduced to an imperfection of an 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.

NG-2579.2 Qualification of Welding Procedures and Welders. The welding procedure and welders or welding operators shall be qualified in accordance with Article NG-4000 and Section IX.

NG-2579.3 Blending of Repaired Areas. After welding, the surface shall be blended uniformly into the surrounding surface.

NG-2579.4 Examination of Repair Welds. Each repair weld shall be examined by the magnetic particle method (NG-2545) or by the liquid penetrant method (NG-2546). In addition, repair welds in cavities the depth of which exceeds the lesser of $\frac{3}{8}$ in. (10 mm) or 10% of the section thickness shall be radiographed in accordance with NG-2573. The radiographic method and acceptance standards of NG-2573 shall apply 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.

NG-2579.5 Heat Treatment After Weld Repair. After repair, the casting shall be heat-treated in accordance with NG-4620, except that the heating and cooling limitations of NG-4623 do not apply.

NG-2579.6 Material Report Describing Defects and Repairs. Each repair weld exceeding in depth either $\frac{3}{8}$ in. (10 mm) or 10% of the section thickness shall be described in the Certified Material Test Report. The Certified Material Test Report shall include a chart for each repaired casting which shows the location and size of the repaired cavity, the welding material identification, the welding procedure, the heat treatment, and the examination results, including radiographs.

NG-2580 EXAMINATION OF THREADED STRUCTURAL FASTENERS

NG-2581 Required Examinations

Threaded structural fasteners shall be visually examined in accordance with NG-2582. In addition, externally threaded structural fasteners $^3/_8$ in. (10 mm) and greater and nuts greater than 1 in. (25 mm) shall be examined by either the magnetic particle or liquid penetrant method in accordance with NG-2583. In addition, nominal sizes greater than $^1/_2$ in. (13 mm) but not over 4 in. (100 mm) shall be examined by ultrasonic methods in accordance with NG-2584, and nominal sizes greater than 4 in. (100 mm) shall be examined by ultrasonic methods in accordance with both NG-2584 and NG-2585.

NG-2582 Visual Examination

The final surfaces of threads, shanks, and heads of externally threaded structural fasteners less than $^3/_8$ in. (10 mm) and nuts 1 in. (25 mm) and smaller shall be visually examined for workmanship, finish, and appearance in accordance with the requirements of ASTM F788 for threaded structural fasteners and ASTM F812 for nuts prior to plating or other surface protection-type treatments. 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 NG-5100 or by personnel qualified in accordance with NG-5500.

NG-2583 Magnetic Particle or Liquid Penetrant Examination

Externally threaded structural fasteners $^3/_8$ in. (10 mm) and greater and nuts greater than 1 in. (25 mm) shall be examined by a magnetic particle method (NG-2545) or a liquid penetrant method (NG-2546). Such examination shall be performed on the finished threaded structural fastener after threading and prior to plating or other surface protection type treatments. On threaded surfaces no relevant indications are permitted. Relevant indications include any linear indications or rounded indications greater than $^1/_{16}$ in. (1.5 mm). Indications, caused by a particular manufacturing method, that may appear to be relevant, such as the crest of rolled threads or root of cut threads, may be shown to be nonrelevant and acceptable by prior process qualification or destructive metallographic examination. On all other accessible surfaces, no linear indications or rounded indications greater than $^1/_{16}$ in. (1.5 mm) are permitted, except that linear axial indications less than one diameter or 1 in. (25 mm) in length are permitted.

NG-2584 Ultrasonic Examination for Sizes Greater Than $^1/_2$ in. (13 mm)

All threaded structural fasteners greater than $^1/_2$ in. (13 mm) nominal bolt size shall be ultrasonically examined over the entire cylindrical surface prior to threading, in accordance with the requirements of the following subparagraphs.

NG-2584.1 Ultrasonic Method. Examination shall be carried out by the straight beam, radial scan method.

NG-2584.2 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^2). (21)

NG-2584.3 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.

NG-2584.4 Acceptance Standards. Any imperfection which causes an indication in excess of 20% of the height of the first back reflection or any imperfection which prevents the production of a first back reflection of 50% of the calibration amplitude is not acceptable.

NG-2585 Ultrasonic Examination for Sizes Over 4 in. (100 mm)

In addition to the requirements of NG-2584, all threaded structural fasteners over 4 in. (100 mm) shall be ultrasonically examined over the entire surface of each end before or after threading in accordance with the requirements of the following subparagraphs.

NG-2585.1 Ultrasonic Method. Examination shall be carried out by the straight beam, longitudinal mode scan method.

NG-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 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). (21)

NG-2585.3 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 × 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 correction curve shall be established by scanning from both ends of the test bar.

NG-2585.4 Acceptance Standards. Any imperfection which causes an indication in excess of 50% of that produced by the calibration hole in the reference specimen, as corrected by the distance–amplitude correction curve, is not acceptable.

NG-2586 Elimination of Surface Defects

Surface defects may be eliminated by grinding or machining, provided the final dimension of the affected portion meets the requirements of the design and the area is reexamined by the magnetic particle or liquid penetrant method in accordance with NG-2583.

NG-2600 MATERIAL ORGANIZATIONS' QUALITY SYSTEM PROGRAMS

NG-2610 DOCUMENTATION AND MAINTENANCE OF QUALITY SYSTEM PROGRAMS

(a) Except as provided in (b) below, Material Organizations shall have a Quality System Program that meets the requirements of NCA-3800.

(b) The requirements of NCA-3862 shall be met as required by NG-2130. The other requirements of NCA-3800 and NCA-4200 need not be used by Material Organizations for small products, as defined in (c), and for material which 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 special requirements of this Subsection.

(c) For the purpose of this paragraph, small products are defined as given in the following:

(1) pipe, tube (except heat exchanger tube), pipe fittings, and flanges 2 in. nominal pipe size (DN 50) and less

(2) threaded structural fastener material, including studs and nuts 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

ARTICLE NG-3000
DESIGN

NG-3100 GENERAL DESIGN

NG-3110 LOADING CRITERIA

NG-3111 Loading Conditions

The loadings that shall be taken into account in designing core support structures include, but are not limited to, those in the following:

(a) pressure differences due to coolant flow

(b) weight of the core support structure

(c) superimposed loads such as those due to other structures, the reactor core, steam separating equipment, flow distributors and baffles, thermal shields, and safety equipment

(d) earthquake loads or other loads which result from motion of the reactor vessel

(e) reactions from supports, restraints, or both

(f) loads due to temperature effects, thermal gradients and differential expansion, or both

(g) loads resulting from the impingement or flow of reactor coolant, or other contained or surrounding fluids

(h) transient pressure difference loads, such as those which result from rupture of the main coolant pipe

(i) vibratory loads

(j) loads resulting from the operation of machinery, such as snubbing of control rods

(k) handling loads experienced in preparation for or during refueling or in-service inspection

NG-3112 Design Loadings

The Design Loadings are the pressure differences, temperatures, and various forces applicable to the design of core support structures as defined in the following subparagraphs.

NG-3112.1 Design Pressure Difference.

(a) The specified internal and external Design Pressure Difference shall be established in accordance with NCA-2142.1(a). It shall be used in the computations made to show compliance with the stress intensity limits of NG-3221, NG-3227.1, NG-3227.2, NG-3227.4, NG-3228.1, NG-3228.2, and NG-3231. The actual service pressure difference at the appropriate time shall be used in the computations made to show compliance with the stress intensity limits of NG-3222, NG-3228.3, and NG-3232. When the occurrence of different pressure differences during service can be predicted for different zones of a structure, the Design Pressure Difference of the different zones may be based on their predicted pressure difference.

(b) The Design Pressure Difference shall include allowances for pressure difference surges.

NG-3112.2 Design Temperature. The Design Temperature shall be established in accordance with NCA-2142.1(b). It shall be used in computations involving the Design Pressure Difference 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 actual service pressure difference is required.

(a) All temperatures referred to in this Article are the metal temperatures expressed in degrees Fahrenheit (°F) [degrees Celsius (°C)].

(b) Where a core support structure 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.

NG-3112.3 Design Mechanical Loads. The specific combinations and values of mechanical loadings which must be considered in conjunction with the Design Pressure Difference and Design Temperature in evaluating the requirements of NG-3221.1 and NG-3221.2 shall be those identified in the Design Specifications (NCA-3250) and designated as the Design Mechanical Loads in accordance with NCA-2142.1(c). The actual mechanical loads at the appropriate time shall be used in the computations made to show compliance with the stress intensity limits of NG-3222.2 and NG-3222.4. The following requirements shall also apply:

(a) Impact forces caused by either external or internal conditions shall be considered.

(b) The effects of earthquake shall be considered in the design of core support structures. The loadings, movements, and number of cycles to be used in the analysis shall be part of the Design Specifications. The stresses resulting from these earthquake effects shall be included with pressure differences or other applied loads.

(c) Core support structures shall be arranged and supported so that vibration will be minimized.

NG-3112.4 Design Stress Intensity Values. Design stress intensity values for materials are listed in Section II, Part D, Subpart 1, Tables 2A and 2B. The material shall not be used at metal temperatures 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.

NG-3113 Service Loadings

Each loading to which the structure 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 these rules.

NG-3120 SPECIAL CONSIDERATIONS

NG-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 structure 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 structure 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 which might accelerate fatigue failure.

NG-3122 Cladding

The rules of this paragraph apply to the design analysis of clad structures constructed of material permitted in Section II, Part D, Subpart 1, Tables 2A and 2B.

NG-3122.1 Primary Stresses. No structural strength shall be attributed to the cladding in satisfying NG-3221.1 and NG-3221.3.

NG-3122.2 Design Dimensions. The dimensions given in (a) and (b) shall be used in the design of the component.

(a) For structures subjected to internal pressure difference, the inside diameter shall be taken at the nominal inner face of the cladding.

(b) For structures subjected to external pressure difference, the outside diameter shall be taken at the outer face of the base metal.

NG-3122.3 Secondary and Peak Stresses. In satisfying NG-3222.2 and NG-3222.4(b), 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 NG-3222.2 and NG-3222.4(b). 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 structure, the presence of the cladding may be neglected.

NG-3122.4 Bearing Stresses. In satisfying NG-3227.1, the presence of cladding shall be included.

NG-3123 Welds Between Dissimilar Metals

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.

NG-3124 Environmental Effects

Changes in material properties may occur due to environmental effects. In particular, fast (>1 MeV) neutron irradiation 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, structural discontinuities in ferritic structures should preferably not be placed in regions of high neutron flux.

NG-3130 GENERAL DESIGN RULES

NG-3131 Scope

Design rules generally applicable to core support structures are provided in the following paragraphs.

NG-3132 Reinforcement for Openings

The rules for reinforcing applicable to Class 1 vessels and piping may be used in the design of core support structures if stipulated in the Design Specifications.

NG-3133 External Pressure Difference

NG-3133.1 General. Rules are given in this paragraph for determining the stresses under external pressure difference loading in spherical shells, 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.

NG-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 NG-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

D_o = outside diameter of the cylindrical shell course or tube under consideration

E = modulus of elasticity of material at Design Temperature (for this value, see Section II, Part D, Subpart 2, Table TM). Use the curve with this value on the material/temperature line of the applicable chart in Section II, Part D, Subpart 3.

I = available moment of inertia of the combined ring–shell section about its neutral axis, parallel to the axis of the shell, in.[4] (mm[4]). The width of the shell which 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 cylindrical 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 cylinder, in. (mm)

L_s = one-half of 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) a circumferential connection to a jacket for a jacketed section of a cylindrical shell

P = external design pressure (gage or absolute, as required)

P_a = allowable external pressure (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

T = minimum required thickness of cylindrical shell or tube, or spherical shell

T_n = nominal thickness used, less corrosion allowance, of a cylindrical shell or tube

NG-3133.3 Cylindrical Shells and Tubular Products.

(a) The minimum thickness of cylindrical shells or tubular products under external pressure difference having D_o/T values equal to or greater than 10 shall be determined by the procedure given in Steps 1 through 8.

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 downwards 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 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 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 pressure difference P_a by 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 difference having D_o/T values less than 10 shall be determined by the procedure given in Steps 1 through 4.

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.

NG-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.

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 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 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 Steps 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.

NG-3133.5 Stiffening Rings for Cylindrical Shells.

(a) The required moment of inertia of the combined ring–shell section is given by the following 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.

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 NG-3133.2. Then calculate B by the following 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 5.

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.

NG-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).

(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, in. (mm)

T = minimum required thickness of the shell or tubular product, exclusive of the corrosion allowance, in. (mm)

The value of B shall be determined from the applicable chart contained in Section II, Part D, Subpart 3 in the manner given in Steps 1 through 5.

Step 1. Using the selected values of T and R, calculate the value of factor A using the following equation:

$$A = 0.125 / (R/T)$$

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:

$$B = AE/2$$

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 which is greater than the compressive stress computed for the loading on the cylindrical shell or tube.

NG-3200 DESIGN BY ANALYSIS

NG-3210 DESIGN CRITERIA

NG-3211 Requirements for Acceptability (21)

The requirements for the acceptability of a design by analysis are those set forth in (a) through (d).

(a) The design shall be such that stress intensities will not exceed the limits of NG-3200 using the design stress intensity values S_m as tabulated in Section II, Part D, Subpart 1, Tables 2A and 2B.

(b) The design details shall conform to the rules given in NG-3100 and NG-3350.

(c) For configurations where compressive stresses occur, in addition to the requirements in (a) and (b), the critical buckling stress shall be taken into account.

(1) For the special case of external pressure difference, see NG-3133. Where dynamic pressure differences are involved, the permissible external pressure difference shall satisfy the requirements of NG-3133 or be limited to 25% of the dynamic instability pressure difference due to Level A Service Loadings.

(2) For all other loadings, buckling shall be considered by performing an evaluation of service and test conditions. Subsection NF provides acceptable methods for plate- and shell-type supports in NF-3220 and linear-type supports in NF-3320.

(d) Protection against nonductile fracture shall be provided. An acceptable procedure for nonductile failure prevention is given in Section III Appendices, Nonmandatory Appendix G.

NG-3212 Basis for Determining Stresses

The theory of failure used in the rules of this Subsection for combining stresses is the maximum shear stress theory unless otherwise permitted by this Subsection. The maximum shear stress at a point is equal to one-half the difference between the algebraically largest and the algebraically smallest of the three principal stresses at the point.

NG-3213 Terms Relating to Stress Analysis

Terms used in this Subsection relating to stress analysis are defined in the following subparagraphs.

NG-3213.1 Stress Intensity. Stress intensity is defined as twice the maximum shear stress, which is the difference between the algebraically largest principal stress and the algebraically smallest principal stress at a given point. Tensile stresses are considered positive and compressive stresses are considered negative.

This definition of stress intensity is not related to the definition of stress intensity applied in the field of Fracture Mechanics.

NG-3213.2 Gross Structural Discontinuity. Gross structural discontinuity is a geometric or material discontinuity that affects the stress or strain distribution through the entire wall thickness. Gross discontinuity-type stresses are those portions of the actual stress distributions that produce net bending and membrane force resultants when integrated through the wall thickness. Examples of a gross structural discontinuity are head-to-shell junctions, flange-to-shell junctions, nozzles, and junctions between shells of different diameters or thicknesses.

NG-3213.3 Local Structural Discontinuity. Local structural discontinuity is a geometric or material discontinuity that affects the stress or strain distribution through a fractional part of the wall thickness. The stress distribution associated with a local discontinuity causes only very localized deformation or strain and has no significant effect on the shell-type discontinuity deformations. Examples are small fillet radii, small attachments, and partial penetration welds.

NG-3213.4 Normal Stress. Normal stress is the component of stress normal to the plane of reference. This is also referred to as direct stress. Usually the distribution of normal stress is not uniform through the thickness of a part, so this stress is considered to have two components — one uniformly distributed and equal to the average stress across the thickness under consideration, and the other varying from this average value across the thickness.

NG-3213.5 Shear Stress. Shear stress is the component of stress tangent to the plane of reference.

NG-3213.6 Membrane Stress. Membrane stress is the component of normal stress that is uniformly distributed and equal to the average stress across the thickness of the section under consideration.

NG-3213.7 Bending Stress. Bending stress is the component of normal stress that varies across the thickness. The variation may or may not be linear.

NG-3213.8 Primary Stress. Primary stress is any normal stress or shear stress developed by an imposed loading that is necessary to satisfy the laws of equilibrium of external and internal forces and moments. The basic characteristic of a primary stress is that it is not self-limiting. Primary stresses that considerably exceed the yield strength will result in failure or, at least, in gross distortion. Primary membrane stress is divided into general and local categories. A general primary membrane stress is one that is so distributed in the structure that no redistribution of load occurs as a result of yielding. Examples of primary stress are

(a) general membrane stress in a circular cylindrical shell or a spherical shell due to internal pressure or to distributed loads

(b) bending stress in the central portion of a flat head due to pressure

Refer to Table NG-3217-1 for examples of primary stress.

NG-3213.9 Secondary Stress. Secondary stress is a normal stress or a shear stress developed by the constraint of adjacent material or by self-constraint of the structure. The basic characteristic of a secondary stress is that it is self-limiting. Local yielding and minor distortions can satisfy the conditions that cause the stress to occur and failure from one application of the stress is not to be expected. Examples of secondary stress are

(a) general thermal stress [NG-3213.12(a)]

(b) bending stress at a gross structural discontinuity

Refer to Table NG-3217-1 for examples of secondary stress.

NG-3213.10 Peak Stress. Peak stress is that increment of stress that is additive to the primary plus secondary stresses by reason of local discontinuities or local thermal stress [NG-3213.12(b)] including the effects, if any, of stress concentrations. The basic characteristic of a peak stress is that it does not cause any noticeable distortion and is objectionable only as a possible source of a fatigue crack or a brittle fracture. A stress that is not highly localized falls into this category if it is of a type that cannot cause noticeable distortion. Examples of peak stress are

(a) the thermal stress in the austenitic steel cladding of a carbon steel part

(b) certain thermal stresses that may cause fatigue but not distortion

(c) the stress at a local structural discontinuity

(d) surface stresses produced by thermal shock

NG-3213.11 Load-Controlled Stress. Load-controlled stress is the stress resulting from application of a loading, such as pressure difference, inertial loads, or gravity, whose magnitude is not reduced as a result of displacement.

NG-3213.12 Thermal Stress. Thermal stress is a self-balancing stress produced by a nonuniform distribution of temperature or by differing thermal coefficients of expansion. Thermal stress is developed in a solid body whenever a volume of material is prevented from assuming the size and shape that it normally would under a change in temperature. For the purpose of establishing allowable stresses, two types of thermal stress are recognized, depending on the volume or area in which distortion takes place, as described in (a) and (b) below.

(a) General thermal stress is associated with distortion of the structure in which it occurs. If a stress of this type, neglecting stress concentrations, exceeds twice the yield strength of the material, the elastic analysis may be invalid and successive thermal cycles may produce incremental distortion. Therefore this type is classified as secondary stress in Table NG-3217-1. Examples of general thermal stress are

(1) stress produced by an axial temperature distribution in a cylindrical shell

(2) stress produced by the temperature difference between a nozzle and the shell to which it is attached

(3) the equivalent linear stress produced by the radial temperature distribution in a cylindrical shell. Equivalent linear stress is defined as the linear stress distribution that has the same net bending moment as the actual stress distribution.

(b) Local thermal stress is associated with almost complete suppression of the differential expansion and thus produces no significant distortion. Such stresses shall be considered only from the fatigue standpoint and are therefore classified as peak stresses in Table NG-3217-1. In evaluating local thermal stresses the procedures of NG-3227.6(b) shall be used. Examples of local thermal stress are

(1) the stress in a small hot spot in a vessel wall

(2) the difference between the actual stress and the equivalent linear stress [(a)(3)] resulting from a radial temperature distribution in a cylindrical shell

(3) the thermal stress in a cladding material that has a coefficient of expansion different from that of the base metal

NG-3213.13 Total Stress. Total stress is the sum of the primary, secondary, and peak stress contributions. Recognition of each of the individual contributions is essential to establishment of appropriate stress limitations.

NG-3213.14 Service Cycle. Service cycle is defined as the initiation and establishment of new conditions followed by a return to the conditions that prevailed at the beginning of the cycle. The types of service conditions that may occur are further defined in NG-3113.

NG-3213.15 Stress Cycle. Stress cycle is a condition in which the alternating stress difference [NG-3222.4(e)] goes from an initial value through an algebraic maximum value and an algebraic minimum value, then returns to the initial value. A single service cycle may result in one or more stress cycles. Dynamic effects shall also be considered as stress cycles.

NG-3213.16 Fatigue Strength Reduction Factor. (21) Fatigue strength reduction factor is a stress intensification factor that accounts for the effect of a local structural discontinuity (stress concentration) on the fatigue strength. A theoretical stress concentration factor or stress index may be used. A fatigue strength reduction factor or stress index may be determined using the procedures in Section III Appendices, Mandatory Appendix II.

NG-3213.17 Shakedown. Shakedown of a structure (21) occurs if, after a few cycles of load application, ratcheting ceases. The subsequent structural response is elastic, or elastic–plastic, and progressive incremental inelastic deformation is absent. Elastic shakedown is the case in which the subsequent response is elastic.

NG-3213.18 Free End Displacement. Free end displacement consists of the relative motions that would occur between an attachment and connected structure or equipment if the two members were separated. Examples of such motions are those that would occur because of relative thermal expansion of piping, equipment, and equipment supports or because of rotations imposed upon the equipment.

NG-3213.19 Limit Analysis. Limit analysis is a special (21) case of plastic analysis in which the material is assumed to be ideally plastic (non-strain-hardening). In limit analysis, the equilibrium and flow characteristics at the limit state are used to calculate the collapse load. The two bounding methods used in limit analysis are the lower bound approach, which is associated with a statically admissible stress field, and the upper bound approach, which is associated with a kinematically admissible velocity field. For beams and frames, the term "mechanism" is commonly used in lieu of "kinematically admissible velocity field."

NG-3213.20 Limit Analysis — Collapse Load. The (21) methods of limit analysis are used to compute the maximum load or combination of loads a structure made of ideally plastic (nonstrain-hardening) material can carry. The deformations of an ideally plastic structure increase without bound at this load, which is termed the *collapse load*.

NG-3213.21 Lower Bound Limit Load. The lower bound (21) limit load, L_L, is that load, determined from the limit analysis (NG-3213.19), in which the material everywhere satisfies equilibrium and nowhere exceeds the defined material yield strength, using either the maximum shear stress theory or a strain energy of distortion theory to relate multiaxial yielding to the uniaxial case.

NG-3213.22 Stress Ratio Method. The methods of plastic analysis which utilize the stress ratio combinations are used to compute the maximum load a strain-hardened material can carry (Section III Appendices, Nonmandatory Appendix A, Article A-9000). Stress ratio combinations are combinations of stresses that consider the ratio of the calculated stress to the allowable plastic or elastic stress. These combinations are useful since the actual shape factor (function of cross section) and the type and magnitude of different stress fields may be considered in determining the load.

NG-3213.23 Ultimate Experimental Load. Ultimate experimental load, L_u, is the ultimate load or the maximum load or load combination used in an experimental test of a prototype or model (NG-3228.4).

NG-3214 Stress Analysis

A detailed stress analysis of all major structural components shall be prepared in sufficient detail to show that each of the stress limitations of NG-3220 and NG-3230 is satisfied when the core support structure is subjected to the loadings of NG-3110. As an aid to the evaluation of these stresses, equations and methods for the solution of certain recurring problems have been placed in Section III Appendices, Nonmandatory Appendix A.

(21) NG-3215 Derivation of Stress Intensities

This paragraph describes the procedure for the calculation of the stress intensities which are subject to the specified limits. The steps in the procedure are stipulated in (a) through (e).

Membrane stress is derived from the stress components averaged across the thickness of the section. The averaging shall be performed at the component level in (b) or (c) below.

(a) At the point on the component which is being investigated, choose an orthogonal set of coordinates, such as tangential, longitudinal, and radial, and designate them by the subscripts *t*, *l*, and *r*. The stress components in these directions are then designated σ_t, σ_l, and σ_r for direct stresses and τ_{lt}, τ_{lr}, and τ_{rt} for shear stresses.

(b) Calculate the stress components for each type of loading to which the part will be subjected and assign each set of stress values to one or a group of the following categories [see Table NG-3217-1 and Figure NG-3222-1, Note (4) and Note (5)].

(1) general primary membrane stress P_m (NG-3213.6 and NG-3213.8)

(2) primary bending stress P_b (NG-3213.7 and NG-3213.8)

(3) secondary stress Q (NG-3213.9)

(4) peak stress F (NG-3213.10)

(c) For each category, calculate the algebraic sum of the values of σ_t which result from the different types of loadings, and similarly for the other five stress components. Certain combinations of the categories must also be considered.

(d) Translate the stress components for the *t*, *l*, and *r* directions into principal stresses σ_1, σ_2, and σ_3. In many pressure component calculations, the *t*, *l*, and *r* directions may be so chosen that the shear stress components are zero and σ_1, σ_2, and σ_3 are identical to σ_t, σ_l, and σ_r.

(e) Calculate the stress differences S_{12}, S_{23}, and S_{31} from the relations

$$S_{12} = \sigma_1 - \sigma_2$$

$$S_{23} = \sigma_2 - \sigma_3$$

$$S_{31} = \sigma_3 - \sigma_1$$

The stress intensity S is the largest absolute value of S_{12}, S_{23}, and S_{31}.

NG-3216 Derivation of Stress Differences for Evaluation of Cyclic Operation (21)

The evaluation of the primary plus secondary plus peak stresses requires the calculation of the cyclic stress ranges due to the loadings for which Level A and Level B Service Limits are specified. The determination of the stress ranges shall be made on the basis of the stresses at a point on the structure using the process defined below. If the specified operation of the structure does not meet the conditions of NG-3222.4(d), the ability of the structure to withstand the specified cyclic service without fatigue failure shall be determined as provided in NG-3222.4(e). Only the stress differences due to cyclic Level A and Level B loadings as specified in the Design Specifications need be considered.

NG-3216.1 Constant Principal Stress Direction. For (21)
any case in which the directions of the principal stresses at the point being considered do not change during the cycle, the steps stipulated in (a) through (c) shall be taken to determine the alternating stress intensity.

(a) Principal Stresses. Consider the values of the three principal stresses at the point versus time for the complete stress cycle, taking into account both the gross and local structural discontinuities and the thermal effects which vary during the cycle. These are designated as σ_1, σ_2, and σ_3 for later identification.

(b) Stress Differences. Determine the stress differences $S_{12} = \sigma_1 - \sigma_2$; $S_{23} = \sigma_2 - \sigma_3$; $S_{31} = \sigma_3 - \sigma_1$ versus time for the complete cycle. In what follows, the symbol S_{ij} is used to represent any one of these three stress differences.

(c) Alternating Stress Intensity. Determine the extremes of the range through which each stress difference S_{ij} fluctuates and find the absolute magnitude of this range for each S_{ij}. Call this magnitude S_{rij} and let $S_{\text{alt }ij} = 0.5S_{rij}$. The stress intensity range, S_r, for the stress cycle is the largest S_{rij}. The alternating stress intensity S_{alt} is the largest of the $S_{\text{alt }ij}$ values.

(21) **NG-3216.2 Varying Principal Stress Direction.** For any case in which the directions of the principal stresses at the point being considered do change during the stress cycle, it is necessary to use the more general procedure of (a) through (e).

(a) Consider the values of the six stress components σ_t, σ_l, σ_r, τ_{lt}, τ_{lr}, τ_{rt} versus time for the complete stress cycle, taking into account both the gross and local structural discontinuities and the thermal effects which vary during the cycle.

(b) Choose a point in time when the conditions are one of the extremes for the cycle (either maximum or minimum, algebraically) and identify the stress components at this time by the subscript i. In most cases it will be possible to choose at least one time during the cycle when the conditions are known to be extreme. In some cases it may be necessary to try different points in time to find the one which results in the largest value of alternating stress intensity.

(c) Subtract each of the six stress components σ_{ti}, σ_{li}, etc., from the corresponding stress components σ_t, σ_l, etc., at each point in time during the cycle and call the resulting components σ'_t, σ'_l, etc.

(d) At each point in time during the cycle, calculate the principal stresses σ'_1, σ'_2, σ'_3 derived from the six stress components σ'_t, σ'_l, etc. Note that the directions of the principal stresses may change during the cycle but each principal stress retains its identity as it rotates.

(e) Determine the stress differences $S'_{12} = \sigma'_1 - \sigma'_2$, $S'_{23} = \sigma'_2 - \sigma'_3$, $S'_{31} = \sigma'_3 - \sigma'_1$ versus time for the complete cycle. The largest absolute magnitude of any stress difference at any time is the stress intensity range, S_r. The alternating stress intensity S_{alt} is one-half of this magnitude.

NG-3217 Classification of Stress

Table NG-3217-1 provides examples in the determination of the classification to which a stress should be assigned.

(21) NG-3220 STRESS LIMITS FOR OTHER THAN THREADED STRUCTURAL FASTENERS

NG-3221 Design Loadings

The stress intensity limits which must be satisfied for the Design Loadings (NG-3112) stated in the Design Specifications are the three limits of this paragraph and the special stress limits of NG-3227. The provisions of NG-3228 may provide relief from certain of these stress limits. The design stress intensity values S_m are given by NG-3229. The limits are summarized by Figure NG-3221-1.

NG-3221.1 General Primary Membrane Stress Intensity. This stress intensity (derived from P_m in Figure NG-3221-1) is derived from the average value across the thickness of a section of the general primary stresses (see NG-3213.8) produced by design internal pressure difference and other specified Design Mechanical Loads, but excluding all secondary and peak stresses. Averaging is to be applied to the stress components prior to determination of the stress intensity values. The allowable value of the stress intensity is S_m at the Design Temperature.

NG-3221.2 Primary Membrane Plus Primary Bending Stress Intensity. This stress intensity (derived from $P_m + P_b$ in Figure NG-3221-1) is derived from the highest value across the thickness of a section of the general primary membrane stresses plus primary bending stresses produced by Design Pressure Difference and other specified Design Mechanical Loads, but excluding all secondary and peak stresses. The allowable value of this stress intensity is $1.5S_m$.

NG-3221.3 External Pressure Difference. The provisions of NG-3133 apply.

NG-3222 Level A Service Limits

The Level A Service Limits must be satisfied for the Service Conditions [NCA-2142.4(b)(1)] for which these limits are designated in the Design Specifications and are the limits of this paragraph and NG-3227. The provisions of NG-3228 may provide relief from certain of these stress limits. The design stress intensity values S_m are given by NG-3229. The limits are summarized by Figure NG-3222-1.

NG-3222.1 General Primary Membrane and Primary Membrane Plus Primary Bending Stress Intensities. Primary stress intensities must be computed and satisfy the limits of NG-3221.

NG-3222.2 Primary Plus Secondary Stress Intensity Range. (21)

(a) The primary plus secondary stress intensity range is derived from $P_m + P_b + Q$ in Figure NG-3222-1. The primary plus secondary stress at a point includes the general primary membrane stress, plus the primary bending stress, plus the secondary stress. These stresses are produced by the specified service pressure differences and other specified mechanical loads, and by general thermal effects associated with the Service Loadings. The primary plus secondary stress intensity range is the absolute value of maximum stress difference range over the life of the component due to the specified Level A and Level B Service Loadings. The allowable value of the primary plus secondary stress intensity range is $3S_m$, except for certain cyclic events which may exceed the $3S_m$ limit during the design life of the plant. For this exception, in lieu of meeting the $3S_m$ limit, an elastic–plastic fatigue analysis in accordance with NG-3228.3 may be performed to demonstrate that the cumulative fatigue usage attributable to the

Table NG-3217-1
Classification of Stress Intensity in Core Support Structures for Some Typical Cases

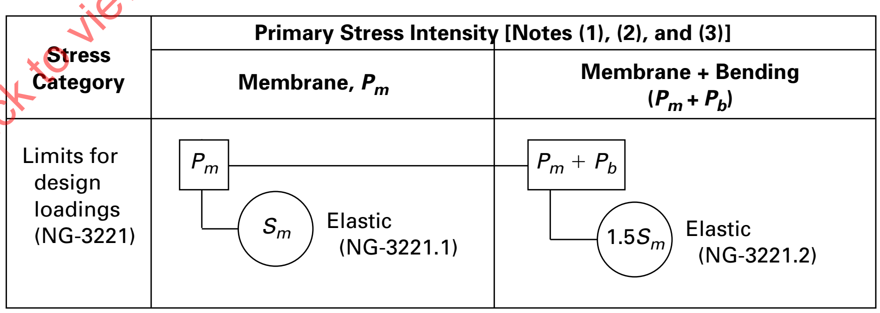
Core Support Structure	Location	Origin of Stress [Note (1)]	Type of Stress [Note (2)]	Classification	Discontinuity Gross	Discontinuity Local
Any shell or head	Any section across entire shell	External load	Membrane averaged across full section. Stress component perpendicular to cross section.	P_m	No	No
			Bending across full section. Stress component perpendicular to cross section.	P_m	No	No
		Self-limiting external load, thermal gradient, thermal expansion difference	Membrane and bending including gradient through plate thickness	Q	Yes	No
			Peak	F	Yes	Yes
	Junction with head or flange	Self-limiting external load, thermal gradient, thermal expansion difference	Membrane and bending	Q	Yes	No
			Peak	F	Yes	Yes
	Near nozzle or other opening	Self-limiting external load, thermal gradient, thermal expansion difference	Membrane and bending	Q	Yes	No
			Peak	F	Yes	Yes
Dished head or conical	Crown	External load	Membrane	P_m	No	No
			Bending	P_b	No	No
		Self-limiting external load, thermal gradient, thermal expansion difference	Membrane and bending	Q	Yes	No
			Peak	F	Yes	Yes
	Knuckle of junction to shell	Self-limiting external load, thermal gradient, thermal expansion difference	Membrane and bending	Q	Yes	No
			Peak	F	Yes	Yes
Flat head	Center region	External load	Membrane	P_m	No	No
			Bending	P_b	No	No
		Self-limiting external load, thermal gradient, thermal expansion difference	Membrane and bending	Q	Yes	No
			Peak	F	Yes	Yes
	Junction to shell	External load, self-limiting external load, thermal gradient, thermal expansion difference	Membrane and bending	Q	Yes	No
			Peak	F	Yes	Yes
Perforated head, plate, or shell	Typical ligament in a uniform pattern	External load	Membrane (averaged through cross section)	P_m	No	No
			Bending (averaged through width of ligament, but gradient through plate)	P_b	No	No
		Self-limiting external load, thermal gradient, thermal expansion difference	Membrane and bending	Q	Yes	No
			Peak	F	Yes	Yes
	Isolated or atypical ligament	External load, self-limiting external load, thermal gradient, thermal expansion difference	Membrane	Q	Yes	No
			Bending	F	Yes	Yes
			Peak	F	Yes	Yes

Table NG-3217-1
Classification of Stress Intensity in Core Support Structures for Some Typical Cases (Cont'd)

Core Support Structure	Location	Origin of Stress [Note (1)]	Type of Stress [Note (2)]	Classification	Discontinuity Gross	Discontinuity Local
Nozzle	Cross section perpendicular to nozzle axis	External load	Membrane average across full section. Stress component perpendicular to section.	P_m	No	No
			Bending across nozzle section	P_m	No	No
		Self-limiting external load, thermal gradients, thermal expansion difference	Membrane and bending	Q	Yes	No
			Peak	F	Yes	Yes
	Nozzle wall	External load	Membrane	P_m	No	No
		Self-limiting external load, thermal gradients, thermal expansion difference	Membrane and bending	Q	Yes	No
			Peak	F	Yes	Yes
Cladding	Any	Differential thermal expansion	Peak	F	Yes	Yes
Any	Any	Radial thermal gradient through plate thickness [Note (3)]	Equivalent linear stress	Q [Note (4)]	Yes	No
			Stress due to nonlinear portion	F	Yes	Yes
Any	Any	Any	Stress concentration (notch effect)	F	Yes	Yes
Beams and columns	Any	External Load	Membrane	P_m	No	No
			Bending	P_b	No	No
		Self-limiting external load, thermal gradients, thermal expansion difference	Membrane and bending	Q	Yes	No
			Peak	F	Yes	Yes

NOTES:
(1) Examples of loadings that shall be considered, including external loadings, are identified in NG-3111.
(2) Where applicable, the possibility of buckling, wrinkling, and excessive deformation in shells with large diameter-to-thickness ratio shall be considered. The possibility of buckling of beams or columns shall also be considered.
(3) The possibility of thermal stress ratchet shall also be considered.
(4) Equivalent linear stress is defined as the linear stress distribution that has the same net bending moment as the actual stress distribution.

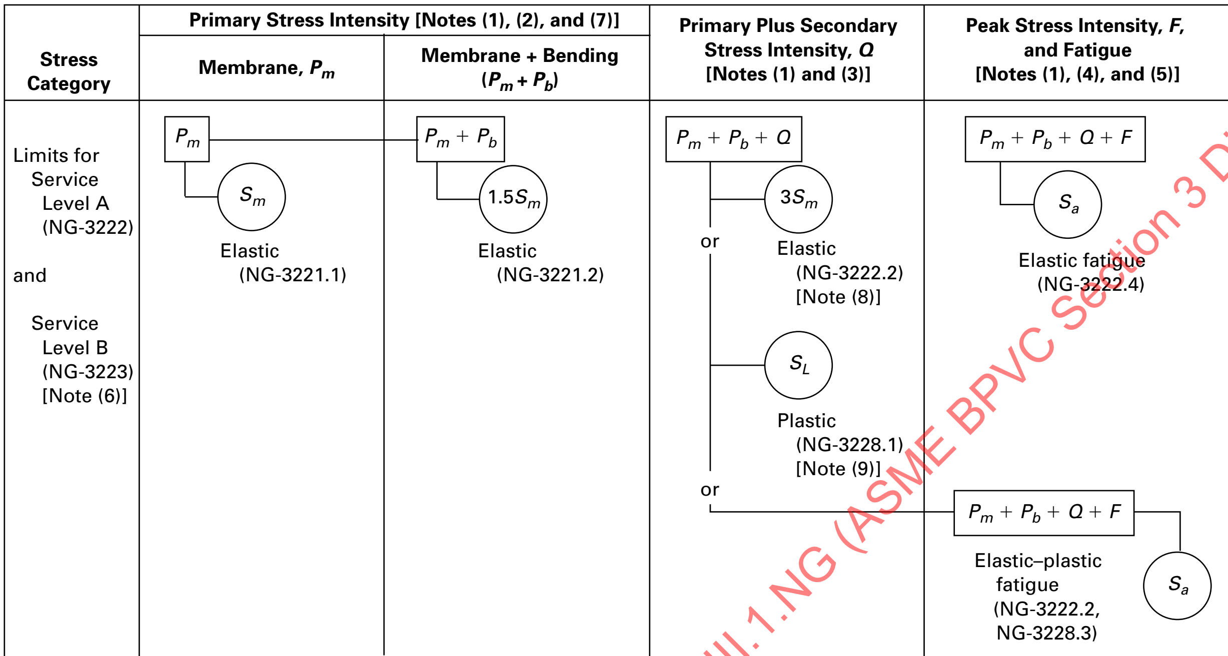
Figure NG-3221-1
Stress Categories and Limits of Stress Intensities for Design Loadings



NOTES:
(1) The symbols P_m and P_b do not represent single quantities, but rather sets of six quantities representing the six stress components σ_t, σ_l, σ_r, τ_{lt}, τ_{lr}, and τ_{rt}.
(2) For configurations where compressive stresses occur, the stress limits shall be reviewed to take into account critical buckling stresses [NG-3211(c)].
(3) In lieu of satisfying these stress limits, a limit analysis in accordance with NG-3228.2 may be performed..

Figure NG-3222-1
Stress Categories and Limits of Stress Intensities for Service Levels A and B

(21)



NOTES:

(1) The symbols P_m, P_b, Q, and F do not represent single quantities, but rather sets of six quantities representing the six stress components σ_t, σ_l, σ_r, τ_{lt}, τ_{lr}, τ_{rt}.

(2) For configurations where compressive stresses occur, the stress limits shall be reviewed to take into account critical buckling stresses [NG-3211(c)].

(3) The secondary stresses, Q, are those parts of the total stress that are produced by thermal gradients, structural discontinuities, etc., and do not include primary stresses that may also exist at the same point. It should be noted, however, that a detailed stress analysis frequently gives the combination of primary and secondary stresses directly and, when appropriate, this calculated value represents the total of $P_m + P_b + Q$, and not Q alone.

(4) If the peak stress, F, is produced by a stress concentration, the quantity F is the additional stress produced by the notch, over and above the nominal stress. For example, if a plate has a nominal stress intensity, $P_m = S$, $P_b = 0$, $Q = 0$, and a notch with a stress concentration K is introduced, then $F = P_m(K - 1)$ and the peak stress intensity equals $P_m + P_m(K - 1) = KP_m$.

(5) Alternating stress intensity, S_{alt}, is one-half of the alternating stress range, per NG-3222.4. Note that adjustments to S_{alt} may be required to account for local discontinuities [NG-3222.4(e)], elastic modulus correction [NG-3222.4(e)], fatigue penalty factors (NG-3228.3), or local thermal effects (NG-3227.6).

(6) Per NG-3223(a), the Level A Service Limits in NG-3222 apply to Service Level B, except that the primary stress intensity limits shall be increased by 10%.

(7) In lieu of satisfying these stress limits, a limit analysis in accordance with NG-3228.2 or experimental analysis in accordance with NG-3228.4 may be performed..

(8) The limit on primary plus secondary stress applies to the range of stresses, per NG-3222.2.

(9) S_L denotes the structural action of shakedown load as defined in NG-3213.17, calculated on a plastic basis as applied to a specific location on the structure.

combination of these low cycle events plus all other cyclic events does not exceed a value of 1.0 when calculated in accordance with NG-3222.4.

(b) The value of S_m shall be determined as follows:

(1) When the secondary stress is due to a temperature transient or to restraint of free end displacement, the value of S_m shall be taken as the average of the tabulated S_m values for the highest and lowest temperatures of the metal (at the point at which the stresses are being analyzed) during the transient.

(2) When part or all of the secondary stress is due to a mechanical load, S_m shall be based on the highest metal temperature during the transient.

(c) The primary plus secondary stress intensity range is determined using the methodology described in NG-3216, where the algebraic signs of the stress differences are retained in the computation. This limitation on range applies to the entire history of applicable transients and Service Loadings, not just to the stress range resulting from an individual transient.

NG-3222.4 Analysis for Cyclic Operation.

(a) Suitability for Cyclic Condition. The suitability of a structure for specified Service Loadings involving cyclic application of loads and thermal conditions shall be determined by the methods described herein, except that the suitability of high strength threaded structural fasteners shall be determined by the methods of NG-3232.3(b) and the possibility of thermal stress ratchet shall be investigated in accordance with NG-3222.5. If the specified Service Loadings of the structure meet all of the conditions of (d) below, no analysis for cyclic service is required, and it may be assumed that the limits on peak stress intensities as governed by fatigue have been satisfied by compliance with the applicable requirements for material, design, fabrication, examination, and testing of this Subsection. If the Service Loadings do not meet all the conditions of (d) below, a fatigue analysis shall be made in accordance with (e) below or a fatigue test shall be made in accordance with Section III Appendices, Mandatory Appendix II, II-1500.

(b) Peak Stress Intensity. This stress intensity is derived from the highest value at any point across the thickness of a section of all primary, secondary, and peak stresses produced by specified service pressure differences and other mechanical loads, and by general and local thermal effects associated with the Service Loadings and including the effects of gross and local structural discontinuities.

(c) Conditions and Procedures. The conditions and procedures of NG-3222.4 are based on a comparison of peak stresses with strain cycling fatigue data. The strain cycling fatigue data are represented by design fatigue strength curves of Section III Appendices, Mandatory Appendix I. These curves show the allowable amplitude S_a of the alternating stress intensity component (one-half of the alternating stress intensity range) plotted against the number of cycles. This stress intensity amplitude is calculated on the assumption of elastic behavior and, hence, has the dimensions of stress, but it does not represent a real stress when the elastic range is exceeded. The design fatigue curves in Section III Appendices, Mandatory Appendix I are derived from both strain-controlled test data and load-controlled fatigue data. When strain-controlled test data is used, the fatigue curves are obtained from uniaxial strain cycling data in which the imposed strains have been multiplied by the elastic modulus and a design margin has been provided so as to make the calculated stress intensity amplitude and the allowable stress intensity amplitude directly comparable. The curves have been adjusted, where necessary, to include the maximum effects of mean stress, which is the condition where the stress fluctuates about a mean value which is different from zero. As a consequence of this procedure, it is essential that the requirements of NG-3222.2 be satisfied at all times with transient stresses included, and that the calculated value of the alternating stress intensity be proportional to the actual strain amplitude. To evaluate the effect of alternating stresses of varying amplitudes, a linear damage relation is assumed in (e)(5) below.

(d) Components Not Requiring Analysis for Cyclic Service. An analysis for cyclic service is not required, and it may be assumed that the limits on peak stress intensities as governed by fatigue have been satisfied for a structure by compliance with the applicable requirements for material, design, fabrication, examination, and testing of this Subsection, provided the specified Service Loadings of the structure or portion thereof meets all the conditions stipulated in (1) through (4) below. As stated in NG-3223, for structures operating within the temperature limits of this Subsection, Service Loadings for which Level B Limits are designated shall be considered as though Level A Limits were designated in evaluating exemptions from fatigue analysis.

(1) Temperature Difference — Startup and Shutdown. The temperature difference in °F (°C) between any two adjacent points of the structure due to the Service Loadings 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 at the mean value of the temperatures at the two points as given by Section II, Part D, Subpart 2, Table TE, and E is taken from Section II, Part D, Subpart 2, Table TM at the mean value of the temperature at the two points. Adjacent points are defined as points that are spaced less than the distance $2\sqrt{(Rt)}$ from each other, where R and t are the mean radius and thickness, respectively, of the shell of revolution. In configurations other than a shell of revolution, either the allowable distance between adjacent points must be determined

in appropriate configurations or a fatigue analysis shall be made.

(2) Temperature Difference — Service Loadings. The temperature difference in °F (°C) between any two adjacent points [(1)] does not change due to the Service Loadings (excluding startup and shutdown) 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 (considering the algebraic range of the difference) shall be considered to be significant if its total algebraic range exceeds the quantity $S/(2E\alpha)$, where S is defined as follows:

(-a) 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.

(-b) 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.

(3) Temperature Difference — Dissimilar Materials. For structures fabricated from materials of differing moduli of elasticity and coefficients of thermal expansion or both, the total algebraic range of temperature fluctuation in °F (°C) experienced by the component due to the Service Loadings 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 at the mean temperature value involved for the two materials of construction (Section II, Part D, Subpart 2, Tables TE and TM). 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:

(-a) 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.

(-b) 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.

(4) Mechanical Loads. The specified full range of mechanical loads, including pipe reactions and pressure differences, does not result in load stresses whose range exceeds the S_a value obtained from the applicable design fatigue curve of Section III Appendices, Mandatory Appendix I for the total specified number of significant load fluctuations. If the total specified number of significant load fluctuations exceeds 10^6, the S_a value at $N = 10^6$ may be used. A load fluctuation shall be considered to be significant if the total excursion of load stress exceeds the value of S_a, where S is defined as follows:

(-a) 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.

(-b) 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) Procedure for Analysis for Cyclic Loading. If the specified Service Loadings for the structure do not meet the conditions of (d) above, the ability of the structure to withstand the specified cyclic service without fatigue failure shall be determined as provided herein. The determination shall be made on the basis of the stresses at a point and the allowable stress cycles shall be adequate for the specified Service Loadings at every point. Only the stresses due to service cycles as specified in the Design Specifications need be considered. Compliance with these requirements means only that the structure is suitable from the standpoint of possible fatigue failure; complete suitability for the specified Service Loadings is also dependent on meeting the general stress limits of NG-3222 and any applicable special stress limits of NG-3227.

(1) Stress Differences. Determine the stress differences and the alternating stress intensity S_{alt} due to the Service Loadings, in accordance with NG-3216.

(2) Local Structural Discontinuities. These effects shall be evaluated by the use of theoretical stress concentration factors for all conditions, except that experimentally determined fatigue strength reduction factors may be used when stated herein or when determined in accordance with the procedures of Section III Appendices, Mandatory Appendix II, II-1600. Except for the case of cracklike defects and specific piping geometries for which specific values are given in NB-3680, no fatigue strength reduction factor greater than 5 need be used.

(3) Design Fatigue Curves. Section III Appendices, Mandatory Appendix I contains the applicable fatigue design curves for the materials permitted by this Subsection. When more than one curve is presented for a given material, the applicability of each curve to material of various strength levels is identified. Linear interpolation may be used for intermediate strength levels of these materials. As used herein the strength level is the specified minimum room temperature value.

(4) Effect of Elastic Modulus. Multiply S_{alt} (NG-3216.1 or NG-3216.2) by the ratio of the modulus of elasticity given on the design fatigue curve to the value of the modulus of elasticity used in the analysis. Enter the applicable design fatigue curve of Section III Appendices, Mandatory Appendix I at this value on the ordinate axis and find the corresponding number of cycles on the abscissa. If the service cycle being considered is

the only one which produces significant fluctuating stresses, this is the allowable number of cycles.

(5) Cumulative Damage. If there are two or more types of stress cycle which produce significant stresses, their cumulative effect shall be evaluated as stipulated in Steps 1 through 6 below.

Step 1. Designate the specified number of times each type of stress cycle of types 1, 2, 3, etc., will be repeated during the life of the component as n_1, n_2, n_3, ..., n_n, respectively.

NOTE: In determining n_1, n_2, n_3, ..., n_n, consideration shall be given to the superposition of cycles of various origins which produce a total stress difference range greater than the stress difference ranges of the individual cycles. For example, if one type of stress cycle produces 1000 cycles of a stress difference variation from zero to +60,000 psi and another type of stress cycle produces 10,000 cycles of a stress difference variation from zero to −50,000 psi, the two types of cycle to be considered are defined by the following parameters:

$$\text{Type 1 cycle: } n_1 = 1000, \quad S_{\text{alt1}} = (60{,}000 + 50{,}000)/2 = 55{,}000 \text{ psi}$$

$$\text{Type 2 cycle: } n_2 = 9000, \quad S_{\text{alt2}} = (50{,}000 + 0)/2 = 25{,}000 \text{ psi}$$

Step 2. For each type of stress cycle, determine the alternating stress intensity S_{alt} by the procedures of NG-3216.1 or NG-3216.2 above. Call these quantities S_{alt1}, S_{alt2}, S_{alt3}, ..., $S_{\text{alt }n}$.

Step 3. For each value S_{alt1}, S_{alt2}, S_{alt3}, ..., $S_{\text{alt }n}$, use the applicable design fatigue curve to determine the maximum number of repetitions which would be allowable if this type of cycle were the only one acting. Call these values N_1, N_2, N_3, ..., N_n.

Step 4. For each type of stress cycle, calculate the usage factors U_1, U_2, U_3, ..., U_n, from $U_1 = n_1/N_1$, $U_2 = n_2/N_2$, $U_3 = n_3/N_3$, ..., $U_n = n_n/N_n$.

Step 5. Calculate the cumulative usage factor U from $U = U_1 + U_2 + U_3 + ... + U_n$.

Step 6. The cumulative usage factor U shall not exceed 1.0.

(21) **NG-3222.5 Thermal Stress Ratchet.** Under certain combinations of steady-state and cyclic loadings there is a possibility of large distortions developing as the result of ratchet action; that is, the deformation increases by a nearly equal amount for each cycle. Examples of this phenomenon are treated in this subparagraph and in NG-3227.3.

(a) The limiting value of the maximum cyclic thermal stress permitted in a portion of an axisymmetric shell loaded by steady-state internal pressure difference in order to prevent cyclic growth in diameter is as follows. Let

y' = maximum allowable range of thermal stress computed on an elastic basis divided by the yield strength S_y or $1.5S_m$, whichever is greater

z' = maximum allowable range of thermal stress averaged through the wall thickness and computed on an elastic basis divided by the yield strength, S_y

x = maximum general membrane stress due to pressure difference divided by the yield strength S_y or $1.5S_m$, whichever is greater

(1) Case 1 — linear variation of temperature through the wall

$$y' = \frac{1}{x} \text{ for } 0 < x < 0.5$$

$$y' = 4(1 - x) \text{ for } 0.5 < x < 1.0$$

$$z' = 2(1 - x) \text{ for } 0 < x < 1.0$$

(2) Case 2 — parabolic constantly increasing or constantly decreasing variation of temperature through the wall

$$y' = 5.2(1 - x) \text{ for } 0.615 < x < 1.0$$

and approximately for $x < 0.615$ as follows:

for x = 0.3, 0.4, 0.5, y' = 4.65, 3.55, 2.70

$$z' = 2(1 - x) \text{ for } 0 < x < 1.0$$

(b) Use of yield strength S_y in the above relations instead of the proportional limit allows a small amount of growth during each cycle until strain hardening raises the proportional limit to S_y. If the yield strength of the material is higher than two times the S_a value for the maximum number of cycles on the applicable fatigue curve of Section III Appendices, Mandatory Appendix I for the material, the latter value shall be used if there is to be a large number of cycles because strain softening may occur.

NG-3222.6 Deformation Limits. Any deformation limits prescribed by the Design Specifications shall be satisfied.

NG-3223 Level B Service Limits

For components operating within the temperature limits of this Section the requirements of (a) and (b) apply.

(a) The Level A Service Limits in NG-3222 shall apply to Service Level B, except that the primary stress intensity limits shall be increased by 10%.

(b) The Design Specifications shall be satisfied.

Figure NG-3224-1
Stress Categories and Limits of Stress Intensities for Service Level C (21)

Stress Category	Primary Stresses [Notes (1), (2), and (3)] — Membrane, P_m	Primary Stresses [Notes (1), (2), and (3)] — Membrane + Bending ($P_m + P_b$)	Primary Plus Secondary Stress Intensity, Q [Note (1)]	Peak Stress Intensity, F, and Fatigue [Note (1)]
Limits for Service Level C (NG-3224)	P_m: $1.5S_m$ Elastic analysis [NG-3224.1(a)(1)] or $1.5S_m$ Plastic analysis [NG-3224.1(c)(1)] or S_E Stress ratio analysis [NG-3224.1(d)(1)]	$P_m + P_b$: $2.25S_m$ Elastic analysis [NG-3224.1(a)(2)] or $2.25S_m$ or $0.5S_u$ Plastic analysis [NG-3224.1(c)(2)] or KS_E Stress ratio analysis [NG-3224.1(d)(2)]	Evaluation not required (NG-3224.4)	Evaluation not required (NG-3224.5)

NOTES:

(1) The symbols P_m, P_b, Q, and F do not represent single quantities, but rather sets of six quantities representing the six stress components σ_t, σ_l, σ_r, τ_{lt}, τ_{lr}, τ_{rt}.

(2) For configurations where compressive stresses occur, the stress limits shall be reviewed to take into account critical buckling stresses [NG-3211(c)].

(3) In lieu of satisfying these stress limits, a limit analysis in accordance with NG-3228.2 or experimental analysis in accordance with NG-3228.4 may be performed.

NG-3224 Level C Service Limits

Level C Service Limits must be satisfied for Service Loadings for which they are designated by the Design Specifications and are those of one of the five methods permitted in NG-3224.1. These stress intensity limits are summarized by Figure NG-3224-1. Dynamic instability shall be considered in meeting the load, stress, and deformation limits. The requirements of NG-3224.2 through NG-3224.6 shall also be met.

(21) **NG-3224.1 Stress Intensity Limits.**

(a) Elastic Analysis Method

(1) The general primary membrane stress intensity (NG-3213.6, NG-3213.8, and NG-3221.1) shall not exceed 1.5 times the allowable stress intensity S_m as given in Section II, Part D, Subpart 1, Tables 2A and 2B.

(2) The primary membrane plus primary bending stress intensity (NG-3213.7, NG-3213.8, and NG-3221.2) shall not exceed 2.25 times the allowable stress intensity S_m as given in Section II, Part D, Subpart 1, Tables 2A and 2B.

(b) Limit Analysis. In lieu of the elastic analysis of (a), a limit analysis in accordance with NG-3228.2 may be performed

(c) Plastic Analysis. Instead of the elastic analysis of (a), a plastic analysis may be performed as set forth in (1) and (2) below. Primary stresses shall be calculated from the elastic–plastic analysis. Strain hardening of the material may be used for the actual monotonic stress–strain curve at the temperature of loading; any approximation to the stress–strain curve that everywhere has a lower stress for the same strain as the actual monotonic curve may also be used. Either the maximum shear stress theory or the strain energy distortion theory shall be used to relate multiaxial yielding to the uniaxial case.

(1) For Service Loadings for which Level C Limits are designated, general primary membrane stress intensity values shall not exceed 1.5 times the allowable stress intensity S_m at temperatures where S_m is given in Section II, Part D, Subpart 1, Tables 2A and 2B.

(2) For Service Loadings for which Level C Limits are designated, the general primary membrane plus primary bending stress intensities shall not exceed the greater of either one-half of the ultimate strength S_u at temperature (multiaxiality effect on S_u shall be considered) or 2.25 times the allowable stress intensity values S_m at temperature as given in Section II, Part D, Subpart 1, Tables 2A and 2B.

(d) Stress Ratio Analysis. Instead of the elastic analysis of (a), a stress ratio analysis (NG-3213.22) may be performed, in which event the limits of (1) and (2) below shall be met.

(1) Service Loadings producing primary membrane stresses shall not result in stress intensities exceeding S_E where $S_E \leq 2.0S_m$.

(2) The stress intensity limits for other stress fields shall be as specified in Section III Appendices, Nonmandatory Appendix A, Article A-9000. For example, for bending

$$P_B \leq S_E\left[1 - \left(\frac{P_m}{S_E}\right)^2\right]$$

for rectangular sections, where

$$n = 2 \quad \text{or} \quad P_B \leq \sqrt{K^2 S_E (S_E - P_m)}$$

where K is the Section Factor for $n = 1$ as determined by the method of Section III Appendices, Nonmandatory Appendix A, Article A-9000.

(e) Experimental Analysis. In lieu of the elastic analysis of (a), an experimental analysis in accordance with NG-3228.4 may be performed.

NG-3224.2 External Pressure. The permissible equivalent static external pressure shall be taken as 150% of that permitted by the rules of NG-3133. Where dynamic pressures are involved, the permissible external pressure shall satisfy the preceding requirements or be limited to one-half the dynamic instability pressure.

NG-3224.3 Special Stress Limits. The permissible values for special stress limits shall be taken as 150% of the values given in NG-3227 and NG-3228.1.

NG-3224.4 Secondary and Peak Stresses. The requirements of NG-3222.2, NG-3222.4, NG-3222.5, and NG-3227.3 need not be satisfied.

NG-3224.5 Fatigue Requirements. Service Loadings for which Level C Limits are designated need not be considered when applying the procedures of NG-3222.4(a) to determine whether or not a fatigue analysis is required.

NG-3224.6 Deformation Limits. Any deformation limits prescribed by the Design Specifications shall be considered.

(21) NG-3225 Level D Service Limits

If the Design Specifications specify any Service Loadings for which Level D Limits are designated [NCA-2142.4(b)(4)], the rules contained in Section III Appendices, Mandatory Appendix XXVII shall be used in evaluating these loadings, independently of all other Design and Service Loadings. The following stipulations apply when using Section III Appendices, Mandatory Appendix XXVII:

(a) When the special stress limits of NG-3227 are applicable for Level D Limits, the calculated stresses shall not exceed twice the stress limits given in NG-3227 as applied for Level A and Level B Service Limits. The bearing and shear limits in XXVII-3500 do not apply to core support structures.

(b) For limit analysis, comply with NG-3228.2.

(c) For experimental analysis, comply with NG-3228.4.

(d) Component inelastic analysis may be combined with elastic system analysis as defined in Section III Appendices, Mandatory Appendix XXVII. For this analysis, the maximum stress limit shall be $0.67S_u$ for primary membrane stress intensity, and shall be equal to the greater of $0.67S_{ut}$ and $[S_y + (1/3)(S_{ut} - S_y)]$, but not to exceed $0.9S_u$ for maximum primary stress intensity, where S_{ut} is defined as the value of ultimate stress obtained from the true stress–strain curve and S_u is defined as the value of ultimate stress from an engineering stress–strain curve. In this case, the elastic system analysis shall be checked, accounting for component plastic deformation.

NG-3227 Special Stress Limits

The following deviations from the basic stress limits are provided to cover special Service Loadings or configurations. Some of these deviations are more restrictive and some are less restrictive than the basic stress limits. Rules governing application of these special stress limits for Level C and Level D Service Limit applications are contained in NG-3224.3 and NG-3225, respectively. In cases of conflict between these requirements and the basic stress limits, the rules of NG-3227 take precedence for the particular situations to which they apply. NG-3227 does not apply to threaded structural fasteners (NG-3230).

NG-3227.1 Bearing Loads.

(a) The average bearing stress for resistance to crushing under the maximum load, experienced as a result of Design Loadings or of Service Loadings for which Level A Limits are designated, shall be limited to S_y at temperature, except that when the distance to a free edge is larger than the distance over which the bearing load is applied, a stress of $1.5S_y$ at temperature is permitted. For clad surfaces the yield strength of the base metal may be used if, when calculating the bearing stress, the bearing area is taken as the lesser of the actual contact area or the area of the base metal supporting the contact surface.

(b) When bearing loads are applied near free edges, such as at a protruding ledge, the possibility of a shear failure shall be considered. In the case of load-controlled stress only (NG-3213.11), the average shear stress shall be limited to $0.6S_m$. In the case of load-controlled stress plus

secondary stress (NG-3213.9), the average shear stress shall not exceed the following:

(1) for material of Section II, Part D, Subpart 1, Table 2A to which Note G7 is applicable and Section II, Part D, Subpart 1, Table 2B to which Note G1 is applicable, the lower of $0.5S_y$ at 100°F (38°C) and $0.675S_y$ at temperature;

(2) for all other material, $0.5S_y$ at temperature.

(c) For clad surfaces, if the configuration or thickness is such that a shear failure could occur entirely within the clad material, the allowable shear stress for the cladding shall be determined from the properties of the equivalent wrought material. If the configuration is such that a shear failure could occur across a path that is partially base metal and partially clad material, the allowable shear stresses for each material shall be used when evaluating the combined resistance to this type of failure.

(d) When considering bearing stresses in pins and similar members, the S_y at temperature value is applicable, except that a value of $1.5S_y$ may be used if no credit is given to bearing area within one pin diameter from a plate edge.

NG-3227.2 Pure Shear.

(a) The average primary shear stress across a section loaded in pure shear, experienced as a result of Design Loadings or Service Loadings for which Level A Limits are designated (e.g., keys, shear rings), shall be limited to $0.6S_m$.

(b) The maximum primary shear, experienced as a result of Design Loadings or Service Loadings for which Level A Limits are designated exclusive of stress concentration at the periphery of a solid circular section in torsion, shall be limited to $0.8S_m$.

(c) Primary plus secondary and peak shear stresses shall be converted to stress intensities (equal to two times pure shear stress) and as such shall not exceed the basic stress limits of NG-3222.2 and NG-3222.4(b).

NG-3227.3 Progressive Distortion of Nonintegral Connections. Screwed on caps, screwed in plugs, shear ring closures, and breechlock closures are examples of nonintegral connections which are subject to failure by bell mouthing or other types of progressive deformation. If any combination of applied loads produces yielding, such joints are subject to ratcheting because the mating members may become loose at the end of each complete operating cycle and start the next cycle in a new relationship with each other, with or without manual manipulation. Additional distortion may occur in each cycle so that interlocking parts, such as threads, can eventually lose engagement. Therefore, primary plus secondary stress intensities (NG-3222.2) which result in slippage between the parts of a nonintegral connection in which disengagement could occur as a result of progressive distortion shall be limited to the value S_y (Section II, Part D, Subpart 1, Table Y-1).

NG-3227.4 Triaxial Stresses. The algebraic sum of the three primary principal stresses ($\sigma_1 + \sigma_2 + \sigma_3$) shall not exceed four times the tabulated value of S_m.

NG-3227.5 Nozzle Piping Transition. The P_m classification of stresses in nozzle resulting from pressure difference, external loads, and moments is applicable for that length of nozzle which lies within the limits or reinforcement given by NG-3132, whether or not nozzle reinforcement is provided. Beyond the limits of reinforcement, a P_m classification shall be applied to the general primary membrane stress intensity averaged across the section (not thickness) resulting from combined pressure difference and external mechanical loads; $P_m + P_b$ classification shall be applied to primary membrane plus primary bending stress intensities that result from Design Pressure Difference and external mechanical loads; and a $P_m + P_b + Q$ classification shall be applied to primary plus secondary stress intensities resulting from all loads including external load or moment attributable to restrained free end displacement of the attached pipe. Beyond the limits of reinforcement, the $3S_m$ limit on the range of primary plus secondary stress intensity may be exceeded as provided in NG-3228.3 except that in the evaluation of NG-3228.3(a), stresses from attached pipe thermal expansion loads and moments may also be excluded. The range of membrane plus bending stress intensity attributable solely to thermal expansion of the attached piping shall be $\leq 3S_m$. The nozzle, outside the reinforcement limit, shall not be thinner than the larger of the pipe thickness or the quantity $t_p (S_{mp}/S_{mn})$ where t_p is the nominal thickness of the mating pipe, S_{mp} is the allowable stress intensity value for the pipe material, and S_{mn} is the allowable stress intensity value for the nozzle material.

NG-3227.6 Applications of Elastic Analysis for Stresses Beyond the Yield Strength. Certain of the allowable stresses permitted in the design criteria are such that the maximum stress calculated on an elastic basis may exceed the yield strength of the material. The limit on primary plus secondary stress intensity of $3S_m$ (NG-3222.2) has been placed at a level which assures shakedown to elastic action after a few repetitions of the stress cycle except in regions containing significant local structural discontinuities or local thermal stresses. These last two factors are considered only in the performance of a fatigue evaluation. Therefore

(a) in evaluating stresses for comparison with the stress limits on other than fatigue allowables, stresses shall be calculated on an elastic basis

(b) in evaluating stresses for comparison with fatigue allowables, all stresses except those which result from local thermal stresses [NG-3213.12(b)] shall be evaluated on an elastic basis. In evaluating local thermal stresses, the elastic equations shall be used except that the numerical

value substituted for Poisson's ratio shall be determined from the expression

$$\nu = 0.5 - 0.2\frac{S_y}{S_{\text{alt}}} \text{ but not less than } 0.3$$

where

S_{alt} = alternating stress intensity determined in NG-3222.4(e) prior to the elastic modulus adjustment in NG-3222.4(e)(4)

S_y = the yield strength of the material at the mean value of the temperature of the cycle

NG-3228 Applications of Plastic Analysis

The following subparagraphs provide guidance in the application of plastic analysis and some relaxation of the basic stress limits which are allowed if plastic analysis is used.

(21) **NG-3228.1 Shakedown Analysis.** The limits on primary plus secondary stress intensity range (NG-3222.2), thermal stress ratchet (NG-3222.5), and progressive distortion of nonintegral connections (NG-3227.3) need not be satisfied at a specific location if, at the location, the procedures of (a) and (b) below are used.

(a) In lieu of satisfying the specific requirements of NG-3222.2, NG-3222.5, and NG-3227.3 at a specific location, the structural action shall be calculated on a plastic basis, and the design shall be considered to be acceptable if shakedown occurs (as opposed to continuing deformation). However, this shakedown requirement need not be satisfied for materials having a minimum specified yield strength to specified minimum ultimate strength ratio of less than 0.80, provided the maximum accumulated local strain at any point, as a result of cyclic operation to which plastic analysis is applied, does not exceed 5.0%. In all cases, the deformations that occur shall not exceed specified limits.

(b) In evaluating stresses for comparison with fatigue allowables, the numerically maximum principal total strain range calculated on a plastic basis shall be multiplied by one-half of the modulus of elasticity of the material (Section II, Part D, Subpart 2, Table TM) at the mean value of the temperature of the cycle.

(21) **NG-3228.2 Limit Analysis.**

(a) For Design, Level A, and Level B Service Loadings, the primary stress limits of NG-3221.1, NG-3221.2, and NG-3222.1 need not be satisfied at a specific location if the service loadings do not exceed the requirements of (1) or (2) below for the lower bound limit load L_L (NG-3213.21). The lower bound limit load L_L may be determined by analysis or by test (test collapse load per Section III Appendices, Mandatory Appendix II, II-1430), using a material yield point equal to 1.5 times the allowable stress intensity S_m at temperature, where S_m is given in Section II, Part D, Subpart 1, Tables 2A and 2B.

(1) Except for the materials identified in (2) below, the specified loadings shall not exceed ⅔ of L_L.

(2) For materials of Section II, Part D, Subpart 1, Table 2A to which Note G7 applies and Table 2B to which Note G1 applies, the specified loadings shall not exceed the product of L_L and the applicable permanent strain-limiting factor of Section II, Part D, Subpart 1, Table Y-2.

(b) For Level C Service Loadings, the primary stress limits of NG-3224.1(a) need not be satisfied at a specific location if the service loadings do not exceed 1.5 times the limits of (a) above, with L_L determined as described in (a).

(c) For Level D Service Loadings with materials identified in (a)(2) above, the specified loadings shall not exceed 2 times the limits of (a)(2), with L_L determined as described in (a). For all other materials, the limit analysis shall comply with Section III Appendices, Mandatory Appendix XXVII.

NG-3228.3 Simplified Elastic–Plastic Analysis. The $3S_m$ limit on the range of primary plus secondary stress intensity (NG-3222.2) may be exceeded, provided that the requirements of (a) through (f) below are met (21)

(a) The range of primary plus secondary membrane plus bending stress intensity, excluding thermal stresses, shall be $\leq 3S_m$.

(b) The value of S_{alt} used for entering the design fatigue curve is multiplied by the factor K_e, where

$$K_e = 1.0 \text{ for } S_n \leq 3S_m$$

$$= 1.0 + \frac{(1-n)}{n(m-1)}\left(\frac{S_n}{3S_m} - 1\right) \text{ for } 3S_m < S_n < 3mS_m$$

$$= 1/n \text{ for } S_n \geq 3mS_m$$

where

S_n = range of primary plus secondary stress intensity

The values of the material parameters m and n for the various classes of permitted materials are as given in Table NG-3228-1.

(c) The rest of the fatigue evaluation stays the same as required in NG-3222.4, except that the procedure of NG-3227.6 need not be used.

(d) The component meets the thermal ratcheting requirement of NG-3222.5.

(e) The temperature does not exceed those listed in Table NG-3228-1 for the various classes of materials.

Table NG-3228-1
Values of m, n, and T_{max} for Various Classes of Permitted Materials

Material	m	n	T_{max}, °F (°C)
Low alloy steel	2.0	0.2	700 (370)
Martensitic stainless steel	2.0	0.2	700 (370)
Carbon steel	3.0	0.2	700 (370)
Austenitic stainless steel	1.7	0.3	800 (425)
Nickel–chromium–iron	1.7	0.3	800 (425)
Nickel–copper	1.7	0.3	800 (425)

GENERAL NOTE: T_{max} is the maximum metal temperature.

(f) The material shall have a specified minimum yield strength to specified minimum tensile strength ratio of less than 0.80.

NG-3228.4 Experimental Analysis.

(a) For Level A and Level B Service Loadings, the primary stress limits of NG-3222.1 need not be satisfied in a structure if it can be shown from the test of a prototype or model that the specified loadings (dynamic or static equivalent) do not exceed 44% of L_u (NG-3213.23), and (d) below is satisfied.

(b) For Level C Service Loadings, the primary stress limits of NG-3224.1(a) need not be satisfied if it can be shown from the test of a prototype or model that the specified loadings (dynamic or static equivalent) do not exceed 60% of L_u (NG-3213.23), and (d) below is satisfied.

(c) For Level D Service Loadings, the specified dynamic or equivalent static loads shall not exceed 80% of the ultimate collapse load as obtained from test P_t. P_t is defined as the load at which the horizontal tangent to the load deformation curve occurs, or 80% of a load combination used in the test of a prototype or model. Paragraph (d) below shall also be satisfied.

(d) In using this method, account shall be taken of the size effect and dimensional tolerances that may exist between the actual part and test part or parts, as well as differences that may exist in the ultimate strength or other governing material properties of the actual part and the tested parts to ensure that the loads obtained from the test are a conservative representation of the load-carrying capability of the actual structure under the postulated Service Loadings.

(21) NG-3229 Design Stress Values and Material Properties

The design stress intensity values S_m are given in Section II, Part D, Subpart 1, Tables 2A and 2B for core support structure material. Values for intermediate temperatures may be found by interpolation. These form the basis for the various stress limits. Values of yield strength are given in Section II, Part D, Subpart 1, Table Y-1. Values of the coefficient of thermal expansion are in Section II, Part D, Subpart 2, Table TE, and values of the modulus of elasticity are in Section II, Part D, Subpart 2, Table TM. The basis for establishing stress values is given in Section III Appendices, Mandatory Appendix III. The design fatigue curves used in conjunction with NG-3222.4 are those of Section III Appendices, Mandatory Appendix I.

NG-3230 STRESS LIMITS FOR THREADED STRUCTURAL FASTENERS

NG-3231 Design Conditions

(a) The rules of this paragraph apply to mechanical connections joining parts in core support structures located within a pressure-retaining boundary. Devices which are used to assemble structural elements of core support structures are referred to as threaded structural fasteners. The design stress intensity values S_m and yield strength values S_y for threaded structural fasteners shall be the values given in Section II, Part D, Subpart 1, Tables 2A and 2B and in Section II, Part D, Subpart 1, Table Y-1, respectively.

(b) The special stress limits of NG-3227 do not apply to threaded structural fasteners. For connections joining parts of pressure-retaining boundaries see Section III Appendices, Mandatory Appendix XIII, Article XIII-4000.

NG-3232 Level A Service Limits

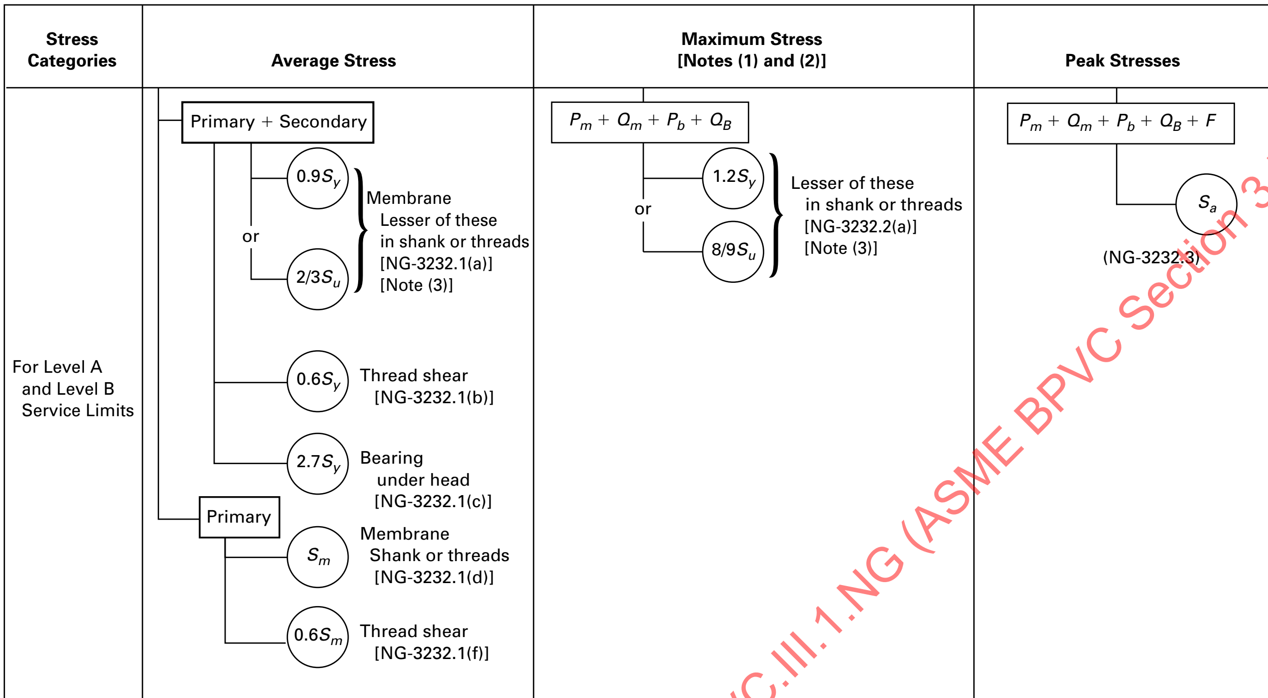
The number and cross-sectional area of threaded structural fasteners shall be such that the stress intensity limits of this paragraph are satisfied for the Service Loadings for which Level A Limits are designated in the Design Specifications. The stress intensity limits are summarized in Figure NG-3232-1. Any deformation limit prescribed in the Design Specifications shall be considered. The total axial load transferred through the fastener threads shall not go to or through zero during the specified Service Loadings.

NG-3232.1 Average Stress. Elastic analysis of specified (21)
conditions shall show that the average stress, including stress from preload for primary plus secondary stress, meets the following requirements:

(a) The maximum value of the primary plus secondary membrane stress intensity averaged across either the area of the fastener shank or the tensile stress area of the threads shall be no greater than the lesser of either $0.9S_y$ or $^2/_3 S_u$, where S_y and S_u are determined at service temperature. Alternatively, a limit analysis using the methods of NG-3228.2, or experimental analysis using the methods of NG-3228.4, may be performed.

(b) The average primary plus secondary shear stress across the threads when loaded in pure shear shall be no greater than $0.6S_y$, where S_y is determined at service temperature.

(21) **Figure NG-3232-1**
Stress Intensity Limits for Design of Threaded Structural Fasteners



NOTES:
(1) Q_m are secondary membrane stresses.
(2) Q_B are secondary bending stresses.
(3) For torquing during installation, see NG-3232.2(b).

(c) The average value of primary plus secondary bearing stress under the fastener head shall be no greater than 2.7S_y, where S_y is determined at service temperature.

(d) The primary membrane stress intensity P_m due only to Design Mechanical Loads applied to the fastener shall be no greater than S_m, where S_m is determined at service temperature.

(e) The primary shear stress across the threads when loaded in pure shear due only to Design Mechanical Loads applied to the fastener shall be no greater than 0.6S_m, where S_m is determined at service temperature.

(21) **NG-3232.2 Maximum Stress.**

(a) The maximum primary membrane and bending plus secondary membrane and bending stress intensities, including stress from preload but excluding effects of stress concentrations, shall be no greater than 1.33 times the limits of NG-3232.1(a). Alternatively, a limit analysis using the methods of NG-3228.2, or experimental analysis using the methods of NG-3228.4, may be performed.

(b) For torquing during installation of fasteners, the maximum value of membrane stress intensity shall be no greater than 1.2 times the limits of NG-3232.1(a), and the maximum value of membrane plus bending stress intensity shall be no greater than 1.2 times the limits of (a) at installation temperature. Note that the alternate analyses permitted in NG-3232.1(a) and NG-3232.2(a) do not apply for torquing during installation.

NG-3232.3 Fatigue Analysis of Threaded Structural Fasteners. Unless threaded structural fasteners meet the conditions of NG-3222.4(d) and thus require no fatigue analysis, the suitability of threaded structural fasteners for cyclic service shall be determined in accordance with the procedures of (a) through (e) below.

(a) Threaded Structural Fasteners Having Less Than 100 ksi (690 MPa) Tensile Strength. Fasteners made of material which has specified minimum tensile strength of less than 100 ksi (690 MPa) shall be evaluated for cyclic service by the methods of NG-3222.4(e), using the applicable design fatigue curves of Section III Appendices, Mandatory Appendix I and an appropriate fatigue strength reduction factor [see (c)].

(b) High-Strength Threaded Structural Fasteners. High-strength fasteners may be evaluated for cyclic service by the methods of NG-3222.4(e) using the applicable design fatigue curve of Section III Appendices, Mandatory Appendix I, provided

(1) the maximum value of primary and secondary stresses, including preload, at the periphery of the fastener cross section (resulting from direct tension plus bending and neglecting stress concentrations) shall not exceed $0.9S_y$, where S_y is determined at service temperature

(2) threads shall have a minimum thread root radius no smaller than 3 mils (0.08 mm)

(3) fillet radii at the end of the shank shall be such that the ratio of fillet radius to shank diameter is not less than 0.06

(c) Fatigue Strength Reduction Factor (NG-3213.16). Unless it can be shown by analysis or tests that a lower value is appropriate, the fatigue strength reduction factor used in the fatigue evaluation of threaded members shall not be less than 4 for the threaded region. However, when applying the rules of (b) for high-strength fasteners, the value used shall not be less than 4 for the threaded region.

(d) Effect of Elastic Modulus. Multiply S_{alt} (NG-3216.1 or NG-3216.2) by the ratio of the modulus of elasticity given on the design fatigue curve to the value of the modulus of elasticity used in the analysis. Enter the applicable design fatigue curve at this value on the ordinate axis and find the corresponding number of cycles on the abscissa. If the service cycle being considered is the only one which produces significant fluctuating stresses, this is the allowable number of cycles.

(e) Cumulative Damage. The fasteners shall be acceptable for the specified cyclic application of loads and thermal stress provided the cumulative usage factor U as determined in NG-3222.4(e)(5) does not exceed 1.

NG-3233 Level B Service Limits

Level A Service Limits (NG-3232) apply.

NG-3234 Level C Service Limits for Threaded Structural Fasteners

The number and cross-sectional area of threaded structural fasteners shall be such that the requirements of NG-3224 are satisfied for the Service Loadings for which Level C Limits are designated in the Design Specifications. For high-strength structural fasteners [specified minimum tensile strength $S_u \geq 100$ ksi (690 MPa)], the limits of NG-3232.1 and NG-3232.2(a) also apply for these Service Loadings. Any deformation limit prescribed in the Design Specifications shall be considered.

NG-3235 Level D Service Limits for Threaded Structural Fasteners (21)

The number and cross-sectional area of threaded structural fasteners shall be such that the requirements of Section III Appendices, Mandatory Appendix XXVII are satisfied for the Service Loadings for which Level D Limits are designated [NCA-2142.4(b)(4)] in the Design Specifications. Any deformation limit prescribed in the Design Specifications shall be considered. The following stipulations apply when using Section III Appendices, Mandatory Appendix XXVII:

(a) The stress limits for high strength threaded structural fasteners with specified minimum ultimate tensile strength greater than or equal to 100 ksi (690 MPa) at operating temperatures for core support structure applications are as given in (1) through (3) below. The requirements of XXVII-2310(b) and Article XXVII-3000 do not apply.

(1) For component elastic analysis, combined with either elastic or inelastic system analysis, P_m shall not exceed $2S_m$, and $P_m + P_b$ shall not exceed $3S_m$.

(2) For component plastic analysis, combined with either elastic or inelastic system analysis, P_m shall not exceed $2S_m$, and maximum primary stress intensity shall not exceed the larger of $0.67S_{ut}$ and $[S_y + (^1/_3)(S_{ut} - S_y)]$, but not to exceed $0.9S_u$ where S_{ut} is defined as the value of ultimate stress obtained from the true stress–strain curve and S_u is defined as the value of ultimate stress from an engineering stress–strain curve.

(3) For component limit analysis, combined with either elastic or inelastic system analysis, in lieu of satisfying the limits on P_m and $P_m + P_b$, the specified loadings shall not exceed $1.33L_L$ (NG-3213.21), with L_L determined in accordance with NG-3228.2.

(b) The stress limits for threaded structural fasteners with specified minimum ultimate tensile strength less than 100 ksi (690 MPa) at operating temperatures shall be determined in accordance with Section III Appendices, Mandatory Appendix XXVII, Article XXVII-3000. The requirements of XXVII-2310(b) and XXVII-3600 do not apply.

NG-3300 CORE SUPPORT STRUCTURE DESIGN

NG-3310 GENERAL REQUIREMENTS

NG-3311 Acceptability

The requirements for acceptability of a core support structure design are given in (a) through (c).

(a) The design shall be such that the requirements of NG-3100 and NG-3200 are satisfied.

(b) The requirements of NG-3300 are satisfied. In case of conflict between NG-3200 and NG-3300, the requirements of NG-3300 shall govern.

(c) The requirements of this subarticle apply to internal structures, NG-1122, only as specifically stipulated by the Certificate Holder; however, the Certificate Holder shall certify that the design used for the internal structures shall not adversely affect the integrity of the core support structure.

NG-3320 DESIGN CONSIDERATIONS

NG-3321 Design and Service Loadings

The provisions of NG-3110 apply.

NG-3322 Special Considerations

The provisions of NG-3120 apply.

NG-3323 General Design Rules

The provisions of NG-3130 apply, except when they conflict with rules of this subarticle. In case of conflict, this subarticle governs in the design of core support structures.

NG-3350 DESIGN FOR WELDED CONSTRUCTION

NG-3351 Welded Joint Categories

(a) The term *category* as used herein defines the location of a joint. The categories established by this paragraph are for use elsewhere in this Subsection to identify special restrictions regarding type of joint permitted for the location. Figures NG-3351(a)-1 and NG-3351(a)-2 illustrate locations of some typical welded joints in each category. Joints whose design functions are neither to restrain nor support the core do not fall into any category.

(b) The *types* of joints that may be used at the various locations are defined in NG-3352.

NG-3351.1 Joints of Category A. Joints of Category A are longitudinal joints in cylindrical members. Category A joints may be of Type I, II, or, with the following restriction, Type IV. When a Type IV joint is used in Category A, the quality factor shall be one-half that permitted for Type I or II by Table NG-3352-1 for the examination used.

NG-3351.2 Joints of Category B. Joints of Category B are girth welds in cylindrical members. Category B joints may be of Type I, II, or, with the following restriction, Type IV or V. When Type IV or V joints are used in Category B, the quality factor shall be one-half that permitted for Type I or II by Table NG-3352-1 for the examination used.

NG-3351.3 Joints of Category C. Joints of Category C are primarily for joining flanges to cylinders. Category C joints may be of Type I, II, III, or, with the following restriction, Type IV or V. When Type IV or V joints are used in Category C, the quality factor shall be one-half that permitted for Type I or II by Table NG-3352-1 for the examination used.

NG-3351.4 Joints of Category D. Joints of Category D are primarily for attaching nozzles to other members. Category D joints may be of Type I, II, III, IV, V, VI, or VII.

NG-3351.5 Joints of Category E. Joints of Category E are for joints at the ends of webs of beams. Category E joints may be of Type I, II, III, IV, V, VI, VII, or VIII.

NG-3352 Permissible Types of Welded Joints

Subject to the limitations given in NG-3351, core support structures may use any of the types of joints described in the following subparagraphs, providing the quality factor, n, and fatigue factor, f, used in the analysis meet the requirements of Table NG-3352-1 for the method of examination employed. The quality factor is used by multiplying the allowable stress limit for primary and secondary categories times the quality factor in evaluating the design. The use of weld quality factor, n, is for static, not fatigue applications. In performing a fatigue analysis, use the fatigue factor, f, designated in Table NG-3352-1, and the applicable fatigue curve in Section III Appendices, Mandatory Appendix I.

NG-3352.1 Type I Joints. Full penetration welds between plates or other elements that lie approximately in the same plane or have an offset angle not greater than 30 deg meet the intent of this subparagraph when made either as double welded butt joints, or with consumable inserts or gas backup, or with metal backing strips that are later removed, provided the backface of such joints meets the requirements of NG-4424.

NG-3352.2 Type II Joints. Full penetration welds between plates or other elements meet the intent of this subparagraph when made either according to NG-3352.1 or with edges of the joint prepared with opposing lips to form an integral backing strip, or with metal backing strips which are not later removed, except that the suitability for cyclic operation shall be analyzed by the method of NG-3222.4 (when used, backing strips shall be continuous and any splices shall be full penetration welded).

NG-3352.3 Type III Joints. Full penetration welds between plates or other elements that may have an offset angle up to 90 deg meet the intent of this subparagraph when either made according to NG-3352.2 or are corner welds. Attachment of connections using deposited weld metal as reinforcement and oblique connections meet the intent of this subparagraph.

NG-3352.4 Type IV Joints. Partial penetration welds of double groove design (minimum depth of each groove equals one-eighth times the thickness of the thinnest element) meet the intent of this subparagraph when the area of the connection is determined by the product of the throat thickness times the length of welds.

Figure NG-3351(a)-1
Typical Locations of Joints of Several Categories

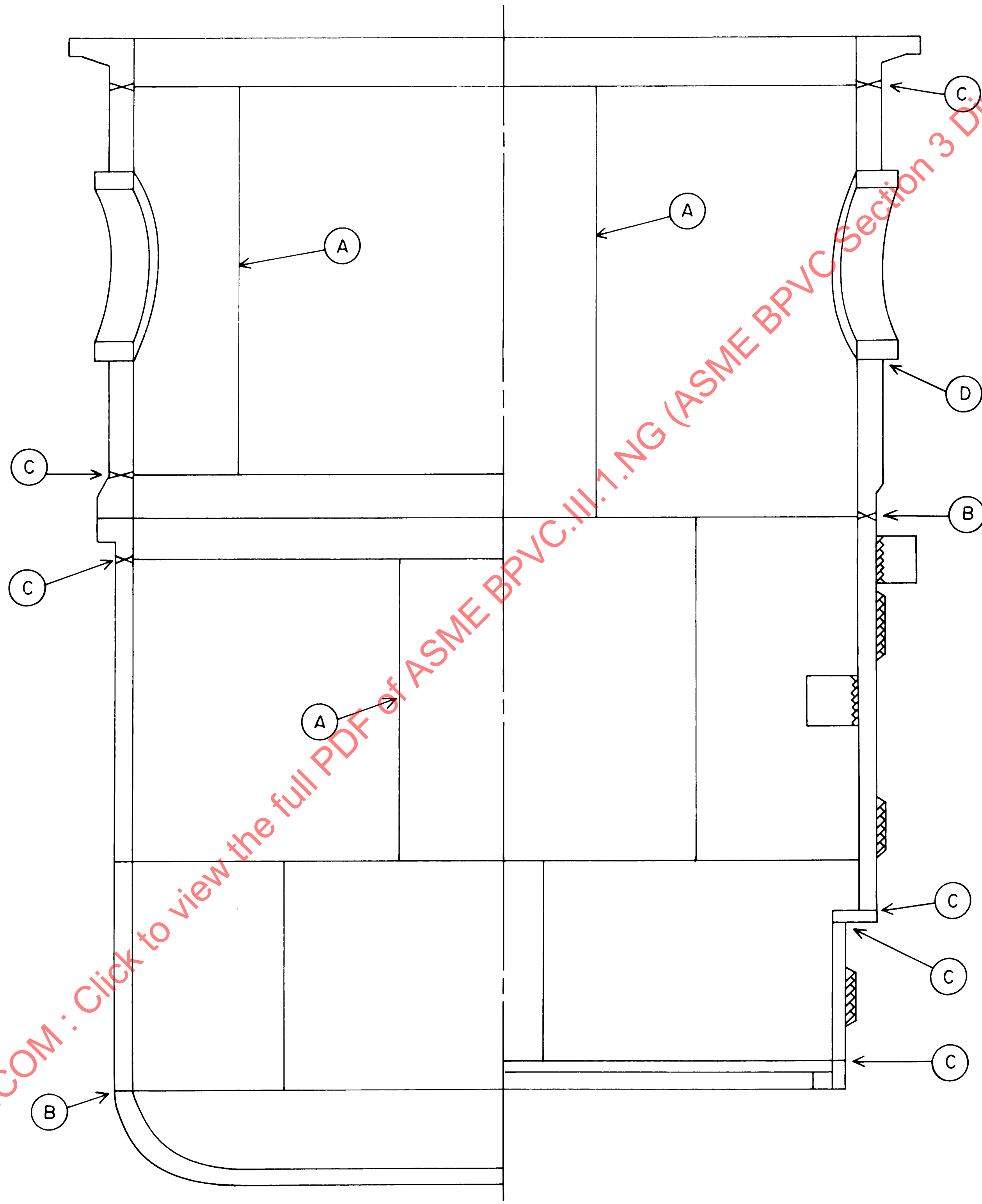


Figure NG-3351(a)-2
Typical Welded Joint Category Locations

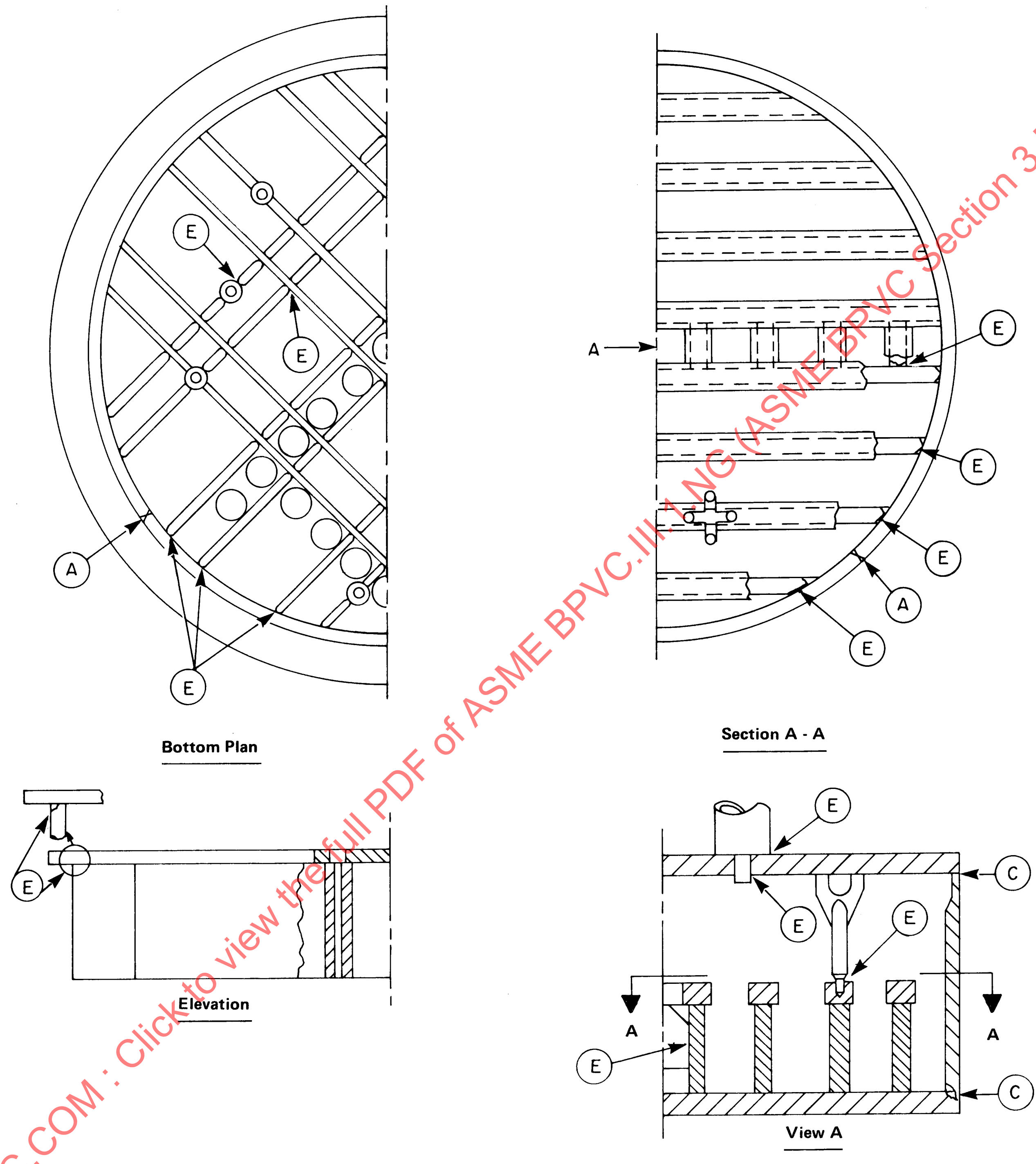


Table NG-3352-1
Permissible Welded Joints and Design Factors

Type of Welded Joint		Permissible for Category Shown Below	Quality Factor and Fatigue Factor [Note (1)]				
			RT or UT [Note (2)] and PT or MT Examination NG-5220	Progressive PT or MT Examination NG-5231	Root and Final PT or MT Examination NG-5232	Surface PT or MT Examination NG-5233	Surface Visual Examination NG-5260
I.	Full penetration	A, B, C, D, E	n = 1.0 f = 1	n = 0.9 f = 1	n = 0.75 f = 1	n = 0.65 f = 1	n = 0.5 f = 1
II.	Full penetration	A, B, C, D, E	n = 1.0 f = 2	n = 0.9 f = 2	n = 0.75 f = 2	n = 0.65 f = 2	n = 0.5 f = 2
III.	Full penetration	C, D, E	n = 1.0 f = 1	n = 0.9 f = 1 [Note (3)]	n = 0.75 f = 1 [Note (3)]	n = 0.65 f = 1 [Note (3)]	n = 0.5 f = 1 [Note (3)]
IV.	Double groove (RT not applicable)	A, B, C	n = 0.5 f = 4	n = 0.45 f = 4	n = 0.4 f = 4	n = 0.35 f = 4	n = 0.25 f = 4
		D, E	n = 0.9 f = 4	n = 0.8 f = 4	n = 0.7 f = 4	n = 0.6 f = 4	n = 0.4 f = 4
V.	Double fillet (RT not applicable)	B, C	n = 0.5 f = 4	n = 0.45 f = 4	n = 0.4 f = 4	n = 0.35 f = 4	n = 0.25 f = 4
		D, E	n = 0.9 f = 4	n = 0.8 f = 4	n = 0.7 f = 4	n = 0.6 f = 4	n = 0.4 f = 4
VI.	Single groove (RT not applicable)	D, E	n = 0.6 f = 4	n = 0.55 f = 4	n = 0.45 f = 4	n = 0.4 f = 4	n = 0.35 f = 4
VII.	Single fillet (RT not applicable)	D, E	n = 0.6 f = 4	n = 0.55 f = 4	n = 0.45 f = 4	n = 0.4 f = 4	n = 0.35 f = 4
VIII.	Intermittent fillet or plug	E	Not applicable	n = 0.45 f = 4	n = 0.4 f = 4	n = 0.35 f = 4	n = 0.3 f = 4

NOTES:
(1) See NG-3352 for definitions.
(2) Electroslag butt welds shall be examined by radiography. Electroslag welds in ferritic material shall also be examined for their full length by the ultrasonic method after a grain refining heat treatment, when performed, or after a postweld heat treatment.
(3) A minimum fatigue strength reduction factor of 1.0 is permitted when both sides of weld are examined; otherwise a factor of 2.0 must be used in analysis for cyclic operation.

NG-3352.5 Type V Joints. Double fillet welds meet the intent of this subparagraph when the area of the connection is determined by the product of the theoretical throat thickness times the length of the welds (Figure NG-4427-1). Joints made having one side a single fillet and the other side a single groove meet the intent of this subparagraph.

NG-3352.6 Type VI Joints. Partial penetration welds of single groove design meet the intent of this subparagraph when the area of the connection is determined as the product of the weld throat thickness times the length of weld.

NG-3352.7 Type VII Joints. Single fillet welds meet the intent of this subparagraph when the area of the connection is determined as the product of the theoretical throat thickness of the fillet welds times the length of weld (Figure NG-4427-1).

NG-3352.8 Type VIII Joints. Intermittent fillet or plug welds meet the intent of this subparagraph when the area of the intermittent fillet weld connection is determined as the product of the theoretical throat thickness times the sum of weld lengths and the area of plug weld connection is determined as the product of the number of plug welds times the area of the minimum cross section.

NG-3352.9 Limitations on Types of Joints. The type of joint used for service shall be one of those permitted for the Category of the joint (NG-3351). Reduced quality factors must be used for certain types of joints when used in Categories A, B, and C (Table NG-3352-1).

ARTICLE NG-4000
FABRICATION AND INSTALLATION

NG-4100 GENERAL REQUIREMENTS

NG-4110 INTRODUCTION

(a) Core support structures (NG-1121) shall be manufactured and installed in accordance with the requirements of this Article and shall be manufactured from materials which meet the requirements of Article NG-2000.

(b) The rules of this Article apply to the internal structures (NG-1122) only as specifically implemented by the Certificate Holder; however, the Certificate Holder shall certify that each internal structure has been fabricated so as to avoid creating an adverse effect on the integrity of the core support structure.

NG-4120 CERTIFICATION OF MATERIAL AND FABRICATION BY CERTIFICATE HOLDER

NG-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 NCA-8000, that the materials used comply with the requirements of Article NG-2000 and that the fabrication and installation comply with the requirements of this Article.

NG-4121.1 Certification of Treatments, Tests, and Examinations. If the Certificate Holder performs treatments, tests, repairs, or examinations required by other Articles, he shall certify that he has fulfilled such requirements. Reports of all required treatments and of the results of all required tests, repairs, and examinations performed shall be available to the Inspector.

NG-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 (NG-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 which have been taken and treated in accordance with the requirements of Article NG-2000.

NG-4122 Material Identification

Material for core support structures shall carry identification markings which will remain distinguishable until the core support structure is fabricated or installed. If the original identification markings are cut off or the material is divided, the marks shall be accurately transferred to the parts or a coded marking shall be used to assure identification of each piece of material during subsequent fabrication or installation, unless otherwise provided by NG-2150. Material supplied with a Certificate of Compliance and welding and brazing material shall be identified and controlled so that they can be traced to the core support structure, or else a control procedure shall be employed which ensures that the specified material is used.

NG-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 NG-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 NG-5500 and NG-5100, respectively, unless so specified.

NG-4125 Testing of Welding Material

All welding material shall meet the requirements of NG-2400.

NG-4130 REPAIR OF MATERIAL

NG-4131 Elimination and Repair of Defects

Material originally accepted on delivery in which defects exceeding the limits of NG-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 NG-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 NG-5130