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# PART 2

## INSPECTION

THE NATIONAL BOARD OF BOILER AND PRESSURE VESSEL INSPECTORS

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# INTRODUCTION

It is the purpose of the *National Board Inspection Code* (NBIC) to maintain the integrity of pressure-retaining items by providing rules for post-construction activities including installation, and by providing rules for post-installation activities including inspections, repairs, and alterations, thereby ensuring the safety of the pressure-retaining items' continued use.

The NBIC is intended to provide rules, information, and guidance to manufacturers, jurisdictions, Inspectors, owner-users, installers, contractors, and other individuals and organizations performing or involved in post-construction activities, thereby encouraging the uniform administration of rules pertaining to pressure retaining items.

## SCOPE

The NBIC recognizes four important areas of post-construction activities where information, understanding, and following specific requirements will promote public and personal safety. These areas include:

- Installation
- Inspection
- Repairs and Alterations
- Testing of Pressure Relief Devices

The NBIC provides rules, information, and guidance for post-construction activities, but does not provide details for all conditions involving pressure-retaining items. Where complete details are not provided in this Code, the Code user is advised to seek guidance from the applicable jurisdiction or other technical sources.

The words "shall," "should," and "may" are used throughout the NBIC and have the following intent:

- Shall – action that is mandatory.
- Should – indicates a preferred but not mandatory means to accomplish the requirement unless specified by other sources, such as the Jurisdiction.
- May – permissive, not required or a means to accomplish the specified task.

## ORGANIZATION

The NBIC is organized into four parts to coincide with specific post-construction activities involving pressure-retaining items. Each part provides general and specific rules, information, and guidance within each applicable post-construction activity. Individual NBIC parts or other published standards may contain additional information or requirements needed to meet the rules of the NBIC. Each part provides specific references to direct the user where to find this additional information. NBIC parts are identified as:

- Part 1, Installation – This part provides requirements and guidance to ensure the proper installation and functioning of all types of pressure-retaining items. Installation includes meeting specific safety criteria for construction, materials, design, supports, safety devices, operation, testing, and maintenance.
- Part 2, Inspection – This part provides information and guidance needed to perform and document inspections for all types of pressure-retaining items. This part includes information on personnel safety, non-destructive examination, tests, failure mechanisms, types of pressure equipment, fitness for service, risk-based assessments, and performance-based standards.
- Part 3, Repairs and Alterations – This part provides requirements and guidance to perform, verify, and document acceptable repairs or alterations to pressure-retaining items regardless of code of construction. Alternative methods for examination, testing, heat treatment, etc., are provided when the original code of construction requirements cannot be met. Specific acceptable and proven repair methods are also provided.
- Part 4, Pressure Relief Devices – This part provides information and guidance to ensure pressure relief devices are installed properly, that inspections of pressure relief devices are performed and documented properly, and that repairs to pressure relief devices are performed, verified, and documented properly.

Each part of the NBIC is divided into major sections as outlined in the Table of Contents.

## TEXT IDENTIFICATION AND NUMBERING

Each page in the text displays the publication name and publication year in the header; the footer of each page displays the designated section and page number. The numbering sequence for each section begins with the section number followed by a period to further designate major sections (e.g., 1.1, 1.2, 1.3). Major sections are further subdivided using periods to designate subsections within that major section (e.g., 1.1.1, 1.2.1, 1.3.1). Subsections can be further divided as necessary. Paragraphs under sections or subsections shall be designated with a small letter followed by a parenthesis (e.g., a), b), c)) and are further subdivided using a number followed by a parenthesis (e.g., 1), 2), 3)).

Subdivisions of paragraphs beyond this point will be designated using a hierarchical sequence of letters and numbers, each of which is followed by a period.

Example: 2.1 Major Section
2.1.1 Section
2.1.2 Section
2.1.2. Subsection
a) paragraph
b) paragraph
1) subparagraph
2) subparagraph
a. subdivisions
1. subdivisions
2. subdivisions
b. subdivisions
1. subdivisions
2. subdivisions

Each part of the NBIC typically contains tables, charts, and figures within or after each major section. Tables, charts, and figures provide relevant illustrations or supporting information for text passages and are designated with numbers corresponding to the paragraph they illustrate or support within each section or subsection. Multiple tables, charts, or figures referenced by the same paragraph are marked with additional letters sequentially arranged to reflect the order of reference.

## SUPPLEMENTS

Supplements are contained in each part of the NBIC to provide requirements and guidance pertaining only to a specific type of pressure-retaining item (e.g., locomotive boilers, historical boilers, graphite pressure vessels) or to a specific subject (e.g., report forms, alternative repair methods, etc.). Supplements follow the same numbering system used for the main text but are preceded by the letter “S”. Each page of the supplement is tabbed to identify the supplement number.

## EDITIONS

Editions of the NBIC are published every two years. Editions are permissive on the date issued; however, they become mandatory six months after the date of issue. Substantive revisions and/or additions that have been incorporated into the NBIC since the last edition are noted with the two-digit publication year, enclosed in parentheses, in the margin next to the section, subsection, or paragraph containing the revision(s) and/or addition(s).

## CODE STAMPING

ASME Code “stamping” referenced throughout the NBIC includes the ASME Boiler and Pressure Vessel Code Symbol Stamps used for conformity assessment prior to the 2010 edition/2011 addenda and the equivalent ASME Certification Mark required to meet the later editions of the ASME Boiler and Pressure Vessel Code sections. When other construction codes or standards are utilized for repairs or alterations, stamping shall mean the identification symbol stamp required by that code or standard.

## INTERPRETATIONS, CODE ADDITIONS, AND CODE REVISIONS

The NBIC Committee meets regularly to consider requests for interpretations, revisions, and additions for this Code. Interpretations are provided for each part and are specific to the Code edition and addenda referenced in the interpretation; interpretations may be used with subsequent editions of the NBIC provided the requirements have not changed. Interpretations provide clarification of existing rules in the NBIC, but are not part of the NBIC. Code revisions and additions are intended to accommodate technological developments, address administrative requirements, or clarify Code intent.

Interested parties may submit requests for Code interpretations, revisions, and additions through the National Board Business Center by following these steps:

1. Navigate to https://buscenter.nationalboard.org in your web browser;
2. Sign in to the Business Center (this may require creating an account);
3. Navigate to the NBIC tab and select “Request”;
4. Click “Make a Request”;
5. Select your request type; and
6. Fill out all fields in the request form and click the “Submit Request” button.

National Board staff will review all new requests before submitting them to the NBIC Committee for consideration at the next scheduled NBIC meeting.

## PRESENTATION REQUESTS

From time to time someone requests to give a presentation to specific NBIC committees (e.g., subgroups, subcommittees, NBIC Main Committee). Requests to give a presentation to any committee must be submitted in writing to the NBIC Committee Secretary at least one month prior to the scheduled NBIC meetings. The written request must specify the subject and committee(s) to which you are requesting to provide the presentation. All requests shall contain a copy of the presentation in a format that is acceptable to the NBIC Secretary, such as Microsoft PowerPoint. Requests should be emailed to the NBIC Secretary at NBICSecretary@nbbi.org.

Commercial promotion is not permitted.

All requests for presentations are subject to the approval of The National Board and the Chair(s) of the specific committee(s).

## JURISDICTIONAL PRECEDENCE

The NBIC references the requirements of the “Jurisdiction.” Where any provision herein presents a direct or implied conflict with any jurisdictional regulation, the jurisdictional regulation shall govern. Where the requirements of the jurisdiction do not meet the minimum requirements of the NBIC Part 3, the National Board “**R**” or “**NR**” Symbol stamp shall not be applied, and the applicable “**R**” reports shall not be signed by the “**R**” or “**NR**” Certificate Holder or the Inspector.

## UNITS OF MEASUREMENT

Both U.S. customary units and metric units are used in the NBIC. The value stated in U.S. customary units or metric units are to be regarded separately as the standard. Within the text, the metric units are noted in parentheses. In NBIC Part 2, Supplement 6 and NBIC Part 3, Supplement 6, regarding DOT Transport Tanks, the U.S. customary unit is noted in parentheses following each metric unit reference.

U.S. customary units or metric units may be used with this edition of the NBIC, but one system of units shall be used consistently throughout a repair or alteration of a pressure-retaining item. It is the responsibility of National Board-accredited repair organizations to ensure the appropriate units are used consistently

throughout all phases of work. This includes materials, design, procedures, testing, documentation, and stamping. The NBIC policy for metrication is outlined in Section 7 of each part of the NBIC.

## ACCREDITATION PROGRAMS

The National Board administers four specific accreditation programs as shown below:

"**R**".....Repairs and alterations to pressure-retaining items (NB-415)
"**VR**".....Repairs to pressure relief valves (NB-514)
"**NR**".....Repair and replacement activities for nuclear items (NB-417)
"**T/O**".....Testing of pressure relief valves (NB-528)

The administrative requirements for these accreditation programs can be viewed on the National Board's website at www.nbbi.org.

The National Board also administers four specific accreditation/acceptance programs for inspection agencies as shown below:

New Construction
*National Board Acceptance of Authorized Inspection Agencies* (AIA) *Accredited by the American Society of Mechanical Engineers* (ASME; NB-360)

Inservice
*Accreditation of Authorized Inspection Agencies* (AIA) *Performing Inservice Inspection Activities* (NB-369)

Owner-User
*Accreditation of Owner-User Inspection Organizations* (OUIO; NB-371)
Owners or users may be accredited for both a repair and inspection program provided the requirements for each accreditation program are met.

Federal Government
*Accreditation of Federal Inspection Agencies* (FIA; NB-390)

These programs can be viewed on the National Board's website at www.nbbi.org. For questions or further information regarding these programs, contact the National Board by phone at (614) 888-8320 or by fax at (614) 847-1828.

## *CERTIFICATES OF AUTHORIZATION* FOR ACCREDITATION PROGRAMS

Any organization seeking accreditation for a National Board program(s) shall apply to the National Board to obtain a *Certificate of Authorization* for the requested scope of activities. A confidential review shall be conducted to evaluate the organization's Quality System and its implementation of the same. Upon completion of the evaluation, a recommendation regarding the applicable *Certificate of Authorizatio*n will be sent to the National Board.

*Certificate of Authorization* scope, issuance, and revisions for National Board accreditation programs are specified in the applicable National Board procedures. When the Quality System requirements of the applicable accreditation program have been met, a *Certificate of Authorization* and National Board Symbol stamp, if applicable, will be issued.

# FOREWORD

The National Board of Boiler and Pressure Vessel Inspectors is an organization comprised of Chief Inspectors for the states, cities, and territories of the United States and provinces and territories of Canada. It is organized for the purpose of promoting greater safety to life and property by securing concerted action and maintaining uniformity in post-construction activities of pressure-retaining items, thereby ensuring acceptance and interchangeability among Jurisdictional authorities responsible for the administration and enforcement of various codes and standards.

In keeping with the principles of promoting safety and maintaining uniformity, the National Board originally published the NBIC in 1946, establishing rules for inspection and repairs to boilers and pressure vessels. The *National Board Inspection Code* (NBIC) Committee is charged with the responsibility for maintaining and revising the NBIC. In the interest of public safety, the NBIC Committee decided, in 1995, to revise the scope of the NBIC to include rules for installation, inspection, and repair or alteration to boilers, pressure vessels, piping, and nonmetallic materials.

In 2007, the NBIC was restructured into three parts specifically identifying important post-construction activities involving safety of pressure-retaining items. This restructuring provides for future expansion, transparency, uniformity, and ultimately improving public safety.

In 2017, the NBIC was once again restructured into 4 parts, adding a new Part 4, Pressure Relief Devices. This purpose of this restructuring was to provide one distinct integrated part for pressure relief devices compiled from all PRD information referenced in Part 1, Installation; Part 2, Inspection; and Part 3, Repairs and Alterations.

The NBIC Committee's function is to establish rules of safety governing post-construction activities for the installation, inspection, and repair and alteration of pressure-retaining items, and to interpret these rules when questions arise regarding their intent. In formulating the rules, the NBIC Committee considers the needs and concerns of individuals and organizations involved in the safety of pressure-retaining items. The objective of the rules is to afford reasonably certain protection of life and property, so as to give a reasonably long, safe period of usefulness. Advancements in design and material and the evidence of experience are recognized.

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

The NBIC Committee meets regularly to consider revisions of existing rules, formulation of new rules, and respond to requests for interpretations. Requests for interpretation must be addressed to the NBIC Secretary in writing and must give full particulars in order to receive Committee consideration and a written reply. Proposed revisions to the code resulting from inquiries will be presented to the NBIC Committee for appropriate action.

Proposed revisions to the code approved by the NBIC Committee are submitted to the American National Standards Institute and published on the National Board web-site to invite comments from all interested persons. After the allotted time for public review and final approval, the new edition is published. The Foreword, Introduction, Personnel and Index Sections of the NBIC are provided for guidance and informational purposes only and shall not be considered a part of the Code. These sections are not approved by the NBIC Committee or submitted to the American National Standards Institute.

Organizations or users of pressure-retaining items are cautioned against making use of revisions that are less restrictive than former requirements without having assurance that they have been accepted by the Jurisdiction where the pressure-retaining item is installed.

The general philosophy underlying the NBIC is to parallel those provisions of the original code of construction, as they can be applied to post-construction activities. The NBIC does not contain rules to cover all details of post-construction activities. Where complete details are not given, it is intended that individuals or organizations, subject to the acceptance of the Inspector and Jurisdiction when applicable, provide details

for post-construction activities that will be as safe as otherwise provided by the rules in the original code of construction.

Activities not conforming to the rules of the original code of construction or the NBIC must receive specific approval from the Jurisdiction, who may establish requirements for design, construction, inspection, testing, and documentation.

There are instances where the NBIC serves to warn against pitfalls; but the code is not a handbook, and cannot substitute for education, experience, and sound engineering judgment. It is intended that this edition of the NBIC not be retroactive. Unless the Jurisdiction imposes the use of an earlier edition, the latest effective edition is the governing document.

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# PART 2, SECTION 1
# INSPECTION — GENERAL REQUIREMENTS FOR INSERVICE INSPECTION OF PRESSURE-RETAINING ITEMS

## 1.1 SCOPE

This section provides general requirements and guidelines for conducting inservice inspection of pressure-retaining items and includes precautions for the safety of inspection personnel. The safety of the public and the Inspector is the most important aspect of any inspection activity.

## 1.2 ADMINISTRATION

Jurisdictional requirements describe the frequency, scope, type of inspection, whether internal, external, or both, and type of documentation required for the inspection. The Inspector shall have a thorough knowledge of jurisdictional regulations where the item is installed, as jurisdictional or regulatory inspection requirements do vary.

Unless otherwise specifically required by the jurisdiction, the duties of the Inspector do not include inspection to other standards and requirements (e.g., environmental, construction, electrical, operational, undefined industry standards, etc.) for which other regulatory agencies have authority and responsibility to oversee.

## 1.3 REFERENCE TO OTHER CODES AND STANDARDS

Other existing inspection codes, standards, and practices pertaining to the inservice inspection of pressure-retaining items can provide useful information and references relative to the inspection techniques listed in this part. Use of these codes, standards, and practices are subject to review and acceptance by the Inspector, and when required by the Jurisdiction. Any inconsistency or discrepancy between the requirements of the NBIC and these inspection codes, standards, and practices shall be resolved by giving precedence to requirements in the following order:

a) The requirements of the Jurisdiction having authority.

b) The requirements of the NBIC supersede general and specific requirements of other inspection codes, standards, and practices.

c) The general and specific requirements of the references to other codes and standards listed herein that are recognized and generally accepted good engineering practices.

Some examples are as follows:

a) National Board *Bulletin* - National Board Classic Articles Series

b) American Society of Mechanical Engineers - *ASME Boiler and Pressure Vessel Code Section V* (Nondestructive Examination)

c) American Society of Mechanical Engineers - *ASME Boiler and Pressure Vessel Code Section VI* (Recommended Rules for the Care and Operation of Heating Boilers) this section when performing inspections of heating boilers. There may be occasions where more detailed procedures will be required.

d) American Society of Mechanical Engineers- *ASME Boiler and Pressure Vessel Code Section VII* (Recommended Guidelines for the Care of Power Boilers)

e) American Society of Mechanical Engineers -*ASME B31G* (Manual for Determining the Remaining Strength of Corroded Pipelines)

f) American Society of Mechanical Engineers - *ASME PCC-1* (Guidelines for Pressure Boundary Bolted Joint Assembly)

g) American Society of Mechanical Engineers - *ASME PCC-2* (Repair of Pressure Equipment and Piping)

h) American Society of Mechanical Engineers - *ASME CRTD Volume 41,* (Risk-Based Inspection for Equipment Life Management: An Application Handbook)

i) American Petroleum Institute/American Society of Mechanical Engineers - *API 579-1/ASME FFS-I* (Fitness-For-Service)

j) American Petroleum Institute – *API-510* (Pressure Vessel Inspection Code: In-service Inspection, Rating, Repair and Alteration)

k) American Petroleum Institute - *API 570* (Piping Inspection Code: In-Service Inspection, Rating, Repair and Alteration of Piping Systems)

l) American Petroleum Institute - *API 572* (Inspection of Pressure Vessels)

m) American Petroleum Institute - (Inspection Practices for Piping System Components)

n) American Petroleum Institute - *API 576* (Inspection of Pressure-Relieving Devices)

o) American Petroleum Institute - *Recommended Practice 580* (Risk Based Inspection)

p) American Petroleum Institute - *Recommended Practice* 581 (Base Resource Document on Risk-Based Inspection)

q) Institute of Petroleum - *Model Code of Safe Practice in the Petroleum Industry Part 12 ,* Pressure Vessel Examination

r) Institute of Petroleum - *Model Code of Safe Practice in the Petroleum Industry Part 13,* (Pressure Piping Systems Examination)

s) Australian Standard - *AS 1210* (Unfired Pressure Vessel Code)

t) Australian Standard - *AS 4343* (Pressure Equipment - Hazard Levels)

u) Alberta Boilers Safety Association - *AB-506* (Pressure Equipment Inspection and Servicing Requirements)

## 1.4 PERSONNEL SAFETY

a) Personnel safety is the joint responsibility of the owner or user and the Inspector. All applicable safety regulations shall be followed. This includes federal, state, regional, and/or local rules and regulations. Owner or user programs, safety programs of the Inspector's employer, or similar standards also apply. In the absence of such rules, prudent and generally accepted engineering safety procedures satisfactory to the Inspector shall be employed by the owner or user.

b) Inspectors are cautioned that the operation of safety devices involves the discharge of fluids, gases, or vapors. Extreme caution should be used when working around these devices due to hazards to

personnel. Suitable hearing protection should be used during testing because extremely high noise levels can damage hearing.

c) Inspectors shall take all safety precautions when examining equipment. Proper personal protective equipment shall be worn, equipment shall be locked out, blanked off, decontaminated, and confined space entry permits obtained before internal inspections are conducted. In addition, Inspectors shall comply with plant safety rules associated with the equipment and area in which they are inspecting. Inspectors are also cautioned that a thorough decontamination of the interior of vessels is sometimes very hard to obtain and proper safety precautions must be followed to prevent contact or inhalation injury with any extraneous substance that may remain in the tank or vessel.

### 1.4.1 PERSONAL SAFETY REQUIREMENTS FOR ENTERING CONFINED SPACES

a) No pressure-retaining item shall be entered until it has been properly prepared for inspection. The owner or user and Inspector shall jointly determine that pressure-retaining items may be entered safely. This shall include:

   1) Recognized hazards associated with entry into the object have been identified by the owner or user and are brought to the attention of the Inspector, along with acceptable means or methods for eliminating or minimizing each of the hazards;

   2) Coordination of entry into the object by the Inspector and owner or user representative(s) working in or near the object;

   3) Personal protective equipment required to enter an object shall be used. This may include, among other items, protective outer clothing, gloves, respiratory protection, eye protection, foot protection, and safety harnesses. The Inspector shall have the proper training governing the selection and use of any personal protective clothing and equipment necessary to safely perform each inspection. Particular attention shall be afforded respiratory protection if the testing of the atmosphere of the object reveals any hazards;

   4) Completing and posting of confined space entry permits, as applicable; and

   5) An effective energy isolation program (lock out and/or tag out) is in place and in effect that will prevent the unexpected energizing, start-up, or release of stored energy.

b) The Inspector shall determine that a safe atmosphere exists before entering the pressure-retaining item. The atmosphere shall be verified by the owner or user as directed by the Inspector.

   1) The oxygen content of the breathable atmosphere shall be between 19.5% and 23.5%.

   2) If any flammable or combustible materials are present in the atmosphere they shall not exceed 10% of their Lower Explosive Limit (LEL) or Lower Flammable Limit (LFL).

   3) The Inspector shall not enter an area if toxic, flammable or inert gases, vapors or dusts are present and above acceptable limits.

c) Remote visual inspection is an acceptable alternative to confined space entry provided the requirements of 4.2.1 c) are met and where allowed by the jurisdiction.

### 1.4.2 EQUIPMENT OPERATION

The Inspector shall not operate owner or user equipment. Operation shall be conducted only by competent owner or user employees familiar with the equipment and qualified to perform such tasks.

## 1.5 INSPECTION ACTIVITIES

A proper inspection of a pressure-retaining item requires many pre-inspection planning activities including: safety considerations, an inspection plan that considers the potential damage mechanisms, selection of appropriate inspection methods, and awareness of the jurisdictional requirements. This Section describes pre-inspection and post-inspection activities applicable to all pressure-retaining items. Specific inspection requirements for pressure-retaining items are identified in NBIC Part 2, 2.2 for boilers, 2.3 for pressure vessels, 2.4 for piping and piping systems, and 2.5 for pressure relief devices.

### 1.5.1 INSERVICE INSPECTION ACTIVITIES

Any defect or deficiency in the condition, operating, and maintenance practices of a boiler, pressure vessel, piping system, and pressure relief devices noted by the Inspector shall be discussed with the owner or user at the time of inspection and recommendations made for the correction of such defect or deficiency shall be documented. Use of a checklist to perform inservice inspections is recommended.

### 1.5.2 PRE-INSPECTION ACTIVITIES

a) Prior to conducting the inspection, a review of the known history of the pressure-retaining item and a general assessment of current conditions shall be performed. This shall include a review of information such as:

   1) Date of last inspection;

   2) Current jurisdictional inspection certificate;

   3) ASME Code Symbol Stamping or mark of code of construction;

   4) National Board and/or jurisdiction registration number;

   5) Operating conditions and normal contents of the vessel (discuss any unique hazards with the owner, previous inspection report, operating/maintenance logs and test records, and any outstanding recommendations from the previous inspection);

   6) Records of wall thickness checks, especially where corrosion or erosion is a consideration;

   7) Review of repairs or alterations and any associated records for compliance with applicable requirements; and

   8) Observation of the condition of the overall complete installation, including maintenance and operation records.

b) The following activities should be considered to support the inspection:

   1) Removal of pressure gages or other devices for testing and calibration; and

   2) Accessibility to inspect and test each pressure-retaining item and its appurtenances.

#### 1.5.2.1 INSPECTION PLANNING

An inspection plan should be developed to better ensure continued safe operation of a pressure-retaining item (PRI).

A formal inspection plan is a document providing the scope of inspection activities necessary to determine if in-service damage has occurred. The plan identifies methods of examination, qualifications of examiners, and frequency of examination necessary to ensure PRI is suitable for continued service. It may provide a

time interval for external and internal inspection as well as describe methods of repair and maintenance for a PRI.

A plan may include the following, as appropriate for a PRI:

a) The known or expected failure mechanisms that affect the specific equipment. See NBIC Part 2, 3.3 *Corrosion*, 3.4 *Failure Mechanisms*, and 4.4.6 *Identification of Damage Mechanisms* for examples;

b) The extent and locations of NDE methods and inspections required to detect and evaluate the failure mechanisms. See NBIC Part 2, Section 4 for examples;

c) The necessary corrosion and erosion monitoring activities such as NDE surveys and changes in process conditions;

d) The preparation required to accomplish the examination and inspection activities; and/or

e) The projected time interval for the inspection and evaluation activities. See NBIC Part 2, 4.4.7 *Determining Inspection Intervals* and 4.4.8 *Evaluating Inspection Intervals of Pressure Retaining Items Exposed to Inservice Failure Mechanisms*.

Recent operating history (e.g., process upsets or process changes or operating excursions) and management of change records should be reviewed during preparation of the inspection plan.

Industry standards may be used to prepare an inspection plan. A plan may be a simple single document or may be complex, having numerous documents. Risk-Based Assessment may be included in a plan. See 4.5 *Risk-Based Inspection Assessment Programs*.

Once a plan has been implemented, deferral of scheduled inspection or assessment activities specified in the plan is to be avoided. Any deviation from the planned intervals or inspection activities needs to be justified and documented. Additional monitoring of the PRI during a deferral period may be employed to better ensure safe PRI operation until the planned activity can be completed.

### 1.5.3 PREPARATION FOR INTERNAL INSPECTION

The owner or user has the responsibility to prepare a pressure-retaining item for internal inspection. Requirements of occupational safety and health regulations (i.e., federal, state, local, or other), as well as the owner-user's own program and the safety program of the Inspector's employer are applicable. The pressure-retaining item should be prepared in the following manner or as deemed necessary by the Inspector:

a) When a vessel is connected to a common header with other vessels or in a system where liquids or gases are present, the vessel shall be isolated by closing, locking, and/or tagging stop valves in accordance with the owner's or user's procedures. When toxic or flammable materials are involved, additional safety precautions may require removing pipe sections or blanking pipelines before entering the vessel. The means of isolating the vessel shall be in compliance with applicable occupational safety and health regulations and procedures. For boilers or fired pressure vessels, the fuel supply and ignition system shall be locked out and/or tagged out, in accordance with the owner's or user's procedures;

b) The vessel temperature shall be allowed to cool or warm at a rate to avoid damage to the vessel. When a boiler is being prepared for internal inspection, the water should not be withdrawn until it has been sufficiently cooled at a rate to avoid damage;

c) The vessel shall be drained of all liquid and shall be purged of any toxic or flammable gases or other contaminants that were contained in the vessel. The continuous use of mechanical ventilation using a fresh air blower or fan may be necessary to maintain the vessel's atmosphere within acceptable limits. During air purging and ventilation of vessels containing flammable gases, the concentration of vapor in air may pass through the flammable range before a safe atmosphere is obtained. All necessary precautions shall be taken to eliminate the possibility of explosion or fire;

d) Items requested by the Inspector, such as manhole and handhole plates, washout plugs, inspection plugs, and any other items shall be removed;

e) The Inspector shall not enter a vessel until all safety precautions have been taken. The temperature of the vessel shall be such that the inspecting personnel will not be exposed to excessive heat. Vessel surfaces should be cleaned as necessary so as to preclude entrant exposure to any toxic or hazardous materials;

f) If requested by the Inspector or required by regulation or procedure, a responsible attendant shall remain outside the vessel at the point of entry while the Inspector is inside and shall monitor activity inside and outside and communicate with the Inspector as necessary. The attendant shall have a means of summoning rescue assistance, if needed, and to facilitate rescue procedures for all entrants without personally entering the vessel.

**Note**: If a vessel has not been properly prepared for an internal inspection, the Inspector shall decline to make the inspection.

### 1.5.4 POST-INSPECTION ACTIVITIES

a) During any inspections or tests of pressure-retaining items, the actual operating and maintenance practices should be noted by the Inspector and a determination made as to their acceptability.

b) Any defects or deficiencies in the condition, operating, and maintenance practices of the pressure-retaining item shall be discussed with the owner or user at the time of inspection and recommendations made for correction. Follow-up inspections should be performed as needed to determine if deficiencies have been corrected satisfactorily.

c) Documentation of inspection shall contain pertinent data such as description of item, classification, identification numbers, inspection intervals, date inspected, type of inspection, and test performed, and any other information required by the inspection agency, jurisdiction, and/or owner or user. The Inspector shall sign, date, and note any deficiencies, comments, or recommendations on the inspection report. The Inspector should retain and distribute copies of the inspection report, as required.

d) The form and format of the inspection report shall be as required by the Jurisdiction. Where no Jurisdiction exists, forms NB-5, NB-6, or NB-7 (see NBIC Part 2, 5.3) or any other form(s) required by the inspection agency or owner or user may be used as appropriate.

## 1.6 CHANGE OF SERVICE

Supplement 9 of this part provides requirements and guidelines to be followed when a change of service or service type is made to a pressure-retaining item.

Whenever there is a change of service, the Jurisdiction where the pressure-retaining item is to be operated, shall be notified for acceptance, when applicable. Any specific jurisdictional requirements shall be met.

## (23) 1.7 SCRAPPING PRESSURE RETAINING ITEMS

The owner or user should deface beyond recognition and remove the code nameplate(s) or stamping of any pressure-retaining item that is scrapped. The removal or defacement of the Code nameplate(s) should be verified by the Inspector, and the National Board form NB-480 should be completed and submitted to the National Board, and Jurisdiction if required.

### 1.7.1 INSTRUCTIONS FOR COMPLETING THE FORM NB-480, *SCRAPPING OF PRESSURE RETAINING ITEMS FORM* (23)

Items 1-9 should be completed by the owner, user, or “R” Certificate Holder making the request.

1) The name, address, and phone number of the jurisdiction, or Authorized Inspection Agency when there is no jurisdiction, to which the for is being submitted for approval.

2) Enter the name and address of your company or organization.

3) Enter the name and address of the manufacturer shown on the nameplate.

4) Enter the name and address of the location where the pressure-retaining item is installed. If this is the same as number 2, check the box “same as # 2.”

5) Manufacturer’s Data Report Attached-check the appropriate box.

6) Is the pressure-retaining item registered with the National Board? Check the appropriate box. If yes, provide the National Board Registration Number.

7) Provide as much information as known to help identify the pressure-retaining item.

8) Enter the date of removal or defacement of the Code nameplate.

9) Enter the name and signature of the owner, user, or “R” Certificate.

**Note:** Once completed the requester should file a copy with the jurisdiction in which the pressure-retaining item is installed, the National Board (if registered with the National Board), the owner or user of the vessel if the request was made by an “R” Certificate Holder, and upon request to the Authorized Inspection Agency who witnessed the removal or defacement of the nameplate.

The National Board of Boiler and Pressure Vessel Inspectors

NB-480, Rev. 0, (02/27/23)

# SCRAPPING OF PRESSURE-RETAINING ITEMS

IN ACCORDANCE WITH PROVISIONS OF THE NATIONAL BOARD INSPECTION CODE

1. **SUBMITTED TO:**

(Name of Jurisdiction)

(Address)

(Phone Number)

2. **SUBMITTED BY:**

(Name of Owner/User)

(Address)

(Phone Number)

3. MANUFACTURED BY: (Name and address) _____

4. LOCATION OF INSTALLATION: (Address) _____

5. MANUFACTURER'S DATA REPORT: YES ☐ NO ☐

6. ITEM REGISTERED WITH NATIONAL BOARD: YES ☐ NO ☐ NB NUMBER: _____

7. ITEM IDENTIFICATION:

Year Built: _____ Mfr. Serial No.: _____

Type: _____ Jurisdiction No.: _____

Dimensions: _____ MAWP: _____

8. DATE OF REMOVAL OR DEFACEMENT OF THE CODE NAMEPLATE(S): _____

**9. I certify that to the best of my knowledge and belief the statements in this report are correct, and with provisions of the National Board Inspection Code.**

Name of Owner/User _____

Signature: _____ Date: _____

This form may be obtained from The National Board of Boiler and Pressure Vessel Inspectors • 1055 Crupper Avenue, Columbus, Ohio 43229-1183

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# PART 2, SECTION 2
# INSPECTION — DETAILED REQUIREMENTS FOR INSERVICE INSPECTION OF PRESSURE-RETAINING ITEMS



## 2.1 SCOPE

This section provides general and detailed inspection requirements and guidelines for pressure-retaining items to determine corrosion deterioration and possible prevention of failures for boilers, pressure vessels, piping, and pressure relief devices.

Materials to be inspected shall be suitably prepared so that surface irregularities will not be confused with or mask any defects. Material conditioning such as cleaning, buffing, wire brushing, or grinding may be required by procedure or, if requested, by the Inspector. The Inspector may require insulation or component parts to be removed.

## 2.2 BOILERS

### 2.2.1 SCOPE

This section provides guidelines for external and internal inspection of boilers used to contain pressure. This pressure may be obtained from an external source or by the application of heat from a direct or indirect source or a combination thereof.

### 2.2.2 SERVICE CONDITIONS

a) Boilers are designed for a variety of service conditions. The temperature and pressure at which they operate should be considered in establishing inspection criteria. This part is provided for guidance of a general nature. There may be occasions where more detailed procedures will be required.

b) The condition of the complete installation, including maintenance and operation, can often be used by the Inspector as a guide in forming an opinion of the care given to the boiler.

c) Usually the conditions to be observed by the Inspector are common to both power and heating boilers; however, where appropriate, the differences are noted.

### 2.2.3 PRE-INSPECTION ACTIVITIES

A review of the known history of the boiler shall be performed. This shall include a review of information contained in NBIC Part 2, 1.5.2, and other items listed in NBIC Part 2, 2.2.4.

### 2.2.4 CONDITION OF BOILER ROOM OR BOILER LOCATION

The general condition of the boiler room or boiler location should be assessed using appropriate jurisdictional requirements and overall engineering practice. Items that are usually considered are lighting, adequacy of ventilation for habitability, combustion air, housekeeping, personal safety, and general safety considerations.

### 2.2.5 EXTERNAL INSPECTION

The external inspection of a boiler is made to determine if it is in a condition to operate safely. Some items to consider are:

a) The boiler fittings, valves, and piping should be checked for compliance with ASME Code or other standards or equivalent requirements. Particular attention should be paid to pressure relief devices and other safety controls;

b) Firing equipment controls;

c) Adequacy of structure, boiler supports, and any associated support steel;

d) Boiler casing should be free from cracks, combustion gas or fluid leaks, excessive corrosion or other degradation that could interfere with proper operation;

e) Soot blowers, valves, and actuating mechanisms;

f) Gaskets on observation doors, access doors, drums, handhole and manhole covers and caps;

g) Valves and actuators, either chains, motors, and/or handwheels; and

h) Leakage of fluids or combustion gases.

### 2.2.6 INTERNAL INSPECTION

a) When a boiler is to be prepared for internal inspection, the water shall not be withdrawn until the setting has been sufficiently cooled at a rate to avoid damage to the boiler as well as additional preparations identified in NBIC Part 2, 1.4.1 and 1.5.3.

b) The owner or user shall prepare a boiler for internal inspection in the following manner:

1) Before opening the manhole(s) and entering any part of the boiler that is connected to a common header with other boilers, the required steam or water system stop valves (including bypass) must be closed, locked out, and/or tagged in accordance with the owner or user's procedures, and drain valves or cocks between the two closed stop valves be opened. After draining the boiler, the blowoff valves shall be closed, locked out, and/or tagged out in accordance with the owner-user's procedures. Alternatively, lines may be blanked or sections of pipe removed. Blowoff lines, where practicable, shall be disconnected between pressure parts and valves. All drains and vent lines shall be open.

2) The Inspector shall review all personnel safety requirements as outlined in NBIC Part 2, 1.4 prior to entry.

**Note**: If a boiler has not been properly prepared for an internal inspection, the Inspector shall decline to make the inspection.

### 2.2.7 EVIDENCE OF LEAKAGE

a) It is not normally necessary to remove insulating material, masonry, or fixed parts of a boiler for inspection, unless defects or deterioration are suspected or are commonly found in the particular type of boiler being inspected. Where there is evidence of leakage showing on the covering, the Inspector shall have the covering removed in order that a thorough inspection of the area may be made. Such inspection may require removal of insulating material, masonry, or fixed parts of the boiler.

b) For additional information regarding a leak in a boiler or determining the extent of a possible defect, a pressure test may be performed per NBIC Part 2, 4.3.1.

### 2.2.8 BOILER CORROSION CONSIDERATIONS

a) Corrosion causes deterioration of the metal surfaces. It can affect large areas, or it can be localized in the form of pitting. Isolated, shallow pitting is not considered serious if not active.

b) The most common causes of corrosion in boilers are the presence of free oxygen and dissolved salts in the feedwater. Where active corrosion is found, the Inspector should advise the owner or user to obtain competent advice regarding proper feedwater treatment.

c) For the purpose of estimating the effect of severe corrosion over large areas on the safe working pressure, the thickness of the remaining sound metal should be determined by ultrasonic examination or by drilling.

d) Grooving is a form of metal deterioration caused by localized corrosion and may be accelerated by stress concentration. This is especially significant adjacent to riveted joints.

e) All flanged surfaces should be inspected, particularly the flanges of unstayed heads. Grooving in the knuckles of such heads is common since there is slight movement in heads of this design, which causes a stress concentration.

f) Some types of boilers have ogee or reversed-flanged, construction which is prone to grooving and may not be readily accessible for examination. The Inspector should insert a mirror through an inspection opening to examine as much area as possible. Other means of examination, such as the ultrasonic method, may be employed.

g) Grooving is usually progressive and when it is detected, its effect should be carefully evaluated and corrective action taken.

h) Pitting and corrosion on the waterside surfaces of the tubes should be examined. In vertical firetube boilers, excessive corrosion and pitting is often noted at and above the water level.

### 2.2.9 WATERSIDE DEPOSITS

a) All accessible surfaces of the exposed metal on the waterside of the boiler should be inspected for deposits caused by water treatment, scale, oil, or other substances. Oil or scale in the tubes of watertube boilers is particularly detrimental since this can cause an insulating effect resulting in overheating, weakening, possible metal fatigue, bulging, or rupture.

b) Excessive scale or other deposits should be removed by chemical or mechanical means.

### 2.2.10 INSPECTION OF BOILER PIPING, PARTS, AND APPURTENANCES

#### 2.2.10.1 BOILER PIPING

Piping should be inspected in accordance with NBIC Part 2, 2.4.

#### 2.2.10.2 FLANGED OR OTHER CONNECTIONS

a) The manhole and reinforcing plates, as well as nozzles or other connections flanged or bolted to the boiler, should be examined for evidence of defects both internally and externally. Whenever possible, observation should be made from both sides, internally and externally, to determine whether connections are properly made to the boiler.

b) All openings leading to external attachments, such as water column connections, low-water fuel cutoff devices, openings in dry pipes, and openings to safety valves, should be examined to ensure they are free from obstruction.

### 2.2.10.3 MISCELLANEOUS

a) The piping to the water column should be carefully inspected to ensure that water cannot accumulate in the steam connection. The position of the water column should be checked to determine that the column is placed in accordance with the original code of construction or jurisdictional requirements.

b) The gas side baffling should be inspected. Absence of proper baffling or defective baffling can cause high temperatures and overheat portions of the boiler. The location and condition of combustion arches should be checked for evidence of flame impingement, which could result in overheating.

c) Any localization of heat caused by improper or defective installation or improper operation of firing equipment shall be corrected before the boiler is returned to service.

d) The refractory supports and settings should be carefully examined, especially at points where the boiler structure comes near the setting walls or floor, to ensure that deposits of ash or soot will not bind the boiler and produce excessive strains on the structure due to the restriction of movement of the parts under operating conditions.

e) When tubes have been re-rolled or replaced, they should be inspected for proper workmanship. Where tubes are readily accessible, they may have been overrolled. Conversely, when it is difficult to reach the tube ends, they may have been underrolled.

f) Valves should be inspected on boiler feedwater, blowdown, drain, and steam systems for gland leakage, operability, tightness, handle or stem damage, body defects, and general corrosion.

### 2.2.10.4 GAGES

a) Ensure that the water level indicated is correct by having the gage tested as follows:

   1) Close the lower gage-glass valve, then open the drain cock and blow the glass clear;

   2) Close the drain cock and open the lower gage-glass valve. Water should return to the gage-glass immediately;

   3) Close the upper gage glass valve, then open the drain cock and allow the water to flow until it runs clean;

   4) Close the drain cock and open the upper gage-glass valve. Water should return to the gage-glass immediately; and

   5) If the water return is sluggish, the test should be discontinued. A sluggish response could indicate an obstruction in the pipe connections to the boiler. Any leakage at these fittings should be promptly corrected to avoid damage to the fittings or a false waterline indication.

b) Unless there is other information to assess their accuracy or reliability, all the pressure gages shall be removed, tested, and their readings compared to the readings of a calibrated standard test gage or a dead weight tester.

c) The location of a steam pressure gage should be noted to determine whether it is exposed to high temperature from an external source or to internal heat due to lack of protection by a proper siphon or trap. The Inspector should check that provisions are made for blowing out the pipe leading to the steam gage.

d) The Inspector should observe the pressure gage reading during tests; for example, the reduction in pressure when testing the low-water fuel cutoff control or safety valve on steam boilers. Defective gages shall be replaced.

### 2.2.10.5 PRESSURE RELIEF DEVICES

See NBIC Part 2, 2.5 for the inspection of safety devices (e.g., pressure relief valves) used to prevent overpressure of boilers.

### 2.2.10.6 CONTROLS

Establishing proper operation and maintenance of controls and safety devices is essential to safe boiler operation. Owners or users are responsible for establishing and implementing management programs which will ensure such action is taken. In addition, any repairs to controls and safety devices must only be made by qualified individuals or organizations. Documentation of compliance with these management systems and repairs is an essential element of demonstrating the effectiveness of such systems.

When required by the Jurisdiction, the following guidelines are provided to aid in the evaluation of installed operating control devices:

a) Verify that the burner is labeled and listed by a recognized testing agency, that piping and wiring diagrams exist, that commissioning tests have been conducted and that a contractor/manufacturer's installation report has been completed and is available for review.

b) Verify that the owner or user has established function tests, inspection requirements, maintenance and testing of all controls and safety devices in accordance with manufacturer's recommendations. Verify that these activities are conducted at assigned intervals in accordance with a written procedure, that non-conformances which impact continued safe operation of the boiler are corrected, and that the results are properly documented. These activities shall be conducted at a frequency recommended by the manufacturer or the frequency required by the jurisdiction. Where no frequencies are recommended or prescribed, the activity should be conducted at least annually.

   Where allowed by the jurisdiction, Performance Evaluation may be used to increase or decrease the frequencies based on document review and approval by an appropriate engineer.

c) Verify that combustion air is supplied to the boiler room as required by the jurisdiction or if no jurisdictional requirements exist see NBIC, Part 1, 2.5.4 and 3.5.4 for additional guidance.

d) Verify that a manually operated remote boiler emergency stop button exists at each boiler room exit door, when required by the jurisdiction.

e) Verify operation of low water protection devices by observing the blowdown of these controls or the actual lowering of boiler water level under carefully controlled conditions with the burner operating. This test should shut off the heat source to the boiler. The return to normal condition such as the restart of the burner, the silencing of an alarm, or stopping of a feed pump should be noted. A sluggish response could indicate an obstruction in the connections to the boiler.

f) The operation of a submerged low-water fuel cutoff mounted directly in a steam boiler shell should be tested by lowering the boiler water level carefully. This should be done only after being assured that the water level gage glass is indicating correctly.

g) On a high-temperature water boiler, it is often not possible to test the control by cutoff indication, but where the control is of the float type, externally mounted, the float chamber should be drained to check for the accumulation of sediment.

h) On forced circulation boilers, the flow sensing device shall be tested to verify that the burner will shut down the boiler on a loss of flow.

i) On electric boilers, it should be verified that the boiler is protected from a low water condition either by construction or a low water cutoff or a low flow sensing device.

j) In the event controls are inoperative or the correct water level is not indicated, the boiler shall be taken out of service until the unsafe condition has been corrected.

k) All automatic low-water fuel cutoff and water-feeding devices should be examined by the Inspector to ensure that they are properly installed. The Inspector should have the float chamber types of control devices disassembled and the float linkage and connections examined for wear. The float chamber should be examined to ensure that it is free of sludge or other accumulation. Any necessary corrective action shall be taken before the device is placed back into service. The Inspector should check that the operating instructions for the devices are readily available.

l) Check that the following controls/devices are provided:

1) Each automatically fired steam boiler is protected from overpressure by not less than two pressure operated controls, one of which may be an operating control.

When required by the code of construction or the jurisdiction, the high pressure limit control shall be of the manual reset type.

2) Each automatically fired hot-water boiler or hot-water boiler system is protected from over-temperature by not less than two temperature operating controls, one of which may be an operating control.

When required by the code of construction or the jurisdiction, the high temperature limit control shall be of the manual reset type.

3) Each hot-water boiler is fitted with a thermometer that will at all times, indicate the water temperature at or near the boiler outlet.

m) Verify that any repair, alteration, or replacement of a control or safety device complies with the following:

1) The requirements of the original installation code or jurisdiction, as appropriate.

2) The work is conducted by trained and qualified individuals, with any additional certification as required by the jurisdiction.

3) The work is documented.

### 2.2.11 RECORDS REVIEW

a) A review of the boiler log, records of maintenance, and feedwater treatment should be made by the Inspector to ensure that regular and adequate tests have been made on the boiler and controls.

b) The owner or user should be consulted regarding repairs or alterations, if any, which have been made since the last inspection. Such repairs or alterations should be reviewed for compliance with the jurisdictional requirements, if applicable.

### 2.2.12 DESCRIPTION AND CONCERNS OF SPECIFIC TYPES OF BOILERS

The following details are unique to specific type boilers and should be considered when performing inspections along with the general requirements as previously outlined.

#### 2.2.12.1 CAST-IRON BOILERS

a) Cast-iron boilers are used in a variety of applications to produce low pressure steam and hot-water heat. Cast-iron boilers should only be used in applications that allow for nearly 100% return of condensate or water and are not typically used in process-type service. These boilers are designed to operate with minimum scale, mud, or sludge, which could occur if makeup water is added to this system.

b) Due to the unique design and material considerations of cast-iron boilers, the following are common areas of inspection:

1) Scale and Sludge — Since combustion occurs at or near the bottom, accumulation of scale or sludge close to the intense heat can cause overheating and lead to cracking;

2) Feedwater — Makeup feedwater should not come in contact with hot surfaces. Supply should be connected to a return pipe for tempering;

3) Section Alignment — Misalignment of sections can cause leakage. Leakage or corrosion between sections will not allow normal expansion and contraction and that may cause cracking;

4) Tie Rods or Draw Rods — Used to assemble the boiler and pull the sections together. These rods must not carry any stress and need to be loose, allowing for section growth during heat up. Expansion washers may be used and nuts should be just snugged allowing for expansion;

5) Push Nipple or Seal Area — Corrosion or leakage is likely at the push-nipple opening, usually caused by the push nipple being pushed into the seat crooked, warping due to overheating, tie rods too tight, and push-nipple corrosion/erosion;

6) Corrosion — Firesides of sections can corrode due to ambient moisture coupled with acidic flue gas deposits; and

7) Soot — Inadequate oxygen supply or improperly adjusted burner can allow for soot buildup in fireside passages. A reduction in efficiency and hot spots may occur. Soot, when mixed with water, can form acidic solutions harmful to the metal.

### 2.2.12.2 FIRETUBE BOILERS

a) The distinguishing characteristic of a firetube boiler is that the products of combustion pass within tubes that are surrounded by the water that is being heated. Combustion of fuel takes place within the furnace area, with the resultant products of combustion traveling through one or more groups of tubes before exiting the boiler. Firetube boilers are classified by the arrangement of the furnace and tubes such as Horizontal Return Tubular (HRT) boiler, Firetube Fire Box (FTFB) boiler, or Vertical Tubular (VT) boiler. The number of passes that the products of combustion make through the tubes is also used in classifying the type of boiler, such as a two-pass or three-pass boiler.

b) Firetube boilers may be used in hot-water or steam applications. They may be either low-pressure or high-pressure construction, but typically are not designed for pressures greater than 250 psig (1,720 kPa). Steam capacities are generally less than 30,000 lb/hr (13,600 kg/hr). Firetube boilers are found in a wide variety of applications ranging from heating to process steam to small power generation.

c) Firetube boilers are subject to thermal stresses due to cycling, which may cause tube leakage and corrosion of joints. The following items are common areas of inspection:

1) Waterside — Scale buildup on and around the furnace tube. Scale on or around the firetubes in the first pass after the furnace (gas temperatures >1,800°F [980°C]). Scale and corrosion buildup on stay rods hiding the actual diameter. Corrosion pitting on all pressure boundaries;

2) Fireside — Tube-to-tube sheet joint leakage. Look for rust trails left by weeping joints. When in doubt where the leakage is coming from, perform a liquid penetrant exam. Take note of refractory locations protecting steel that is not water-cooled. Partial or complete removal of the refractory may be required for inspection purposes. Condensation of combustion gas dripping out of the fireside gaskets during a cold boiler start-up is expected. However, if it continues after the water temperature in the boiler is at least 150°F (65°C), then further investigation to determine the source of water shall be conducted;

3) The fireside surfaces of tubes in horizontal firetube boilers usually deteriorate more rapidly at the ends nearest the fire. The Inspector should examine the tube ends to determine if there has been serious reduction in thickness. The tube surfaces in some vertical tube boilers are more susceptible to deterioration at the upper ends when exposed to the heat of combustion. These tube ends should be closely examined to determine if there has been a serious reduction in thickness. The upper tube sheet in a vertical “dry top” boiler should be inspected for evidence of overheating;

4) All stays, whether diagonal or through, should be inspected to determine whether or not they are in even tension. Staybolt ends and the stayed plates should be examined to determine whether cracks exist. In addition, stayed plates should be inspected for bulging in the general area of the stay. Each staybolt end should be checked for excessive cold working (heading) and seal welds as evidence of a possible leakage problem. Stays or staybolts that are not in tension or adjustment should be repaired. Broken stays or staybolts shall be replaced; and

5) The Inspector should test firebox staybolts by tapping one end of each bolt with a hammer and, where practicable, a hammer or other heavy tool should be held on the opposite end to make the test more effective. An unbroken bolt should give a ringing sound while a broken bolt will give a hollow or non-responsive sound. Staybolts with telltale holes should be examined for evidence of leakage, which will indicate a broken or cracked bolt. Broken staybolts shall be replaced.

d) Practical considerations lead to the use of basically cylindrical shells. Flat-end tubesheet surfaces are supported by various methods: diagonal stays, through-bolts, or the tubes themselves. Tubes may be rolled, welded, or rolled and seal-welded into the tubesheets. For steam applications, the water level is maintained several inches above the uppermost row of tubes, which allows for a steam space in the upper portion of the boiler shell. There are several different types of firetube boilers:

1) Firetube Scotch Marine (FTSM)

a. A Firetube Scotch Marine boiler consists of a horizontal cylindrical shell with an internal furnace. Fuel is burned in the furnace with the products of combustion making two, three, or four passes through the boiler tubes. The rear door may be either a dry refractory lined design (dry back) or a water-cooled (wet back) design. Two designs of the furnace are commonly used: one, the corrugated type, is known as a Morrison furnace; the other is the plain furnace.

b. The FTSM boiler design is one of the oldest firetube boiler designs with internal furnaces. Extensive use in early marine service added “marine” to the name of this type of boiler. Currently both the wet back design and the dry back design can be found in stationary applications. Firetube Scotch Marine boilers are used for both high-pressure and low-pressure steam applications and are also used for hot-water service.

2) Horizontal Return Tubular (HRT)

a. Horizontal Return Tubular boilers consist of a cylindrical shell with flat tube sheets on the ends. The tubes occupy the lower two-thirds of the shell with a steam space above the tubes. The lower portion of the shell is enclosed by refractory brick work forming the furnace of the boiler, which is normally quite large to accommodate solid fuel firing. The shell is supported by the brick work or by support beams that are connected by buckstays to suspension lugs mounted on the shell. This type of boiler is highly susceptible to overheating of the lower portion of the shell due to scale accumulation that prevents heat transfer from the shell to the water. Another area of concern is the bottom blowdown line, which passes through the rear of the furnace. It must be protected with a refractory baffle to prevent direct contact with the products of combustion. Another potential problem is deterioration of the furnace brickwork, allowing the products of combustion to escape and thus reducing efficiency.

b. HRT boilers were originally used for both high-pressure and low-pressure steam applications. HRT boilers were quite common in the early to-mid-1900s. These boilers are frequently of riveted construction. The design is quite inefficient due to the one pass design and the large

amount of brickwork that is heated by the products of combustion. Units that are still in service are typically found in old industrial facilities and are generally only used for steam heating applications.

3) Firetube Fire Box (FTFB)

   a. Firetube Fire Box boilers were popular in the mid-1900s, although many can still be found in service. An FTFB boiler consists of an external furnace that is enclosed by water legs on three or four sides. The water legs extend upward to the crownsheet to form the lower part of the boiler shell while the upper part of the shell is formed by the extension of the water leg outer shell. Flat heads are used on both ends of the boiler shell. The boilers may be two-, three-, or four-pass designs.

   b. Since the water legs of FTFB boilers are the lowest point of the water side, loose scale and sludge tends to accumulate. Besides interfering with water flow, the accumulated sediment may accelerate corrosion of water leg stay bolts or the water legs themselves. The handholes in the water legs should be open during an internal inspection.

4) Locomotive

   Locomotive boilers are similar in design to the boilers on old steam locomotives. This design saw limited stationary applications and few remain in service today. Most are of riveted construction. See Supplement 1 for detailed drawings.

5) Vertical Firetube

   As the name implies, vertical firetube boilers are arranged with the shell and tubes in the vertical orientation. These boilers are generally small (<10,000 lb/hr [ 4,540 kg/hr] capacity) and are used where the rapid development of steam is necessary for operation. Vertical firetube boilers are found in many high- and low-pressure applications. The burner may be located on the top or bottom of the boiler. Due to their small size and frequent application where considerable makeup water is used, scale development is an important concern.

### 2.2.12.3 WATERTUBE BOILERS

a) Typically constructed of drums, headers, and tubes, watertube boilers are used to produce steam or hot water commonly in large quantities. They range in size and pressure from small package units to extremely large field-erected boilers with pressures in excess of 3,000 psig (21 MPa). These boilers may be fired by many types of fuels such as wood, coal, gas, oil, trash, and black liquor. Their size and type of construction poses mechanical and thermal cyclic stresses.

b) There are many locations, both internal and external, where moisture and oxygen combine, causing a primary concern for corrosion. The fuels burned in watertube boilers may contain ash, which can form an abrasive grit in the flue gas stream. The abrasive action of the ash in high-velocity flue gas can quickly erode boiler tubes.

c) Unique parts associated with this type of construction, such as casing, expansion supports, superheater, economizer, soot blowers, drums, headers, and tubes should be inspected carefully and thoroughly in accordance with NBIC Part 2, 2.2.

d) The surfaces of tubes should be carefully examined to detect corrosion, erosion, bulges, cracks, or evidence of defective welds. Tubes may become thinned by high velocity impingement of fuel and ash particles or by the improper installation or use of soot blowers. A leak from a tube frequently causes serious corrosion or erosion on adjacent tubes.

e) In restricted fireside spaces, such as where short tubes or nipples are used to join drums or headers, there is a tendency for fuel and ash to lodge at junction points. Such deposits are likely to cause corrosion if moisture is present, and the area should be thoroughly cleaned and examined.

f) Drums and headers should be inspected internally and externally for signs of leakage, corrosion, overheating, and erosion. Inspect blowdown piping and connections for expansion and flexibility. Check header seals for gasket leakage.

g) Soot blower mechanical gears, chains, pulleys, etc., should be checked for broken or worn parts. Inspect supply piping to the soot blowers for faulty supports, leakage, and expansion and contraction provisions. Check design for proper installation to allow for complete drainage of condensate, which may cause erosion.

h) Watertube boilers may contain dead air spaces between the boiler casing and the fireside cavity. These dead air spaces include the penthouse, upper arch dead air space and lower throat dead air spaces that frequently house the drums and headers. There is a tendency for unburned solid fuel and ash to collect in these dead air spaces which may limit the ability to inspect these spaces for corrosion, tube bulges, service-induced cracking, or defective welds. These dead air spaces should be thoroughly cleaned and examined.

### 2.2.12.4 ELECTRIC BOILERS

a) Electric boilers are heated by an electrical energy source, either by use of electric resistant coils or induction coils. These boilers may be used in either high-or low-pressure steam or hot water applications.

b) Due to the unique design and material considerations of electric boilers, the following are common areas of inspection:

1) Weight stress of the elements —Some electrodes and elements can be quite heavy, especially if covered with scale deposits. These elements will scale sooner and at a faster rate than internal surfaces. Excessive weight puts severe stress on the attachment fittings and welds at support points;

2) Thermal shock — Heaters are constantly cycling on and off, creating temperature gradients, but are less susceptible to thermal shock than a fired boiler; and

3) Leakage — Any leakage noted at the opening where electrodes or elements are inserted is extremely dangerous due to the possible exposure of electrical wires, contacts, and breakers.

### 2.2.12.5 FIRED COIL WATER HEATERS

a) Fired coil water heaters are used for rapid heating of potable water or hot water service. This design utilizes a coil through which the water being heated is passed. This type of heater has very little volume and may be used in conjunction with a hot-water storage vessel.

b) Due to the unique design and material considerations of fired coil water heaters, the following are common areas of inspection:

1) Erosion — Size and velocity of water flow through the coil combines to create wear and thinning of the coils. If a temperature differential is created within the coil, bubbles or steam may cause grooving or cavitation;

2) Corrosion — This type of system uses 100% makeup water that contains free oxygen, creating opportunities for extensive corrosion;

3) Vibration — Operation of the burner creates a certain amount of vibration. Creation of steam, hot spots, or lack of flow may create a water hammer, causing extensive vibration and mechanical stresses;

4) Scale — Due to the large volume of makeup, significant amounts of scale-forming particles will adhere to the hot surfaces.

### 2.2.12.6 FIRED STORAGE WATER HEATERS

a) Fired storage water heaters are vertical pressure vessels containing water to which heat is applied. Typically, gas burners are located directly beneath the storage vessel. These heaters should be insulated and fitted with an outer jacket and may be lined with porcelain, glass, galvanized metal, cement, or epoxy.

b) Due to the unique design and material considerations of fired storage water heaters, the following are common areas of inspection:

1) Corrosion — Moisture may be trapped between the insulation and outer jacket, which may cause corrosion of the pressure boundary;

2) Mud and sludge — There is 100% makeup of water, allowing for accumulation of mud and sludge in the bottom portions of the vessel. Any buildup can cause overheating and failure of the metal in this area;

3) Scale — Loose scale may accumulate in areas adjacent to the burner and lower portions of the vessel, interfering with heat transfer process and causing localized overheating. Scale and sludge can also shield temperature control probes, giving false readings and allowing the water to overheat;

4) Thermal cycling — Heated water is continually replaced with cold water causing thermal stress within the vessel;

5) Lining — Loss of lining or coating will allow for rapid deterioration of the pressure boundary;

6) Pressure — If water supply pressure exceeds 75% of set pressure of safety relief valve, a pressure-reducing valve may be required;

7) Expansion — If the water heater can be isolated by devices such as a check valve, it is recommended that an expansion tank be provided.

### 2.2.12.7 THERMAL FLUID HEATERS (23)

a) Design and Operating Features

1) Many thermal fluid heaters are pressure vessels in which a synthetic or organic fluid is heated or vaporized. Some thermal fluid heaters operate at atmospheric pressure. The fluids are typically flammable, are heated above the liquid flash point, and may be heated above the liquid boiling point. The heaters are commonly direct-fired by combustion of a fuel or by electric resistance elements. Heater design may be similar to that of an electric resistance heated boiler, a firetube boiler or, more commonly, a watertube boiler. Depending on process heating requirements, the fluid may be vaporized with a natural circulation, but more often, the fluid is heated and circulated by pumping the liquid. Use of thermal fluid heating permits heating at a high temperature with a low system pressure (600°F to 700°F [316°C to 371°C] at pressures just above atmospheric). To heat water to those temperatures would require pressures of at least 1,530 psig (10.6 MPa).

2) Nearly all thermal heating fluids are flammable. Leaks within a fired heater can result in destruction of the heater. Leaks in external piping can result in fire and may result in an explosion. Water

accumulation in a thermal heating system may cause upsets and possible fluid release from the system if the water contacts heated fluid (remember, flashing water expands approximately 1,600 times). It is essential for safe system operation to have installed and to maintain appropriate fluid level, temperature and flow controls for liquid systems, and level, temperature, and pressure controls for vapor systems. Expansion tanks used in thermal heater systems, including vented systems, should be designed and constructed to a recognized standard, such as ASME Section VIII, Div. 1, to withstand pressure surges that may occur during process upsets. This is due to the rapid expansion of water exceeding the venting capability.

3) Because heat transfer fluids contract and become more viscous when cooled, proper controls and expansion tank venting are required to prevent low fluid level and collapse of the tank. Some commonly used fluids will solidify at temperatures as high as 54°F (12°C). Others do not become solid until -40°F (-40°C) or even lower. The fluids that become viscous will also become difficult to pump when cooled. Increased viscosity could cause low flow rates through the heater. The heater manufacturer recommendations and the fluid manufacturer's Material Safety Data Sheets (MSDS) should be reviewed for heat tracing requirements.

4) Verify the thermal fluid heaters have stack gas temperature indicators, alarms, and safety shut down devices. Stack gas temperatures shall be monitored and recorded daily while in operation.

b) Industrial Applications

Thermal fluid heaters, often called boilers, are used in a variety of industrial applications, such as solid wood products manufacturing, resins, turpentine, and various types of chemicals, drugs, plastics, corrugating plants, and wherever high temperatures are required. They are also frequently found in asphalt plants for heating of oils, tars, asphalt pitches, and other viscous materials. Many chemical plants use this type of heater in jacketed reactors or other types of heat exchangers.

c) Inspection

1) Due to the unique design and material considerations of thermal fluid heaters and vaporizers, common areas of inspection are:

a. Design — Specific requirements outlined in construction codes must be met. Some jurisdictions may require ASME Section I or Section VIII construction. Code requirements for the particular Jurisdiction should be reviewed for specific design criteria;

b. Materials — For some thermal fluids, the use of aluminum or zinc anywhere in the system is not advisable. Aluminum acts as a catalyst that will hasten decomposition of the fluid. In addition, some fluids when hot will cause aluminum to corrode rapidly or will dissolve zinc. The zinc will then form a precipitate that can cause localized corrosion or plug instrumentation, valves, or even piping in extreme cases. These fluids should not be used in systems containing aluminum or galvanized pipe. The fluid specifications will list such restrictions;

**Note**: Some manufacturers of these fluids recommend not using aluminum paint on valves or fittings in the heat transfer system.

c. Corrosion — When used in applications and installations recommended by fluid manufacturer, heat transfer fluids are typically noncorrosive. However, some fluids, if used at temperatures above 150°F (65°C) in systems containing aluminum or zinc, can cause rapid corrosion;

d. Leakage — Any sign of leakage could signify problems since the fluid or its vapors can be hazardous as well as flammable. Areas for potential leaks include cracks at weld attachment points and tube thinning in areas where tubes are near soot blowers. The thermal fluid manufacturer specifications will list the potential hazards;

e. Solidification of the fluid — Determine that no conditions exist that would allow solidification of the thermal fluid. When heat tracing or insulation on piping is recommended by the heater manufacturer, the heat tracing and insulation should be checked for proper operation and installation;

f. Pressure relief valves — Pressure relief valves shall be a closed bonnet design with no manual lift lever. Pressure relief valves shall be periodically tested by a "VR" or "T/O" Certificate Holder with a frequency in accordance with jurisdictional requirements or an initial frequency of one year or less. Testing intervals shall be evaluated and may be adjusted based on inspection history up to a maximum of three years. The pressure relief valve installation shall meet the requirements of NBIC Part 4, 2.3. Inspection and testing of the pressure relief valve shall meet the requirements of NBIC Part 4, 3.0;

g. Inspection of thermal fluid heaters shall include verifying that fluid testing is conducted annually and that results are compared to the fluid manufacturer's standard. The inspector shall annually verify the documentation of testing of controls and safety devices; and

h. Vapor phase systems must have a documented vessel and piping risk-based inspection assessment program in accordance with NBIC Part 2, 4.5.

### 2.2.12.8 WASTE HEAT BOILERS

a) Waste heat boilers are usually of firetube or watertube type and obtain their heat from an external source or process in which a portion of the thermal energy has been utilized. Generation of electrical energy is usually the primary application of waste heat boilers. The biggest disadvantage of this type of boiler is that it is not fired on the basis of load demand. Since the boiler does not have effective control over the amount of heat entering the boiler, there may be wide variations or fluctuations of metal temperatures. Waste process gases are usually in a temperature range of 400°F (205°C) to 800°F (427°C), where combustion gases of conventionally fired boilers are at about 2,000°F (1,010°C). Special design considerations are made to compensate for lower combustion gas temperatures such as the use of finned high-efficiency heat absorbing tubes, and by slowing the velocity of gases through the boiler.

b) Due to the unique design and material considerations of waste heat boilers, the following are common areas of inspection:

1) Corrosion — Chemicals in waste heat gases may create corrosive conditions and react adversely when combined with normal gasses of combustion. Water or steam leakage can create localized corrosion. Extreme thermal cycling can cause cracks and leakage at joints;

2) Erosion — Typically waste heat flow is very low and erosion is not a problem. However, when waste heat is supplied from an internal combustion engine, exhaust gasses can be high enough to cause erosion;

3) Vibration — In some process applications and all engine waste heat applications, the boiler may be subjected to high vibration stresses;

4) Acid attack — In sulfuric acid processes refractory supports and steel casings are subject to acid attack. Piping, filters, heat exchangers, valves, fittings, and appurtenances are subject to corrosive attacks because these parts are not normally made of corrosion resistant materials; and

5) Dry operation — in certain applications waste heat boilers are operated without water. Care must be taken not to expose carbon steel material to temperatures in excess of 800°F (427°C) for prolonged periods. Carbides in the steel may precipitate to graphite at elevated temperatures.

### 2.2.12.9 KRAFT OR SULFATE BLACK LIQUOR RECOVERY BOILERS

a) Kraft or Sulfate Black Liquor Recovery boilers are used in the pulp and paper industry. Black liquor is a by-product of pulp processing. It contains organic and inorganic constituents concentrated to at least 58% solids for firing in the recovery boilers. The organic material that is dissolved in the pulping process combusts, and the spent pulping chemicals form a molten pool in the furnace. The molten material, or "smelt," drains from the furnace wall through smelt spouts into a smelt-dissolving tank for recovery of the chemicals. Ultimately, the by-product of the recovery process is steam used for processing and power. Gas or oil auxiliary burners are used to start the self-sustaining black liquor combustion process and may be used to produce supplemental steam if sufficient liquor is not available.

b) The recovery combustion process requires a reducing atmosphere near the furnace floor and an oxidizing atmosphere in the upper furnace for completion of combustion. Pressure parts within the furnace require protection from the reducing atmosphere and from sulfidation. The rate of corrosion within the furnace is temperature dependent. Boilers operating up to 900 psi (6.21 MPa) typically have plain carbon steel steam generating tubes with pin studs applied to the lower furnace to retain a protective layer of refractory or "frozen" smelt. Above 900 psi (6.21 MPa) the lower furnace tubes will typically have a special corrosion protection outer layer. The most common is a stainless steel clad "composite tube." Other protection methods are corrosion-resistant overlay welding, thermal or plasma spray coating, and diffusion coating.

c) The unique hazard of these boilers is the potential for an explosion if water should be combined with the molten smelt. The primary source of water is from pressure part failure, permitting water to enter the furnace. The owner's inspection program is carefully developed and executed at appropriate intervals to avoid pressure part failure that could admit water to the furnace. A second source of water is the liquor fuel.

d) Permitting black liquor of 58% or lower of solids content to enter the furnace can also result in an explosion. The black liquor firing controls include devices that monitor and automatically divert the liquor from the furnace if solids content is 58% or lower.

e) In addition to the general inspection requirements for all watertube-type boilers, particular awareness in the following areas is necessary:

    1) Furnace — The type and scope of wall, roof, and water screen tube inspection is dependent on materials of construction, type of construction, and mode of boiler operation. In all cases, furnace wall opening tubes need inspection for thinning and cracking. The typical water-cooled smelt spout can admit water to the furnace if the spout fails. Common practice is to replace these spouts in an interval shorter than that in which failure is known to occur;

    2) Water — Percentage of solids contained in the black liquor before entering the furnace shall be closely monitored. Verify that the black liquor firing system will automatically divert the liquor if solids drop to or below 58%;

    3) Corrosion/erosion — The potential consequences of corrosion or erosion (smelt-water explosion due to pressure-retaining part failure) requires a well planned and executed inspection program by the owner. Maintenance of boiler water quality is crucial to minimizing tube failure originating from the water side;

    4) Tubes — Depending on type of construction, inspect for damage such as loss of corrosion protection, thinning, erosion, overheating, warping, elongation, bulging, blistering, and misalignment. If floor tubes may have been mechanically damaged or overheated, clean the floor and perform the appropriate type of inspection for suspected damage. Excursions in water treatment may result in scale and sludge on internal surfaces, creating conditions of poor heat transfer and ultimately causing tube cracks or rupture;

5) Welds — Leaks frequently originate at welds. The owner and repair agency should carefully plan and inspect all repair welds and seal welds that could admit water to the furnace. Tube butt welds that could admit water to the furnace should be examined by a volumetric NDE method acceptable to the inspector. Tube leaks at attachment welds may originate from the internal stress-assisted corrosion (SAC). Minor upsets in boiler water quality and improper chemical cleaning may initiate SAC;

6) Emergency response to water entering furnace — Operators of Kraft recovery boilers should have a plan to immediately terminate all fuel firing and drain water from the boiler if a tube is known or suspected to be leaking into the furnace. This system may be called Emergency Shutdown Procedure (ESP). The inspector should confirm the ESP is tested and maintained such that it will function as intended and that operators will activate the system when a leak into the furnace occurs or is suspected; and

7) Overheating — Tube rupture due to overheating from low water level may admit water to the furnace. The inspector should verify a redundant low-water protection system is provided and maintained.

f) Recommended procedures for inspection of black liquor recovery boilers are identified below:

1) American Forest and Paper Association:

"Recovery Boiler Reference Manual for Owners and Operators of Kraft Recovery Boilers," sponsored by the Operations/Maintenance Subcommittee of the Recovery Boiler Committee, Volumes I, II, and III (current published editions);

2) The Black Liquor Recovery Boiler Advisory Committee (BLRBAC), Recommended Practices:

a. Emergency Shutdown Procedure (ESP) and Procedure for Testing ESP;

b. Safe Firing of Black Liquor Recovery Boilers;

c. System for Black Liquor Boilers;

d. Safe Firing of Black Liquor in Black Liquor Recovery Boilers;

e. Safe Firing of Auxiliary Fuel in Black Liquor Recovery Boilers;

f. Thermal Oxidation of Waste Streams in Black Liquor Recovery Boilers;

g. Instrumentation Checklist and Classification Guide for Instruments and Control Systems Used in the Operation of Black Liquor Recovery Boilers; and

h. Recommended Guidelines for Personnel Safety.

3) Technical Association of the Pulp and Paper Industry (TAPPI), Technical Information Papers:

a. 0402-13, Guidelines for Specification and Inspection of Electric Resistance Welded (ERW) and Seamless Boiler Tube for Critical and Non-Critical Service;

b. 0402-15, Installation and Repair of Pin Studs in Black Liquor Recovery Boilers;

c. 0402-18, Ultrasonic Testing (UT) for Tube Thickness in Black Liquor Recovery Boilers:

1. Part I: Guidelines for Accurate Tube Thickness Testing;

2. Part II: Default Layouts for Tube Thickness Surveys in Various Boiler Zones;

d. 0402-21, Ultrasonic Technician Performance Test for Boiler Tube Inspection;

e. 0402-30, Inspection for Cracking of Composite Tubes in Black Liquor Recovery Boilers;

f. 0402-31, Guidelines for Evaluating the Quality of Boiler Tube Butt Welds with Ultrasonic Testing; and

g. 0402-33, Guidelines for Obtaining High Quality Radiographic Testing (RT) of Butt Welds in Boiler Tubes.

## 2.3 PRESSURE VESSELS

### 2.3.1 SCOPE

This section provides guidelines for inservice inspection of pressure vessels used to contain pressure either internal or external. This pressure may be obtained from an external source, or by the application of heat from a direct or indirect source, or a combination thereof.

### 2.3.2 SERVICE CONDITIONS

a) Pressure vessels are designed for a variety of service conditions. The media that a pressure vessel contains and the temperature and pressure at which it operates should be considered in establishing inspection criteria. Usage, materials, and installation conditions should be considered in determining damage mechanisms that will affect the mechanical integrity of a pressure vessel as described in NBIC Part 2, Section 3. The general requirements for safety, pre-inspection, and post-inspection activities are specified in NBIC Part 2, Section 1 and should be followed in conjunction with the specific requirements outlined in this Section when performing inspections of pressure vessels. There may be occasions where more detailed procedures will be required.

b) The type of inspection given to pressure vessels should take into consideration the condition of the vessel and the environment in which it operates. This inspection may be either external or internal and use a variety of nondestructive examination methods as described in NBIC Part 2, Section 4. The inspection method may be performed when the vessel is operating on-stream or depressurized, but shall provide the necessary information to determine that the essential sections of the vessel are in satisfactory condition to operate for the expected time interval. On-stream inspection, including while under pressure, may be used to satisfy inspection requirements provided the accuracy of the method can be demonstrated.

c) New pressure vessels are placed in service to operate under their design conditions for a period of time determined by the service conditions and the corrosion rate. If the pressure vessel is to remain in operation, the allowable conditions of service and the length of time before the next inspection shall be based on the conditions of the vessel as determined by the inspection. See NBIC Part 2, 4.4.7 for determining remaining service life and inspection intervals.

### 2.3.3 EXTERNAL INSPECTION

The purpose of an external inspection is to provide information regarding the general condition of the pressure vessel. The following should be reviewed:

a) Insulation or Other Coverings

If it is found that external coverings such as insulation and corrosion-resistant linings are in good condition and there is no reason to suspect any unsafe condition behind them, it is not necessary to remove them for inspection of the vessel. However, it may be advisable to remove small portions of the coverings in order to investigate attachments, nozzles, and material conditions;
**Note**: Precautions should be taken when removing insulation while vessel is under pressure.

b) Evidence of Leakage

Any leakage of gas, vapor, or liquid should be investigated. Leakage coming from behind insulation coverings, supports or settings, or evidence of past leakage should be thoroughly investigated by removing any covering necessary until the source of leakage is established;

For additional information regarding a leak in a pressure vessel or determining extent of a possible defect, a pressure test may be performed per NBIC Part 2, 4.3.1;

c) Structural Attachments

The pressure vessel mountings should be checked for adequate allowance for expansion and contraction, such as provided by slotted bolt holes or unobstructed saddle mountings. Attachments of legs, saddles, skirts, or other supports should be examined for distortion or cracks at welds;

d) Vessel Connections

Manholes, reinforcing plates, nozzles, or other connections should be examined for cracks, deformation, or other defects. Bolts and nuts should be checked for corrosion or defects. Weep holes in reinforcing plates should remain open to provide visual evidence of leakage as well as to prevent pressure buildup between the vessel and the reinforcing plate. Accessible flange faces should be examined for distortion and to determine the condition of gasket-seating surfaces; and

e) Miscellaneous Conditions

1) Abrasives — The surfaces of the vessel should be checked for erosion.

2) Dents — Dents in a vessel are deformations caused by their coming in contact with a blunt object in such a way that the thickness of metal is not materially impaired. Dents can create stress risers that may lead to cracking.

3) Distortion — If any distortion is suspected or observed, the overall dimensions of the vessel shall be checked to determine the extent and seriousness of the distortion.

4) Cuts or gouges — Cuts or gouges can cause high stress concentrations and decrease the wall thickness. Depending upon the extent of the defect, repair may be necessary.

5) Surface inspection — The surfaces of shells and heads should be examined for possible cracks, blisters, bulges, corrosion, erosion, and other evidence of deterioration, giving particular attention to the skirt and to support attachment and knuckle regions of the heads.

6) Welded joints — Welded joints and the adjacent heat-affected zones should be examined for cracks or other defects. Magnetic particle or liquid penetrant examination is a useful means for doing this.

7) Riveted vessels — On riveted vessels, examine rivet head, butt strap, plate, and caulked edge conditions. If rivet shank corrosion is suspected, hammer testing for soundness or spot radiography at an angle to the shank axis may be useful.

## 2.3.4 INTERNAL INSPECTION

a) A general visual inspection is the first step in making an internal inspection of pressure vessels that are susceptible to corrosion. Vessels should be inspected for the conditions identified in NBIC Part 2, Section 3.

b) The following should be reviewed:

1) Vessel Connections

Threaded connections should be inspected to ensure that an adequate number of threads are engaged. All openings leading to any external fittings or controls should be examined as thoroughly as possible to ensure they are free from obstructions;

2) Vessel Closures

Any special closures including those on autoclaves, normally termed quick actuating (quick opening) closures, see NBIC Part 2, 2.3.6.5, which are used frequently in the operation of a pressure vessel, should be checked by the Inspector for integrity and wear. A check should also be made for cracks at areas of high stress concentration. Door safety interlock mechanisms, “man inside” alarm and associated audible and visual alarms should be verified. The “man inside” alarm is a safety cable running the length of the internal workspace that can be pulled by the operator, thereby shutting down all autoclave functions and initiating audible and visual alarms;

3) Vessel Internals

a. Where pressure vessels are equipped with removable internals, these internals need not be completely removed provided assurance exists that deterioration in regions rendered inaccessible by the internals is not occurring to an extent that might constitute a hazard, or to an extent beyond that found in more readily accessible parts of the vessel;

b. If a preliminary inspection reveals unsafe conditions such as loose or corroded internals or badly corroded internal ladders or platforms, steps should be taken to remove or repair such parts so that a detailed inspection may be made; and

4) Corrosion

The type of corrosion (local pitting or uniform), its location, and any obvious data should be established. Data collected for vessels in similar service will aid in locating and analyzing corrosion in the vessel being inspected. The liquid level lines, the bottom, and the shell area adjacent to and opposite inlet nozzles are often locations of most-severe corrosion. Welded seams, nozzles, and areas adjacent to welds are often subjected to accelerated corrosion.

## 2.3.5 INSPECTION OF PRESSURE VESSEL PARTS AND APPURTENANCES

Parts and appurtenances to be inspected depend upon the type of vessel and its operating conditions. The Inspector should be familiar with the operating conditions of the vessel and with the causes and characteristics of potential defects and deterioration.

### 2.3.5.1 GAGES

a) The pressure indicated by the required gage should be compared with other gages on the same system. If the pressure gage is not mounted on the vessel itself, it shall be installed in such a manner that it correctly indicates the actual pressure in the vessel. When required, the accuracy of pressure gages should be verified by comparing the readings with a calibrated test gage or a dead weight tester.

b) The location of a pressure gage should be observed to determine whether it is exposed to high temperature from an external source or to internal heat due to lack of protection by a proper siphon or trap. Provisions should be made for blowing out the pipe leading to the steam gage.

### 2.3.5.2 SAFETY DEVICES

See NBIC Part 2, 2.5 for the inspection of safety devices (pressure relief valves and non-closing devices such as rupture disks) used to prevent the overpressure of pressure vessels.

### 2.3.5.3 CONTROLS/DEVICES

a) Any control device attached to a vessel should be demonstrated by operation or the Inspector should review the procedures and records for verification of proper operation.

b) Temperature measuring devices shall be checked for accuracy and general condition.

### 2.3.5.4 RECORDS REVIEW

a) The Inspector shall review any pressure vessel log, record of maintenance, corrosion rate record, or any other examination results. The Inspector should consult with the owner or user regarding repairs or alterations made, if any, since the last internal inspection. The Inspector shall review the records of such repairs or alterations for compliance with applicable requirements.

b) A permanent record shall be maintained for each pressure vessel. This record should include the following:

   1) An ASME *Manufacturer's Data Report* or, if the vessel is not ASME Code stamped, other equivalent specifications or reports;

   2) Form NB-5, *Boiler or Pressure Vessel Data Report — First Internal Inspection*, may be used for this purpose. It shall show the following identification numbers as applicable:

      a. National Board No.

      b. Jurisdiction No.

      c. Manufacturer Serial No.

      d. Owner or User No.

   3) Complete pressure-relieving device information, including safety or safety relief valve spring data, or rupture disk data and date of latest inspection;

   4) Progressive record including, but not limited to, the following:

      a. Location and thickness of monitor samples and other critical inspection locations;

      b. Limiting metal temperature and location on the vessel when this is a factor in establishing the minimum allowable thickness;

      c. Computed required metal thicknesses and maximum allowable working pressure for the design temperature and pressure-relieving device opening pressure, static head, and other loadings;

      d. Test pressure, if tested at the time of inspection; and

      e. Required date of next inspection.

   5) Date of installation and date of any significant change in service conditions (pressure, temperature, character of contents, or rate of corrosion); and

6) Drawings showing sufficient details to permit calculation of the service rating of all components on pressure vessels used in process operations subject to corrosive conditions. Detailed data with sketches, where necessary, may serve this purpose when drawings are not available.

### 2.3.6 DESCRIPTION AND CONCERNS OF SPECIFIC TYPES OF PRESSURE VESSELS

Inspection and examination requirements identified below should also include any additional requirements mentioned above.

#### 2.3.6.1 DEAERATORS

a) A deaerator is used to remove undesirable gases and is exposed to the following service conditions: harmful gases, fluctuation in temperature and pressure, erosion, and vibration. The air and water atmosphere in the deaerator has a corrosive effect and may contain high concentrations of hydrogen ions, which can cause hydrogen cracking, hydrogen embrittlement, or corrosion fatigue. The water entering the deaerator sometimes carries acids or oil that can cause acidic attacks on the metal.

b) Inspection shall consist of the following:

1) Welds — Inspect all longitudinal and circumferential welds, including the Heat Affected Zone (HAZ), visually along their entire length. Examine nozzle and attachment welds for erosion, corrosion, or cracking. Inspect with special attention all exposed internal welds at or below the normal water line;

2) Shell — Inspect exterior surfaces for corrosion or leaks. Inspect interior for pitting, corrosion, erosion, thinning, wastage of metal, cracks, etc.;

3) Spray nozzles and trays — Inspect all nozzles and spray areas for erosion, wear, wastage, and broken parts or supports. Check to see that nozzles are not plugged and that all lines to nozzles are open. Inspect all trays for holes, erosion, wastage, broken or defective brackets, and broken support attachments;

4) Condenser and vents — Examine all vent lines to see that they are open to ensure proper exiting of the gases. Inspect the condenser unit to verify it is operable and not plugged with scale or sludge. Check for corrosion, pitting, erosion, and broken parts; and

5) Supports — Inspect all support structures for mechanical damage, cracks, loose bolting, and bent or warped components. Check all welds, especially attaching supports to the pressure boundary.

#### 2.3.6.2 COMPRESSED AIR VESSELS

a) Compressed air vessels include receivers, separators, filters, and coolers. Considerations of concern include temperature variances, pressure limitations, vibration, and condensation. Drain connections should be verified to be free of any foreign material that may cause plugging.

b) Inspection shall consist of the following:

1) Welds — Inspect all welds for cracking or gouging, corrosion, and erosion. Particular attention should be given to the welds that attach brackets supporting the compressor. These welds may fail due to vibration;

2) Shells/Heads — Externally, inspect the base material for environmental deterioration and impacts from objects. Hot spots and bulges are signs of overheating and should be noted and evaluated for acceptability. Particular attention should be paid to the lower half of the vessel for corrosion and leakage. For vessels with manways or inspection openings, an internal inspection should be performed for corrosion, erosion, pitting, excessive deposit buildup, and leakage around inspection

openings. UT thickness testing may be used where internal inspection access is limited or to determine actual thickness when corrosion is suspected;

a. UT Acceptance Criteria

1. For line or crevice corrosion, the depth of the corrosion shall not exceed 25% of the required wall thickness.

2. Isolated pits may be disregarded provided that their depth is not more than 50% of the required thickness of the pressure vessel wall (exclusive of any corrosion allowance), provided the total area of the pits does not exceed 7 sq. in. (4,500 sq. mm) within any 8 in. (200 mm) diameter circle, and provided the sum of their dimensions along any straight line within that circle does not exceed 2 in. (50 mm).

3. For a corroded area of considerable size, the thickness along the most critical plane of such area may be averaged over a length not exceeding 10 in. (250 mm). The thickness at the thinnest point shall not be less than 75% of the required wall thickness.

b. If the corrosion exceeds any of the above criteria, the following options are available to the owner/user.

1. The owner/user may conduct a complete UT survey of the vessel to verify remaining vessel wall thickness.

2. The vessel shall be removed from service until the vessel is repaired by an “R” stamp holder.

3. The vessel shall be removed from service until it can be de-rated to a lower MAWP subject to review and approval by the Jurisdiction.

4. A fitness-for service analysis is performed by a qualified organization.

5. The vessel is permanently removed from service.

3) Fittings and Attachments — Inspect all fittings and attachments for alignment, support, deterioration, damage, and leakage around threaded joints. Any internal attachments such as supports, brackets, or rings shall be visually examined for wear, corrosion, erosion, and cracks;

4) Operation — Check the vessel nameplate to determine the maximum allowed working pressure and temperature of the vessel. Ensure the set pressure of the safety valve does not exceed that allowed on the vessel nameplate and determine that the capacity of the safety valve is greater than the capacity of the compressor. Ensure there is a functioning manual or automatic condensate drain; and

5) Quick-Closure Attachments — Filter-type vessels usually have one quick-type closure head for making filter changes, see NBIC Part 2, 2.3.6.5.

### 2.3.6.3 EXPANSION TANKS

a) The purpose of an expansion tank is to provide an air cushion to a system that will allow for expansion and contraction, thus minimizing fluctuations in pressure due to temperature variances. These vessels are susceptible to corrosion due to the air and water interface.

b) Inspection shall consist of the following:

1) Design/operation — Verify from the nameplate the code of construction, temperature, and pressure ratings to ensure jurisdictional and system compatibility. It is common to find expansion tanks water logged due to leakage of air out of the tank; therefore, it is important to verify the water level either

by sight glass or sounding the tank. If the vessel is fitted with a water sight glass, inspect for visual cleanliness, water leakage, and gasket tightness;

2) Surface conditions — Check all surfaces external and internal, if possible, for any leaks, corrosion, erosion, cracks, and dents that may lead to failure. Thickness checks may be applicable to determine any reduction of base material thickness; and

3) Supports and attachments — These vessels are usually suspended from the ceiling by hangers or straps causing concentration of stresses in these areas. Specifically inspect for corrosion, wear, and cracks in these areas.

### 2.3.6.4 LIQUID AMMONIA VESSELS

Vessels in liquid ammonia service are susceptible to stress corrosion cracking (SCC) [(see NBIC Part 2, 3.3.2 b))] in areas of high stress. High-strength and coarse-grained materials seem to be more at risk of SCC than are fine-grained or more moderate strength materials, although no commonly used steels appear to be immune to the problem. Postweld heat treatment of new or weld-repaired vessels or cold formed heads is beneficial in reducing the incidence of SCC. The presence of 0.2% minimum water in the liquid ammonia also inhibits SCC. Any leak should be thoroughly investigated and the necessary corrective action initiated.

a) Internal inspection

1) Where existing openings permit, perform a visual internal inspection of the vessel. Look for any obvious cracks (very advanced SCC) and note areas that are subject to high stress such as welds, welded repairs, head-to-shell transitions, sharp interior corners, and interior surfaces opposite external attachments or supports.

2) Fittings, such as liquid level gage floats and excess flow valves, should be removed or otherwise protected from power buffing or light sandblasting when preparing the interior surface of the vessels for inspection.

3) Vessels in services where liquid ammonia is used as a reactant or is being preheated/vaporized should be inspected for localized corrosion in the reaction or vaporizing zones.

b) Examination and detection of SCC

1) All interior welds and highly stressed areas should be examined by the Wet Fluorescent Magnetic Particle Testing method (WFMT) using an A/C yoke for magnetization. Note that weld cracks are often transverse in orientation. It is extremely important to ensure that the NDE method used will disclose cracks in any orientation.

2) If cracks are discovered, a calculation shall be made to determine what depth of grinding may be carried out for crack removal (without encroaching on the minimum thickness required by the original code of construction).

3) Where possible, crack removal by grinding is the preferred method of repair. Since the stresses at the crack tips are quite high, even very fine cracking shall be eliminated.

4) Where crack depth is such that removal requires welded repair, a weld procedure shall be employed that will minimize HAZ hardening and residual stresses. Welded repairs, regardless of the depth of the repair, shall be postweld heat treated. The use of alternative welding methods in lieu of PWHT is permitted. Any repairs required and associated postweld heat treatment shall be completed in accordance with NBIC Part 3.

5) Re-inspection by WFMT after welded repair shall be done to ensure complete crack removal.

6) It is not intended to inhibit or limit the use of other NDE evaluation methods. It is recognized that acoustic emission and fracture mechanics are acceptable techniques for assessing structural integrity of vessels. Analysis by fracture mechanics may be used to assess the structural integrity of vessels when complete removal of all ammonia stress cracks is not practical. If alternative methods are used, the above recommendation that all cracks be removed, even fine cracks, may not apply.

   In addition to NDE and repair of liquid ammonia vessels that are susceptible to SCC, it is acceptable to use fitness for service evaluation methods to determine acceptability of a pressure-retaining item to perform its intended function. These methods shall be consistent with NBIC Part 2, 4.4, *Methods To Assess Damage Mechanisms And Inspection Frequency For Pressure-Retaining Items*.

c) Inspection of parts and appurtenances

   1) If valves or fittings are in place, check to ensure that these are complete and functional. Parts made of copper, zinc, silver, or alloys of these metals are unsuitable for ammonia service and shall be replaced with parts fabricated of steel or other suitable materials.

   2) Check that globe valves are installed with the direction of flow away from the vessel.

   3) Observe that excess flow valves are properly installed and in good repair.

   4) Check that hydrostatic relief valves are installed in the system piping where required.

   5) Piping shall be observed to be a minimum of Schedule 80 if threaded and Schedule 40 if welded. Seamless or ERW piping is acceptable. Type F piping shall not be used for ammonia service.

   6) Fittings shall be forged or Class 300 malleable iron. Seal welding is permitted only with forged fittings.

   7) The Inspector shall note the pressure indicated by the gage and compare it with other gages on the same system. If the pressure gage is not mounted on the vessel itself, it should be ascertained that the gage is installed on the system in such a manner that it correctly indicates actual pressure in the vessel.

   8) The Inspector shall note the liquid level in the vessel by observing the liquid level gage or other liquid level indicating device.

d) Inspection of pressure relief devices

   1) See NBIC Part 2, 2.5 for the inspection of pressure relief devices used to prevent the overpressure of liquid ammonia vessels. Pressure relief devices in ammonia service shall not be tested in place using system pressure. Bench testing or replacement is required, depending on the type of pressure relief device used.

   2) The Inspector shall note the replacement date marked on vessel safety valves and piping system hydrostatic relief valves requiring replacement every five years.

e) External inspection of insulated vessels

   1) Insulated pressure vessels can suffer from aggressive external corrosion that is often found beneath moist insulation. The Inspector should closely examine the external insulation scaling surfaces for cold spots, bulges, rust stains, or any unusual conditions in previous repair areas. Bulging or distorted insulation on refrigerated vessels may indicate the formation of ice patches between the vessel shell and insulation due to trapped moisture. Careful observation is also required where the temperatures of insulated vessels cycle continually through the freezing temperature range.

   2) The lower half and the bottom portions of insulated vessels should receive special focus, as condensation or moisture may gravitate down the vessel shell and soak into the insulation, keeping it moist for long periods of time.

Penetration locations in the insulation or fireproofing, such as saddle supports, sphere support legs, nozzles, or fittings should be examined closely for potential moisture ingress paths. When moisture penetrates the insulation, the insulation may actually work in reverse, holding moisture in the insulation and/or near the vessel shell.

3) Insulated vessels that are run on an intermittent basis or that have been out of service require close scrutiny. In general, a visual inspection of the vessel's insulated surfaces should be conducted once per year.

4) The most common and superior method to inspect for suspected corrosion under insulation (CUI) damage is to completely or partially remove the insulation for visual inspection. The method most commonly utilized to inspect for CUI without insulation removal is by x-ray and isotope radiography (film or digital) or by real-time radiography, utilizing imaging scopes and surface profilers. The real time imaging tools will work well if the vessel geometry and insulation thickness allows. Other less common methods to detect CUI include specialized electromagnetic methods (pulsed eddy current and electromagnetic waves) and long range ultrasonic techniques (guided waves).

5) There are also several methods to detect moisture soaked insulation, which is often the beginning for potential CUI damage. Moisture probe detectors, neutron backscatter, and thermography are tools that can be used for CUI moisture screening.

6) Proper surface treatment (coating) of the vessel external shell and maintaining weather-tight external insulation are the keys to prevention of CUI damage.

f) Acceptance criteria

The following are the acceptance criteria for liquid ammonia vessels. Vessels showing indications or imperfections exceeding the conditions noted below are considered unacceptable.

1) Cracks

Cracks in the pressure vessel boundary (e.g., heads, shells, welds) are unacceptable. When a crack is identified, the vessel shall be removed from service until the crack is repaired by an "R" Stamp holder or the vessel permanently removed from service. (See NBIC Part 3, *Repairs and Alterations*.)

2) Dents

When dents are identified that exceed the limits set forth below, the vessel shall be removed from service until the dents are repaired by an "R" Stamp holder, a fitness for service analysis is performed, or the vessel permanently retired from service.

a. Dents in Shells

The maximum mean dent diameter in shells shall not exceed 10% of the shell diameter, and the maximum depth of the dent shall not exceed 10% of the mean dent diameter. The mean dent diameter is defined as the average of the maximum dent diameter and the minimum dent diameter. If any portion of the dent is closer to a weld than 5% of the shell diameter, the dent shall be treated as a dent in a weld area, as shown in b. below.

b. Dents in Welds

The maximum mean dent diameter on welds (i.e., part of the deformation includes a weld) shall not exceed 10% of the shell diameter. The maximum depth shall not exceed 5% of the mean dent diameter.

c. Dents in Heads

The maximum mean dent diameter on heads shall not exceed 10% of the shell diameter. The maximum depth shall not exceed 5% of the mean dent diameter. The use of a template may be required to measure dents on heads.

3) Bulges

When bulges are identified that exceed the limits set forth below, the vessel shall be removed from service until the bulges are repaired by an “R” Stamp holder or a fitness for service analysis is performed, the vessel may also be permanently retired from service.

a. Bulges in Shells

If a bulge is suspected, the circumference shall be measured at the suspect location and at several places remote from the suspect location. The variation between measurements shall not exceed 1%.

b. Dents in Heads

If a bulge is suspected, the radius of the curvature shall be measured by the use of templates. At any point the radius of curvature shall not exceed 1.25% of the diameter for the specified shape of the head.

4) Cuts or Gouges

When a cut or gouge exceeds 25% of the thickness of the vessel, the vessel shall be removed from service until it is repaired by an “R” Stamp Holder or a fitness-for-service analysis is performed. The vessel may also be permanently retired from service.

5) Corrosion

a. For line or crevice corrosion, the depth of the corrosion shall not exceed 25% of the original wall thickness.

b. Isolated pits may be disregarded provided that their depth is not more than 50% of the required thickness of the pressure vessel wall (exclusive of any corrosion allowance), provided the total area of the pits does not exceed 7 sq. in. (4,500 sq. mm) within any 8 in. (200 mm) diameter circle, and provided the sum of their dimensions along any straight line within that circle does not exceed 2 in. (50 mm).

c. For a corroded area of considerable size, the thickness along the most critical plane of such area may be averaged over a length not exceeding 10 in. (250 mm). The thickness at the thinnest point shall not be less than 75% of the required wall thickness. When general corrosion is identified that exceeds the limits set forth in this paragraph, the pressure vessel shall be removed from service until it is repaired by an “R” Stamp holder or a fitness-for-service analysis is performed, or the vessel may be permanently retired from service.

### 2.3.6.5 INSPECTION OF PRESSURE VESSELS WITH QUICK-ACTUATING CLOSURES

a) This section describes guidelines for inspection of pressure vessels equipped with quick-actuating closures. Due to the many different designs of quick-actuating closures, potential failures of components that are not specifically covered should be considered. The scope of inspection should include areas affected by abuse or lack of maintenance and a check for inoperable or bypassed safety and warning devices.

b) Temperatures above that for which the quick-actuating closure was designed can have an adverse effect on the safe operation of the device. If parts are found damaged and excessive temperatures are suspected as the cause, the operating temperatures may have exceeded those temperatures recommended by the manufacturer. Rapid fluctuations in temperatures due to rapid start-up and shutdown may lead to cracks or yielding caused by excessive warping and high thermal stress. A careful observation should be made of the condition of the complete installation, including maintenance and operation, as a guide in forming an opinion of the care the equipment receives. The history of the vessel should be established, including: year built, materials of construction, extent of postweld heat treatment, previous inspection results, and repairs or alterations performed. Any leak should be thoroughly investigated and the necessary corrective action initiated.

1) Inspection of parts and appurtenances

a. Seating surfaces of the closure device, including but not limited to the gaskets, O-rings, or any mechanical appurtenance to ensure proper alignment of the closure to the seating surface, should be inspected. This inspection can be made by using powdered chalk or any substance that will indicate that the closure is properly striking the seating surface of the vessel flange. If this method is used, a check should be made to ensure that:

1. Material used shall not contaminate the gasket or material with which it comes into contact; and

2. The substance used shall be completely removed after the examination.

b. The closure mechanism of the device should be inspected for freedom of movement and proper contact with the locking elements. This inspection should indicate that the movable portions of the locking mechanism are striking the locking element in such a manner that full stroke can be obtained. Inspection should be made to ensure that the seating surface of the locking mechanism is free of metal burrs and deep scars, which would indicate misalignment or improper operation. A check should be made for proper alignment of the door hinge mechanisms to ensure that adjustment screws and locking nuts are properly secured. When deficiencies are noted, the following corrective actions should be initiated:

1. If any deterioration of the gasket, O-ring, etc., is found, the gasket, O-ring, etc., should be replaced immediately. Replacements should be in accordance with the vessel manufacturer's specifications;

2. If any cracking or excessive wear is discovered on the closing mechanism, the owner or user should contact the original manufacturer of the device for spare parts or repair information. If this cannot be accomplished, the owner or user should contact an organization competent in quick-actuating closure design and construction prior to implementing any repairs;

3. Defective safety or warning devices should be repaired or replaced prior to further operation of the vessel;

4. Deflections, wear, or warping of the sealing surfaces may cause out-of-roundness and misalignment. The manufacturer of the closure should be contacted for acceptable tolerances for out-of-roundness and deflection; and

5. The operation of the closure device through its normal operating cycle should be observed while under control of the operator. This should indicate if the operator is following posted procedures and if the operating procedures for the vessel are adequate.

2) Gages, safety devices, and controls

a. The required pressure gage should be installed so that it is visible from the operating area located in such a way that the operator can accurately determine the pressure in the vessel

while it is in operation. The gage dial size should be of such a diameter that it can be easily read by the operator. This gage should have a pressure range of at least 1-1/2 times, but not more than four times, the operating pressure of the vessel. There should be no intervening valve between the vessel and gage.

b. The pressure gage should be of a type that will give accurate readings, especially when there is a rapid change in pressure. It should be of rugged construction and capable of withstanding severe service conditions. Where necessary, the gage should be protected by a siphon or trap.

c. Pressure gages intended to measure the operating pressure in the vessel are not usually sensitive or easily read at low pressures approaching atmospheric. It may be advisable to install an auxiliary gage that reads inches of water (mm of mercury) and is intended to measure pressure from atmospheric through low pressures. This ensures that there is zero pressure in the vessel before opening. It would be necessary to protect the auxiliary low pressure gage from the higher operating pressures.

d. Provisions should be made to calibrate pressure gages or to have them checked against a master gage as frequently as necessary.

e. A check should be made to ensure that the closure and its holding elements must be fully engaged in their intended operating position before pressure can be applied to the vessel. A safety interlock device should be provided that prevents the opening mechanism from operating unless the vessel is completely depressurized.

f. Quick-actuating closures held in position by manually operated locking devices or mechanisms, and which are subject to leakage of the vessel contents prior to disengagement of the locking elements and release of the closure, shall be provided with an audible and/or visible warning device to warn the operator if pressure is applied to the vessel before the closure and its holding elements are fully engaged, and to warn the operator if an attempt is made to operate the locking device before the pressure within the vessel is released. Pressure tending to force the closure clear of the vessel must be released before the closure can be opened for access.

### 2.3.6.6 TRANSPORT TANKS

For transport tanks, the Competent Authority (DOT) shall be consulted for any requirements which it has established since they take precedence.

a) Transport tanks manufactured prior to the adoption of ASME Section XII by the Competent Authority (DOT) were constructed in accordance with the ASME Section VIII Division 1. Certain transport tanks manufactured to this code were required to be stamped in accordance with Section VIII Division 1 if the design pressure of the transport tank was 241 kPa (35 psi) (depending on material being transported) and greater. If the design pressure was less than 241 kPa (35 psi) (depending on material being transported), the transport tank was manufactured in accordance with Section VIII, Division 1, but not required by the Competent Authority (DOT) to be stamped.

b) ASME stamped transport tanks are subject to the requirements of NBIC Part 2 for inservice inspection, unless exempted by the Competent Authority (DOT).

### 2.3.6.7 ANHYDROUS AMMONIA NURSE TANKS

a) Nurse tanks (considered as implements of husbandry) are anhydrous ammonia pressure vessels on farm wagons, not exceeding a capacity of 3,000 water gallons (11,355 liters), used for agricultural application of liquid anhydrous ammonia to farm fields as fertilizer. Nurse tanks come under United States Department of Transportation (DOT) requirements and may also be subject to various local jurisdictional requirements. Nurse tanks shall be inspected closely by the owner or operator at least once per seasonal use. Inspections of nurse tanks include the following items. These items are not meant to be all inclusive.

b) Inspection shall consist of the following:

1) Pressure vessel - Verify that the pressure vessel is constructed for anhydrous ammonia service and that it is ASME stamped and National Board registered, as required by the jurisdiction. Check that the data plate is legible and not painted over or sand blasted. If the data plate is missing or illegible, welding is prohibited, and the tank shall be tested and operated under the DOT Hazardous Material Regulation (HMR) as required in Title 49 Code of Federal Regulations (CFR) 173.315m or the tank shall be removed from service. Post-construction welding, if any, to the pressure vessel, nozzles or support legs shall be in accordance with NBIC procedures and stamping as required in NBIC, Part 3 (Also see ANSI K61.1 for the definition of repair). Cracks, dents, bulges, cuts, gouges and corrosion shall not exceed the acceptance criteria of NBIC Part 2, 2.3.6.4 f).

2) Valves and fittings - Verify that the pressure relief device is ASME constructed and National Board capacity certified, has correct capacity and set pressure, is date current, and is not leaking, corroded or painted. Check that a rain cap is installed. Ensure that the hydrostatic relief valve is set for 350-400 psi (2,415-2,760 kPa), is in place in or on the liquid withdrawal valve and that it is in good condition and date current. A liquid level float gage shall be installed and be operable. In addition, a fixed liquid level gage (85% gage) shall be operable and unobstructed by tape or paint. A pressure gage with a clear lens and with a 0-400 psi (0-2,760 kPa) dial range shall be installed and be observed to be operable. A liquid withdrawal valve shall be in place and observed to be in good condition. Liquid and vapor fill valves shall be in operable condition and their end fittings protected with valve covers. In addition, check that no galvanized, brass, or cast iron fittings are installed.

3) Nurse tank painting, decals, and marking – The paint shall be white or aluminum, the painted surface not damaged or faded, and the tank surface not rusted. A nurse tank unique owner identification number shall be observed to be in place. A DOT approved slow-moving vehicle (SMV) emblem or sign shall be installed at the rear. Legible transfer and safety decals shall be in place near the fill valves. “INHALATION HAZARD” markings or decals shall be observed to be in place on each side. On each side and on each end, observe that “DOT 1005” markings or decals and “ANHYDROUS AMMONIA” markings or decals are in place (Note that these markings or decals are not required on the end of a tank with valves and fittings on that end). Liquid and vapor valves shall be observed to be color coded or labeled for liquid or vapor. Markings for tests and inspections required due to a missing or illegible data plates shall be in place as required by DOT Hazardous Material Regulations.

4) Safety specific and miscellaneous equipment - Roll-over protection for valves and appurtenances, to include the pressure relief device, shall be observed to be in place. This required protection must include any bottom liquid withdrawal valves. Observe that the transfer hose, if so equipped, is date current and in good condition (not cut to the cords or showing stretch damage, bulging, or kinking). Check that a fitting is in place to secure the transfer hose (if so equipped) during transport and storage. Protective gloves and Z87 rated goggles shall be observed to be in a safety kit on the nurse tank. A safety water container [5 gal (19 l) minimum capacity] with adequate withdrawal hose shall be on the nurse tank and be in usable condition.

5) Trailer and running gear – Ensure that the hitch and undercarriage are in good repair. Observe that welds are not cracked or the rails bent. The trailer tires shall be in serviceable condition with no cuts to the cords. Two safety chains and hooks shall be in place with one hitch pin and lock pin available. The tank to trailer anchorage shall be satisfactory and any bolting tightened. Spring leaves shall not be cracked or broken on inspection and the ends secured.

### 2.3.6.8 INSPECTION OF PRESSURE VESSELS FOR HUMAN OCCUPANCY (PVHO’s)

A pressure vessel for human occupancy (PVHO), as defined by ASME PVHO-1 is a pressure vessel that encloses a human being or animal within its pressure boundary while it is subject to internal or external pressure that exceeds a 2 psi (14 kPa) differential pressure. PVHOs include, but are not limited to

submersibles, diving bells, personal transfer capsules, decompression chambers, recompression chambers, hyperbaric chambers, high altitude chambers and medical hyperbaric oxygenation facilities.

This section provides guidelines for inspection of PVHOs. Due to the many different designs and applications of PVHOs, potential failures of components or safety concerns that are not specifically covered, such as rapid decompression or fire/sparking issues should be considered.

a) General/operational

1) PVHOs should be constructed in accordance with ASME PVHO-1. This code adopts Section VIII and therefore the vessels should bear a “U” or “U2” ASME designator. Inspections may be conducted using ASME PVHO-2 for reference. ASME PVHO-1 also has several Code Cases that address PVHOs manufactured from non-traditional materials such as various fabrics. PVHOs built under such Code Cases shall have all the documentation required by the Code Case, but may not necessarily have any related Section VIII forms.

2) Cast and ductile iron fittings are not allowed.

3) The installation should be such that there is adequate clearance to inspect it properly.

b) Internal Inspection

1) Where existing openings permit, perform a visual internal inspection of the vessel. Look for any obvious cracks and note areas that are subject to high stress such as welds, welded repairs, head-to-shell transitions, sharp interior corners, and interior surfaces opposite external attachments or supports.

2) The vessel should be free of corrosion, damage, dents, gouges, or other damage. Special attention should be paid to areas under chamber floors and the interiors of chamber drain fittings.

3) All openings leading to external fittings or controls should be free from obstruction.

4) All exhaust inlets should be checked for the presence of fittings that prevent a chamber occupant from blocking the opening.

5) The inlets to all chamber pressure gage lines should be located where they are either protected from possible blockage or are fitted with multiple openings.

6) Chamber doors:

a. should operate freely and smoothly. However, doors should not move on their own when released;

b. that close/seal with pressure and which are fitted with “dogs” or other restraints to hold them in place until an initial seal is obtained, shall be fitted with features to prevent the door from maintaining a seal in the event the pressure differential on the door is reversed;

c. should have seals that are supple, free from flat spots, cracking, etc.; and

d. that close/seal against pressure shall have provisions as follows:

1. Positive protection against pressurization of the vessel unless the restraint mechanism is fully engaged. This includes pressurization by back-up methods as well as primary methods; and

2. Positive protection against release of the restraint mechanism unless pressure in the vessel is fully relieved.

c) External Inspection

1) The Inspector should closely examine the external condition of the pressure vessel for corrosion, dents, gouges or other damage.

2) The lower half and the bottom portions of insulated vessels should receive special focus, as condensation or moisture may gravitate down the vessel shell and soak into the insulation, keeping it moist for long periods of time. Penetration locations in the insulation or fireproofing such as saddle supports, sphere support legs, nozzles, or fittings should be examined closely for potential moisture ingress. When moisture penetrates the insulation, the insulation may actually work in reverse, holding moisture in the insulation and/or near the vessel shell.

3) The most common and superior method to inspect for suspected corrosion under insulation (CUI) damage is to completely or partially remove the insulation for visual inspection. The method most commonly utilized to inspect for CUI without insulation removal is by X-ray and isotope radiography (film or digital) or by real time radiography, utilizing imaging scopes and surface profilers. The real time imaging tools will work well if the vessel geometry and insulation thickness allows. Other less common methods to detect CUI include specialized electromagnetic methods (pulsed eddy current and electromagnetic waves) and long-range ultrasonic techniques (guided waves).

4) There are also several methods to detect moisture soaked insulation, which is often the beginning for potential CUI damage. Moisture probe detectors, neutron backscatter, and thermography are tools that can be used for CUI moisture screening.

5) Couplers and doors that open with pressure:

a. should operate freely and smoothly;

b. should have seals that are supple, and free from flat spots, cracking, etc.; and

c. that close/seal against pressure shall have provisions as follows:

1. Positive protection against pressurization of the vessel unless the restraint mechanism is fully engaged. This includes pressurization by back-up methods as well as primary methods; and

2. Positive protection against release of the restraint mechanism unless pressure in the vessel is fully released.

d) Inspection of parts and appurtenances (e.g., piping systems, pressure gage, bottom drain)

1) As stated above, cast iron is not allowed on PVHOs and shall be replaced with parts fabricated with other suitable materials, in accordance with ASME Code Section II.

2) If valves or fittings are in place, check to ensure that these are complete and functional.

3) The Inspector shall note the pressure indicated by the gage and compare it with other gages on the same system. If the pressure gage is not mounted on the vessel itself, it should be ascertained that the gage is installed on the system in such a manner that it correctly indicates actual pressure in the vessel. Lines leading to chamber primary depth gages should connect only to the depth gage.

4) The system should have a pressure gage designed for the most severe condition of pressure in normal operation. This gage should be clearly visible to the person adjusting the setting of the pressure control valve. The graduation on the pressure gage should be graduated to not less than 1.5 times the pressure at which the lowest safety/relief valve is set.

5) Provisions should be made to calibrate pressure gages or to have them checked against a standard test gage.

6) The exhausts from the depressurization of PVHOs located inside enclosures should be piped to a location outside the enclosure and located at least 10 ft. (3.0 m) from any air intake.

e) Inspection of view ports / windows

1) Each window should be individually identified and be marked in accordance with ASME PVHO-1.

2) If there are any penetrations through windows, they must be circular in accordance with ASME PVHO-1 requirements..

3) Windows must be free of crazing, cracks and scratches that exceed “superficial” defects as defined by ASME PVHO-2.

4) Windows and viewports have a maximum interval for seat/seal inspection and refurbishment. Documentation should be checked to ensure compliance with ASME PVHO-2, Section 2-4.4.

5) Windows have a maximum service life ranging from 10 to 20 years depending on the type of window and service conditions.

6) Documentation should be checked to ensure compliance with ASME PVHO-2 inspection and refurbishment requirements (ASME PVHO-2-2016, Tables 2-4.3-1 and 2-4.3-2) and service life limitations (ASME PVHO-2-2016, Section 2-4.4).

f) Inspection of pressure relief devices

1) Pressure relief devices for chambers only must have a quick opening manual shutoff valve installed between the chamber and the pressure relief device, with a frangible seal in place, within easy access to the operator.

2) The pressure relief device shall be constructed in accordance with ASME Code Section VIII.

3) The discharge from the chamber pressure relief device shall be piped outside to a safe point of discharge as determined by the Authority having Jurisdiction (AHJ).

4) Rupture disks shall not be used, except in series upstream of pressure relief valves to prevent gas leakage.

5) Verify that the safety valve is periodically tested either manually by raising the disk from the seat or by removing and testing the valve on a test stand.

g) Acceptance criteria

The following forms are required to be available for review:

1) ASME BPV Forms U-1, U-1A or U-2 as appropriate for vessels built to ASME B&PV Code Section VIII. For vessels built to other rule sets, the equivalent forms shall be available;

2) ASME PVHO-1-2016 Form GR-1 Manufacturer’s Data Report for Pressure Vessels for Human Occupancy;

3) ASME PVHO-1-2016 Form VP-1 Fabrication Certification for Acrylic Windows (one for each window);

4) ASME PVHO-1-2016 Form VP-2 Design Certification for Acrylic Windows (one for each window);

5) ASME PVHO-2-2016 Form VM-1 Viewport Inspection (one for each window, current within ASME PVHO-2 inspection interval requirements); and

6) For any repaired windows, ASME PVHO-2-2016 Form VM-2 Acrylic Window Repair Certificate for Windows. Repaired by the User (or his Authorized Agent) or ASME PVHO-2-2016 Form VM-3 Acrylic Window Repair Certificate for Severely Damaged Windows.

h) All PVHOs under the jurisdiction of the U.S. Coast Guard must also comply with 46 CFR Part 197.

### 2.3.6.9 INSPECTION OF STATIC VACUUM INSULATED CRYOGENIC VESSELS

a) This section covers the periodic inspection and testing of static vacuum insulated cryogenic pressure vessels used in the storage of cryogenic liquefied gases. Owner-users should inspect static cryogenic vacuum-insulated storage tanks to ensure that the equipment is in safe operable condition.

b) A static vacuum insulated cryogenic vessel is a vessel that is thermally insulated for use with one or more cryogenic liquid, consisting of: 1) an inner vessel holding the cryogenic liquid, 2) an outer jacket that serves as an air tight enclosure which supports the inner vessel, holds the insulation and enables the vacuum to be established, and 3) the associated piping system.

c) Check that the following conditions or safeguards are adequate prior to doing a periodic external inspection of the vessel:

1) Surface water drainage is directed away from the location of installation. Proximity of storage tank to sewer inlets shall comply with local fire jurisdictional requirements.

2) Protective measures are in place for the vessels and components from mechanical impact damage (such as barricades, safe set-back distances, poles and bars.

3) Any fire proofing for external supports is in acceptable condition. Any gas from pressure relief devices or vents is discharged to a safe point of discharge. Relief valve discharges are not aimed directly at external supports or the outer jacket wall.

4) There is sufficient ventilation to avoid the formation of explosive gas-air mixtures or an oxygen deficient/enriched atmosphere.

d) A periodic external visual inspection of the vessel and equipment should be made to ensure that the vacuum between the inner vessel and outer jacket has not been compromised. If the vessel has lost vacuum, the owner-user of the cryogenic storage vessel shall immediately investigate the cause. Any loss of vacuum should be investigated as this could affect the integrity of the vessel and support system. If the cause is due to an internal pipe failure as evidenced by vapor escaping from the vacuum relief device, the pressure should be immediately reduced to atmospheric pressure followed by emptying of all of the cryogenic liquid in a safe manner.

e) External visual inspections are possible at all accessible parts of the vessel and piping. The following inspections should be included as part of the periodic external visual inspection.

1) A functional check of essential and critical valves and their operability.

2) Leak tests under operating conditions of the vessel and piping.

3) Assessing if there have been any significant changes in the operational conditions of the installation and its surroundings.

4) Check that there is no excessive out-of-roundness or deformation of the outer jacket.

5) Check all nozzles for corrosion or damage.

6) Check the vessel supports for structural damage.

7) Check that any attachments to the outer jacket are not damaged or affecting the vessel condition.

8) Verification of periodic testing and repair (or replacement) of the pressure relief device(s).

9) Check that the pressure relief device(s) are not continually venting. PRD's may vent periodically under normal circumstances but should be reported for maintenance testing and repair if venting continually.

10) Check the condition of the outer jacket, piping and accessories.

11) Check for abnormal frosting on outer jacket surface. Under normal usage, frost and ice will develop around pipes, valves, controls and vaporizers.

12) Inspect the outer skin of the outer jacket for any new or abnormal signs of excessive frosting.

13) Confirm that the duplicate ASME nameplate is attached to the outer jacket, tank leg or other permanent location affixed to the vessel.

### 2.3.6.10 INSPECTION OF WIRE WOUND PRESSURE VESSELS

a) This section provides guidelines for inspection of wire wound pressure vessels typically designed for 10,000 psi or greater service. The scope of inspection of these vessels should include components affected by repeated opening and closing, such as the frame, yolk and cylinder inner diameter surface, or alignment of the yolk with the cylinder, lack of maintenance and a check for inoperable or bypassed safety and warning devices. Early detection of any damage to the cylinder, closures or frame is essential to avoid catastrophic failure.

b) These vessels consist of four parts, a wire wound cylinder, two end closures and a frame to retain the closures in the cylinder. The wire is one continuous piece and is wound in tension. On the cylinder, the wire can only carry circumferential or radial loading. The cylinder is typically not of sufficient thickness to carry axial load which requires the end closures have no threads or retaining grooves and requires a frame to retain the pressure vessel axial load imposed on the closures. The purpose for this design is to minimize weight of the containment cylinder using thinner wall materials and using external wound wire to induce a compressive preload. This design also provides increased resistance to damage from fatigue loading.

   **Note**: Some vessels may be monoblock cylinders (no winding) with wire wound frame and some vessels may be wire wound cylinder with a forged or welded plate frame (not wire wound). Use of a frame to retain the end closures removes the sharp transitions in shape (threads or grooves) associated with monoblock cylinder failures. The design of high pressure vessels is typically based on fatigue life criteria. The majority of operating wire wound vessels in North America were manufactured to ASME BPVC Section VIII Division 3, Alternative Rules for Construction of High Pressure Vessels. Some inservice vessels may have been manufactured to ASME BPVC Section VIII Division 1 or Division 2, and others have been installed as "State Specials" that require fatigue life analysis to determine a safe operating life. The primary failure mode is fatigue cracking. Early detection of any damage to the cylinder, closures, or frame is essential to avoid catastrophic failure.

c) Record keeping

   1) Since these vessels have a finite fatigue life, a record shall be maintained of each operating cycle, recording both temperature and pressure. Deviation beyond design limits is cause for suspending operation and reevaluation of remaining fatigue life. Vessels having no operating record should be inspected and a fracture mechanics evaluation with a fatigue analysis test be performed to establish remaining life before resuming operation. Vessels having no operating record shall not be used for service until such time as previous operating history can be determined.

   2) Operating data should be recorded and include the following whenever the vessel is operating:

      a. Number of cycles;

b. Maximum pressure;

c. Maximum temperature; and

d. Any unusual conditions.

d) Any damage to the cylinder or closures can lead to premature failure. Frequent visual inspection should be made of internal and external surfaces of the cylinder, frame and closures. A thorough examination should be completed if any visually apparent damage is identified or if any excursion beyond design temperature or pressure occurs.

In addition, surfaces of the cylinder and closures should be examined by dye penetrant or magnetic particle method at intervals based on vessel remaining life. Closures may require ultrasonic examination of passageways.

As part of this inspection guideline for wire wound pressure vessels, the following items should be reviewed:

1) Verify no change in the process, such as the processing fluid, that might adversely impact vessel integrity.

2) Review the vessel manufacturer's inspection recommendations for vessel, closures and frame. If manufacturer's recommendations are not available, obtain recommendations from a recognized wire wound vessel service provider.

3) Verify any repair to pressure retaining items has been completed by National Board authorized service provider having wire wound vessel expertise.

4) Verify overpressure protection with appropriate set pressure and capacity is provided. Rupture discs are commonly used for pressures exceeding 14,500 psi (100 MPa) to avoid valve seat leakage. Overpressure protection devices are frequently replaced to avoid premature operation.

5) If there are no manufacturer's recommendations available for the vessel, the following are additional recommended inspections that should be conducted to ensure vessel integrity and safety:

a. Conduct annual visual and dimensional vessel inspections with liquid penetrant examination of maximum stressed areas to ensure that the surfaces are free of defects. Conduct ultrasonic examination of the vessel after every 25% of the design cycle life or every five years, whichever comes first, to detect subsurface cracks. Special attention should be given to the roots of threads and closures using threaded head retention construction. Other geometric discontinuities that are inherent in the design or irregularities resulting from localized corrosion, erosion, or mechanical damage should be carefully examined. This is particularly important for units of monoblock construction.

b. The closure mechanism of the vessel end-closure is opened and closed frequently during operation. It should be closely inspected for freedom of movement and proper contact with its locking elements. Wire wound vessels must have yoke-type closures so the yoke frame will need to be closely inspected on a regular basis.

6) Gages, Safety Devices, and Controls

a. Verify that the vessel is provided with control and monitoring of pressure, temperature, the electrical system, fluid flow, liquid levels and all variables that are essential for the safe operation of the system. If the vessel is automatically controlled, manual override should be available. Also, safety interlocks should be provided on the vessel closure to prevent vessel pressurization if the vessel closure is not complete and locked.

b. Verify that all safety device isolation valves are locked open if used.

c. Verify appropriate pressure relief device is installed with the setpoint at the lowest pressure possible, consistent with the normal operating pressure but in no case higher than the design operating pressure of the vessel. Rupture discs are normally considered more suitable for these types of applications since pressure relief devices operating at pressures above 14,500(100MPa) psi may tend to leak by their seat.

d. Verify that pressure and temperature of the vessel coolant and vessel wall is controlled and monitored. Interlock devices should be installed that will de-energize or depressurize the vessel at established setpoints.

e. Verify audible and visual alarms are installed to indicate unsafe conditions.

### 2.3.6.11 INSPECTION OF VESSELS FOR PRESSURES AT AND ABOVE 10,000 PSI (23)

This section provides guidelines for the inspection of pressure vessels designed for pressures at or above 10,000 PSI (68.95 MPa).

a) The Inspector shall verify the vessel is constructed to a standard acceptable to the jurisdiction.

b) The Inspector shall verify the following requirements as part of the inspection:

1) Records of cycles are being kept;

2) Complete documentation of installation of safety interlocks for this vessel as required by the manufacturer and the jurisdiction, with listed set points, readily available to the operator and Inspector. All devices must be listed;

3) Documentation of safety device alarms and interlock checks are being completed on each protective device and controls are calibrated in accordance with manufacturer's specifications;

4) Operators and maintenance personnel are trained for the inspection, maintenance, and operation of the vessel and systems; and

5) Documentation of pressure relief device inspection and testing.

c) Vessels constructed for a set number of cycles, as defined by the code of construction, which have reached the end of those cycles, must be removed from service or requalified for continued use. Any requalification for continued service must be completed in accordance with the requirements of the jurisdiction where applicable. The Inspector shall verify that documentation of any requalification is retained.

d) Requalification of any vessel shall either be completed by the original manufacturer or a manufacturer familiar with the construction of pressure vessels at and above 10,000 PSI (68.95 MPa). Guidance for completing requalification can be found in ASME PCC-3, *Inspection Planning and Using Risk-Based Methods*.

## 2.4 PIPING AND PIPING SYSTEMS

### 2.4.1 SCOPE

This section provides guidelines for internal and external inspection of piping and piping systems.

### 2.4.2 SERVICE CONDITIONS

a) Piping systems are designed for a variety of service conditions. The media that a piping system contains, the temperature at which it operates, and the piping corrosion history should be considered in

establishing piping inspection criteria. Particular attention should be given to piping systems that are subject to corrosion, high temperatures, and hazardous fluid or gases. Piping operating beyond design temperature limits can cause sufficient deterioration of piping material properties due to graphitization, embrittlement, and creep to render the piping system unfit for continued service.

b) Any externally or internally corroded piping should be evaluated for integrity and repaired or replaced as necessary.

c) Requirements specified for inspection activities and safety are identified in NBIC Part 2, Section 1, and should be reviewed and followed as applicable.

### 2.4.3 ASSESSMENT OF PIPING DESIGN

a) All pipe material and fittings should be properly rated for the maximum service conditions to which they are subjected under normal operating conditions and shall be provided with suitable relief device protection. The design corrosion allowance of the piping system should be considered when reviewing the current piping thickness data.

b) If a piping system has a previous history of ultrasonic wall thickness measurements, the Inspector should review the data and request additional wall thickness measurements, if warranted.

### 2.4.4 EXTERNAL INSPECTION OF PIPING

Piping should be inspected externally for the following:

a) Evidence of leakage (See NBIC Part 2, 2.4.6);

b) Provision for expansion and adequate support (See NBIC Part 2, 2.4.7);

c) Proper alignment of piping joints and bolted connections. Check for missing bolts or studs, nuts, and improper or inadequate bolted connection thread engagement. Also check visible gasket and gasket alignment condition. Threaded connections should also be inspected for inadequate or excessive thread engagement;

d) Past or present evidence of excessive vibration or cyclic activity such as loose or missing piping supports or piping insulation. If such activity is present, piping and piping joints should be inspected for potential fatigue cracking;

e) Evidence of general corrosion, excessive external pitting, corrosion scale buildup, exfoliation, erosion, cuts, dents, distortion, or other detrimental conditions such as pipe sweating, water hammer damage, or hot spots. Ultrasonic thickness measurements should be taken in suspect areas to ensure adequate remaining piping wall thickness;

f) Evidence of corrosion under piping insulation or other weather related damage to piping coatings;

g) Evidence of freeze damage such as bulging, striations, or surface fissures; and

h) Dead leg or stagnant piping tends to have internal corrosion issues. Ultrasonic thickness measurements should be taken in suspect locations. Radiography is also useful to assess internal deposits and subsequent corrosion in no flow piping locations.

### 2.4.5 INTERNAL INSPECTION OF PIPING

a) Where the internal surfaces of piping, valves, and gasket surfaces are accessible to visual examination, internal inspection should include an examination of all available surfaces. Nondestructive examination for internal corrosion may be used to supplement the inspection. Boroscope or camera inspections are also useful to augment piping internal inspections.

b) Internal pipe surfaces should be cleaned before inspection, if necessary.

c) The internal surfaces of piping, piping welds, and connections, fittings, valves, and gasket surfaces should be inspected for localized corrosion, pitting, erosion, blistering, cracking, and impingement damage.



### 2.4.6 EVIDENCE OF LEAKAGE

a) A leak should be investigated thoroughly and corrective action initiated. Leaks beneath piping insulation should be approached with caution, especially when removing insulation from a pressurized piping system for inspection.

b) A pressure test may be required to obtain additional information regarding the extent of a defect or detrimental condition.

For additional information regarding a leak in piping or determining the extent of a possible defect, a pressure test may be performed per NBIC Part 2, 4.3.1.

### 2.4.7 PROVISIONS FOR EXPANSION AND SUPPORT

a) Visual inspection should include a check for evidence of improper provision for piping expansion and support. Piping supports shall indicate loads within their design range. Piping supports should keep piping in alignment and prevent piping from colliding with other piping or stationary objects. The alignment of connections between anchored equipment should be observed to determine if any change in position of the equipment due to settling, excessive cyclic activity, steady-state stresses beyond design allowances, or other causes has placed an undue strain on the piping or its connections. Inadequate support or the lack of provision for expansion may cause broken attachment welds, cracks, or leakage at fittings. Missing, damaged, or loose insulation materials may be an indication of vibration or pipe movements resulting from improper support.

b) Piping support locations should be inspected closely at the support points for external and crevice corrosion concerns.

### 2.4.8 INSPECTION OF GAGES, SAFETY DEVICES, AND CONTROLS

#### 2.4.8.1 GAGES

Piping system pressure gages should be removed for testing unless there is other information to assess their accuracy. Faulty pressure gages should be recalibrated or replaced as necessary.

#### 2.4.8.2 SAFETY DEVICES

See NBIC Part 2, 2.5 for information on the inspection of pressure-relieving devices used to prevent the overpressure of piping systems.

#### 2.4.8.3 QUICK-DISCONNECT COUPLING

Piping connections utilizing a quick-disconnect coupling should be checked to ensure that the coupling and its holding elements are fully engaged in their intended operating position. Means should be provided that warn the operator against disengaging the coupling or prevent the opening mechanism from operating unless the piping is completely depressurized.

### 2.4.9 COVERED PIPING SYSTEMS

Covered Piping Systems (CPS) designed to ASME B31.1 or other construction piping codes as deemed necessary by the owner may be subjected to the same damage mechanisms as “uncovered piping”, such as boiler and boiler external piping, based on temperature, pressure and environmental conditions. Examples of CPS are main steam, hot and cold reheat, feedwater, drains and other piping systems where failure may occur as a result of creep, fatigue, erosion–corrosion, corrosion–fatigue, wall thinning, graphitization and other failure mechanisms. Based on these considerations a program should be established where CPS is periodically evaluated by an owner’s assessment program using suitable NDE, metallurgical analysis or other methods to determine whether continued operation of this piping is justified. ASME B31.1, Chapter VII -Operation and Maintenance provides guidance on how these systems should be evaluated, maintained and documented. It is recognized that all of the documentation, data and records for CPS, identified in ASME B31.1, Chapter VII may not be available for a specific plant, particularly for older plants and for piping systems identified as nonboiler external or similar piping. The rigor and detail of the owner’s CPS assessment programs are the responsibility of the owner and should ensure the continued safe operation of this piping. The owner should ensure to the extent possible that CPS do not represent safety risks. The assessment program should be made available for review.

## 2.5 PRESSURE RELIEF DEVICES

### 2.5.1 SCOPE

a) The most important appurtenances on any pressurized system are the pressure relief devices (PRDs) provided for overpressure protection of that system. These are devices such as pressure relief valves and rupture disks or other non-reclosing devices that are called upon to operate and reduce an overpressure condition.

b) These devices are not designed or intended to control the pressure in the system during normal operation. Instead, they are intended to function when normal operating controls fail or abnormal system conditions are encountered.

c) Periodic inspection and maintenance of these important safety devices is critical to ensure their continued functioning and availability when called upon to operate. See NBIC Part 2, 2.5.8 for recommended testing frequency for PRDs.

d) Inspection areas of concern include:

    1) Correct set pressure (matching of set pressure to MAWP);

    2) Safety considerations;

    3) Device data;

    4) Condition of the device;

    5) Condition of the installation; and

    6) Testing and operational inspection.

### 2.5.2 PRESSURE RELIEF DEVICE DATA

a) Nameplate marking or stamping of the device should be compared to stamping on the protected pressure-retaining item. For a single device, the set pressure shall be no higher than the maximum allowable working pressure (MAWP) marked on the protected pressure-retaining item or system.

b) When more than one pressure relief device is provided to obtain the required capacity, only one pressure relief device set pressure need be at or below the maximum allowable working pressure. The set pressure of additional devices may exceed the MAWP, as permitted by the original code of construction.

c) Verify nameplate capacity and, if possible, compare to system capacity requirements.

d) Check identification on seals and ensure they match nameplates or other identification (repair or reset nameplate) on the valve or device.

### 2.5.3 INSERVICE INSPECTION REQUIREMENTS FOR PRESSURE RELIEF DEVICE CONDITIONS

a) The valve or device shall be checked for evidence that it is leaking or not sealing properly. Evidence of leakage through pressure-relief valves may indicate that the system is being operated at a pressure that is too close to the valve's set pressure. (See Supplement 8 for guidance on the pressure differential between the pressure relief valve set pressure and system operating pressure.)

b) Seals for adjustments shall be intact and show no evidence of tampering.

c) Connecting bolting should be tight and all bolts intact.

d) The valve or device should be examined for deposits or material buildup.

e) The valve or device shall be checked for evidence of rust or corrosion.

f) The valve or device shall be checked for damaged or misapplied parts.

g) If a drain hole is visible, the valve or device should be checked to ensure it is not clogged with debris or deposits.

h) The valve or device shall be checked for test gags left in place after pressure testing of the unit.

i) Bellows valves shall be checked to ensure the bonnet vent is open or piped to a safe location. The vent shall not be plugged since this will cause the valve set pressure to be high if the bellows develops a leak. Leakage noted from the vent indicates the bellows is damaged and will no longer protect the valve from the effects of back pressure.

### 2.5.4 INSERVICE INSPECTION REQUIREMENTS FOR PRESSURE RELIEF DEVICE INSTALLATION CONDITION

a) Ensure all covers, caps, plugs, and/or lift lever wires utilized for shipping or transport are removed.

b) Inlet piping shall be inspected to ensure it meets the requirements of the original code of construction. For pressure relief valves, the inlet pipe shall be checked to ensure the inlet pipe size is not smaller than the device inlet size.

c) Discharge piping shall be inspected to ensure it meets the original code of construction. For pressure relief valves, the discharge pipe shall be checked to ensure the discharge pipe size is not smaller than the device outlet size.

d) The valve drain piping shall be checked to ensure the piping is open.

e) The discharge piping shall be checked to ensure it drains properly.

f) The inlet and discharge piping shall be checked to ensure they are not binding or placing excessive stress on the valve body, which can lead to distortion of the valve body and leakage or malfunction.

g) The condition and adequacy of the pipe supports shall be inspected. Discharge piping should be supported independent of the device itself.

h) The valve discharge and discharge pipe shall be checked for possible hazards to personnel.

i) The installation shall be checked to ensure that there are no intervening isolation valves between the pressure source and the valve inlet or between the valve outlet and its point of discharge. Isolation valves may be permitted in some pressure vessel service (See NBIC Part 4, 2.6.6 e) and jurisdictional requirements). Isolation valves shall not be used for power boilers, heating boilers, or water heaters.

j) A change-over valve, which is used to install two pressure relief devices on a single vessel location for the purpose of switching from one device to a spare device, is not considered a block valve if it is arranged such that there is no intermediate position that will isolate both pressure relief devices from the protected system. Change-over valves should be carefully evaluated to ensure they do not have excessive pressure drop that could affect the pressure relief device operation or capacity. These devices are commonly used in pressure vessel service. They may also be used in some boiler applications. It is recommended that the Jurisdiction be contacted to determine their acceptability on boiler applications.

### 2.5.5 ADDITIONAL INSPECTION REQUIREMENTS

The following are additional items that should be considered for the specified types of installations or services.

#### 2.5.5.1 BOILERS

If boilers are piped together with maximum allowable working pressures differing by more than 6%, additional protective devices may be required on the lower-pressure units to protect them from overpressure from the higher pressure unit.

#### 2.5.5.2 HOT WATER SUPPLY BOILERS, AND POTABLE WATER HEATERS

a) These units generally do not use any water treatment and therefore may be more prone to problems with deposits forming that may impair a safety device's operation. Particular attention should be paid to signs of leakage through valves or buildups of deposits.

b) Hot-water boilers tend to have buildups of corrosion products since the system is closed with little makeup. These products can foul or block the valve inlet.

c) Water heaters will have cleaner water due to continuous makeup. However, these valves usually have a thermal element that will cause the valve to open slightly when the water is heated and the heat is not removed from the system. When this hot water evaporates in the discharge piping, scale deposits may tend to form in the valve inlet and outlet.

#### (23) 2.5.5.3 PRESSURE VESSELS AND PIPING

Standard practice for overpressure protection devices is to not permit the use of any type of isolation valve either before or after the device. However, some pressure vessel standards permit the use of isolation valves under certain controlled conditions when shutting down the vessel to repair a damaged or leaking valve. If isolation block valves are employed, their use should be carefully controlled by written procedures. Block valves should have provisions to be either car-sealed or locked in an open position when not being used. For ASME Section VIII, Div. 1 pressure vessels, see UG-156, Appendix M, and jurisdictional rules for more information.

### 2.5.5.4 NON-RECLOSING PRESSURE RELIEF DEVICES (23)

a) Rupture disks or other non-reclosing devices may be used as sole relieving devices or in combination with safety relief valves to protect pressure vessels.

b) The selection of the correct rupture disk device for the intended service is critical to obtaining acceptable disk performance. Different disk designs are intended for constant pressure, varying pressure, or pulsating pressure. Some designs include features that make them suitable for back pressure and/or internal vacuum in the pressure vessel.

c) The margin between the operating pressure and the burst pressure is an important factor in obtaining acceptable performance and service life of the disk. Flat and pre-bulged solid metal disks are typically used with an operating pressure that is no more than 60% to 70% of the burst pressure. Other designs are available that increase the operating pressure to as much as 90% of the burst pressure. Disks that have been exposed to pressures above the normal operating pressure for which they are designed are subject to fatigue or creep and may fail at unexpectedly low pressures. Disks used in cyclic service are also subject to fatigue and may require a greater operating margin or selection of a device suitable for such service.

d) The disk material is also critical to obtaining acceptable service life from the disk. Disks are available in a variety of materials and coatings, and materials that are unaffected by the process fluid should be used. Disks that experience corrosion may fail and open at an unexpectedly low pressure.

e) Disk designs must also be properly selected for the fluid state. Some disk types are not suitable for use in liquid service. Some disks may have a different flow resistance when used in liquid service, which may affect the sizing of the disk.

f) Information from the rupture disk manufacturer, including catalog data and installation instructions, should be consulted when selecting a disk for a particular service.

g) For rupture disks and other non-reclosing devices, the following additional items should be considered during inspections.

    1) The rupture disk nameplate information, including stamped burst pressure and coincident temperature, should be checked to ensure it is compatible with the intended service. The coincident temperature on the rupture disk shall be the expected temperature of the disk when the disk is expected to burst and will usually be related to the process temperature, not the temperature on the pressure vessel nameplate.

    2) Markings indicating direction of flow should be checked carefully to ensure they are correct. Some rupture disks when installed in the incorrect position may burst well above the stamped pressure.

    3) The marked burst pressure for a rupture disk installed at the inlet of a safety relief valve shall be equal to or less than the safety relief valve set pressure. A marked burst pressure of 90% to 100% of the safety relief valve set pressure is recommended. A disk with a non-fragmenting design that cannot affect the safety relief valve shall be used.

        **Note:** If the safety relief valve set pressure is less than the vessel MAWP, the marked burst pressure may be higher than the valve set pressure, but no higher than the MAWP.

    4) The rupture disk shall be checked that the space between the rupture disk and a pressure relief valve is supplied with a pressure gage, try cock, or telltale indicator to indicate signs of leakage through the rupture disk. The pressure relief valve shall be inspected and the leaking disk shall be replaced if leakage through the disk is observed.

    5) If a rupture disk is used on a valve outlet, the valve design shall be of a type not influenced by back pressure due to leakage through the valve. Otherwise, for nontoxic and non-hazardous fluids, the

space between the valve and the rupture disk shall be vented or drained to prevent the accumulation of pressure.

6) For rupture disks installed on the valve inlet, the installation should be reviewed to ensure that the combination rules of the original code of construction have been applied. A reduction in the valve capacity up to 10% is expected when used in combination with a non-reclosing device.

7) The frequency of inspection for rupture disks and other non-reclosing devices is greatly dependent on the nature of the contents and operation of the system and only general recommendations can be given. Inspection frequency should be based on previous inspection history. If devices have been found to be leaking, defective, or damaged by system contents during inspection, intervals should be shortened until acceptable inspection results are obtained. With this in mind, the inspection frequency guidelines specified in NBIC Part 2, 2.5.8 are suggested for similar services.

8) Rupture disks are often used to isolate pressure relief valves from services where fouling or plugging of the valve inlet occurs. This tendency should be considered in establishing the inspection frequency.

9) Since rupture disks are single activation devices, a visual inspection is the only inspection that can be performed. A rupture disk that is removed from its holder should not be reinstalled. A rupture disk contained in an assembly that can be removed from a system without releasing the force maintaining the intimate contact between the disk and the holder, such as pre-torqued, welded, soldered, and some threaded assemblies, may be suitable for reinstallation after visual inspection. The manufacturer should be consulted for specific recommendations.

10) It is recommended that all rupture disks be replaced periodically to prevent unintended failure while in service due to deterioration of the device. Rupture disks should be checked carefully for damage prior to installation and handled by the disk edges, if possible. Any damage to the surface of the ruptured disk can affect the burst pressure.

11) For pin devices, pins or bars shall be checked for permanent deformation (e.g., bent/deflection), cracks, or corrosion. Pin deflection may be the result of pin fasteners being overtightened.

12) For pin devices, markings on replaceable pins or bars shall be checked against information on the device nameplate to ensure that they are installed on the correct device. If markings are illegible or missing, the device should be taken out of service and the pin or bar should be replaced with a component specified by the manufacturer. Replacement shall not be performed while the device is pressurized.

13) For pin devices, check that there is no foreign object present that could interfere with the bar or pin, prevent proper operation of the device, or hold the device shut.

## 2.5.6 PACKAGING, SHIPPING, AND TRANSPORTATION

a) The improper packaging, shipment, and transport of pressure relief devices can have detrimental effects on device operation. Pressure relief devices should be treated with the same precautions as instrumentation, with care taken to avoid rough handling or contamination prior to installation.

b) The following practices are recommended:

1) Valves should be securely fastened to pallets in the vertical position to avoid side loads on guiding surfaces, except threaded and socket-weld valves up to 2 in. (50 mm) may be securely packaged and cushioned during transport;

2) Valve inlet and outlet connection, drain connections, and bonnet vents should be protected during shipment and storage to avoid internal contamination of the valve;

3) The valve should not be picked up or carried using the lifting lever. Lifting levers should be wired or secured so they cannot be moved while the valve is being shipped or stored. These wires shall be removed before the valve is placed in service; and

4) Pilot valve tubing should be protected during shipment and storage to avoid damage and/or breakage.

### 2.5.7 GENERAL CONSIDERATIONS FOR TESTING AND OPERATIONAL INSPECTION OF PRESSURE RELIEF DEVICES (23)

a) Pressure relief devices shall be subject to periodic inspection and/or testing based upon the type of device.

b) The owner may perform testing on the unit wherever the valve is installed, or testing may be performed at a qualified test facility. In many cases testing on the unit may be impractical, especially if the service fluid is hazardous or toxic. Testing on the unit may involve the bypassing of operating controls and should only be performed by qualified individuals under carefully controlled conditions. It is recommended to have available a written procedure to conduct this testing.

1) The Inspector should ensure that calibrated equipment has been used to perform this test and the results should be documented by the owner.

2) If the testing is performed at a test facility, the record of this test should be reviewed to ensure the device meets the requirements of the original code of construction. Devices which have been in toxic, flammable, or other hazardous services shall be carefully decontaminated before being tested. In particular, the closed bonnet of valves in these services may contain fluids that are not easily removed or neutralized. If a test cannot be safely performed, the device shall be disassembled, cleaned, decontaminated, repaired, and reset.

3) If a device has been removed for testing, the inlet and outlet connections should be checked for blockage by product buildup or corrosion.

#### 2.5.7.1 TESTING AND OPERATIONAL INSPECTION OF PRESSURE RELIEF VALVES (23)

In addition to the requirements of 2.5.7, the following apply to testing and operational inspection of pressure relief valves.

a) Pressure relief valves shall be tested periodically to ensure that they are free to operate and will operate in accordance with the requirements of the original code of construction. Testing should include device set or opening pressure, reclosing pressure (where applicable), and seat leakage evaluation. Tolerances for these operating requirements specified in the original code of construction shall be used to determine the acceptability of test results.

b) Valves may be tested using lift assist devices when testing at full pressure may cause damage to the valve being tested or when it is impractical to test at full pressure due to system design considerations. Lift assist devices apply an auxiliary load to the valve spindle or stem, and using the measured inlet pressure, applied load and other valve data allow the set pressure to be calculated. If a lift assist device is used to determine valve set pressure, the conditions of NBIC Part 4, 4.6.3 shall be met. It should be noted that false set pressure readings may be obtained for valves which are leaking excessively or otherwise damaged.

c) If valves are not tested on the system using the system fluid, the following test mediums shall be used:

1) High-pressure boiler pressure relief valves, high-temperature hot-water boiler pressure relief valves, low-pressure steam heating boilers: steam;

2) Hot-water heating boiler pressure relief valves: steam, air, or water;

3) Hot-water heater temperature and pressure relief valves: air or water;

4) Air and gas service process pressure relief valves: air, nitrogen, or other suitable gas; and

5) Process steam service pressure relief valves: steam or air with manufacturer's steam to air correction factor.

**Note**: Valves being tested after a repair must be tested on steam except as permitted by NBIC Part 4, 4.6.2.

d) As an alternative to a pressure test, the owner may check the valve for freedom of operation by activating the test or "try" lever (i.e., manual check). For high pressure boiler and process valves, this test should be performed only at a pressure greater than 75% of the stamped set pressure of the valve or the lifting device may be damaged. This test will only indicate that the valve is free to operate and does not provide any information on the actual set pressure. All manual checks should be performed with some pressure under the valve in order to flush out from the seat debris that could cause leakage.

**Note:** The manual check at 75% or higher is based on lift lever design requirements for ASME Sections I and VIII valves. Code design requirements for lifting levers for ASME Section IV valves require that the valve is capable of being lifted without pressure.

e) Systems with multiple valves will require the lower set valves to be held closed to permit the higher set valves to be tested. A test clamp or "gag" should be used for this purpose. The spring compression screw shall not be tightened. It is recommended that when the valve is at or near the test temperature, the test clamps are applied in accordance with the valve manufacturer's instructions; application should be hand-tight only to avoid damage to the valve stem or spindle.

f) Upon completion of set pressure testing, all pressure relief valve gags shall be removed. Any stop valves used to isolate lower set pressure relief devices shall be reopened (and locked, if applicable).

### (23) 2.5.7.2 TESTING AND OPERATIONAL INSPECTION OF NON-RECLOSING PRESSURE RELIEF DEVICES (PRD) WITH PINS OR BARS

In addition to the requirements of 2.5.7, the following apply to testing and operational inspection of non-reclosing PRDs with pins or bars.

a) Periodic set point testing is not required since pins or bars are single use.

b) Periodic inspection shall be per 2.5.5.4.

c) The owner shall periodically inspect non-reclosing PRDs for freedom of motion. Freedom of motion inspection frequency shall be per 2.5.5.4.

1) Remove pressure from the PRD, or remove the PRD from service, prior to performing this check.

2) Remove the pin or bar.

3) Manually exercise the sealing mechanism to ensure it is capable of its full range of motion.

4) Reinstall the pin or bar or replace with new. Replacement pin or bar shall be per manufacturer's recommendations.

5) Restore pressure to the PRD.

6) The PRD should be checked for seat leakage following restoration of pressure.

d) The owner may elect to have a non-reclosing PRD tested periodically in order to determine service life of the device. Such tests should ensure that the PRD is free to operate and will operate in accordance with the requirements of the original code of construction. Testing should include device set or opening pressure and seat leakage evaluation. Tolerances for these operating requirements specified in the original code of construction should be used to determine the acceptability of test results.

### 2.5.7.3 TESTING AND OPERATIONAL INSPECTION OF RUPTURE DISKS (23)

In addition to the requirements of 2.5.7, the following apply to testing and operational inspection of rupture disks.

a) Periodic testing of rupture disks is not required,

b) Rupture disks shall be subject to periodic inspection per 2.5.5.4.

c) The owner may elect to have a rupture disks tested periodically in order to determine service life. Such tests should ensure that the disk is free to operate inside its holder and will operate in accordance with the requirements of the original code of construction. Testing should include an evaluation of leakage through the disk (e.g., due to cracks or porosity), followed by device opening or burst pressure at rated temperature. Tolerances for these operating requirements specified in the original code of construction should be used to determine the acceptability of test results.

d) If PRDs are not tested on the system using the system fluid, the following test mediums shall be used:

   1) Air and gas service PRDs: air, nitrogen, or other suitable gas; and

   2) Liquid service PRDs: water or other suitable fluid.

### 2.5.7.4 CORRECTIVE ACTION (23)

a) If a pressure relief valve or a pin device is found to be stuck closed, the system should immediately be taken out of service until the condition can be corrected, unless specific provisions have been made to operate on a temporary basis (e.g., additional relief capacity provided by another valve). The owner shall be notified and corrective action such as repairing or replacing the inoperable device shall be taken.

b) If a pressure relief device leaks, the owner shall be notified and will need to decide what corrective action, if any, will be taken.

### 2.5.7.5 VALVE ADJUSTMENTS

a) If a set pressure test indicates the valve does not open within the requirements of the original code of construction, but otherwise is in acceptable condition, minor adjustments (defined as no more than twice the permitted set pressure tolerance) shall be made by a National Board “VR” or “T/O” Certificate Holder to reset the valve to the correct opening pressure. All adjustments shall be resealed with a seal identifying the responsible organization and a tag shall be installed identifying the organization and the date of the adjustment.

b) If a major adjustment is needed, this may indicate the valve is in need of repair or has damaged or mis-applied parts. Its condition should be investigated accordingly.

## 2.5.8 RECOMMENDED INSPECTION AND TEST FREQUENCIES FOR PRESSURE RELIEF DEVICES

Frequency of test and inspection of pressure relief devices is greatly dependent on service, external environment, and operation of the system; therefore only general recommendations can be given. Inspection frequency should be based on previous inspection history and/or manufacturer's recommendations. If, during inspection, valves are found to be defective or damaged, intervals should be shortened until acceptable inspection results are obtained. Where test records and/or inspection history are not available, the inspection frequencies in Table 2.5.8 are suggested.

### TABLE 2.5.8

| Service | Inspection Frequency |
|---|---|
| Power boilers less than 400 psi (2.76 MPa) | Lift lever test every six months, set pressure test annually or prior to planned boiler shutdown |
| Power boilers 400 psi (2.76 MPa) or greater | Set pressure test every three years or prior to planned boiler shutdown |
| High-temperature hot water boilers (See Note 1) | Set pressure test annually |
| Low-pressure steam heating boilers | Lift lever test quarterly, set pressure test annually prior to heating season |
| Organic Fluid Vaporizers | Remove, inspect, and set pressure test annually |
| Hot water heating boilers (See Note 2) | Lift lever test quarterly, set pressure test annually prior to heating season |
| Water heaters (See Note 3) | Lift lever test every two months, remove and inspect temperature probe for damage, buildup or corrosion every three years. |
| Pressure vessels/piping-steam service | Set pressure test annually |
| Pressure vessels/piping-air/clean, dry gas | Set pressure test every three years |
| Pressure vessels/piping-propane/refrigerant | Set pressure test every five years |
| Pressure relief valves in combination with rupture disks | Set pressure test every five years |
| All others | Per inspection history |

**Note 1:**

For safety reasons, removal and testing on a steam test bench is recommended. Such testing will avoid damaging the pressure relief valve by discharge of a steam water mixture, which could occur if the valve is tested in place.

**Note 2:**

The frequencies specified for the testing of pressure relief valves on boilers is primarily based on differences between high pressure boilers that are continuously manned, and lower pressure automatically controlled boilers that are not monitored by a boiler operator at all times. When any boiler experiences an overpressure condition such that the pressure relief valves actuate, the valves should be inspected for seat leakage and other damage as soon as possible and any deficiencies corrected.

**Note 3:**

The temperature probe shall be checked for the condition of the coating material and freedom of movement without detaching. If the probe pulls out or falls off during inspection, the valve shall be repaired or replaced. Due to the relatively low cost of temperature and pressure relief valves for this service, it is recommended that a defective valve be replaced with a new valve if a repair or resetting is indicated.

### 2.5.8.1 ESTABLISHMENT OF INSPECTION AND TEST INTERVALS

Where a recommended test frequency is not listed, the valve user and Inspector must determine and agree on a suitable interval for inspection and test. Some items to be considered in making this determination are:

a) Jurisdictional requirements;

b) Records of test data and inspections from similar processes and similar devices in operation at that facility;

c) Recommendations from the device manufacturer. In particular, when the valve includes a non-metallic part such as a diaphragm or soft seat, periodic replacement of those parts may be specified;

d) Operating history of the system. Systems with frequent upsets where a valve has actuated require more frequent inspection;

e) Results of visual inspection of the device and installation conditions. Signs of valve leakage, corrosion or damaged parts all indicate more-frequent operational inspections;

f) Installation of a valve in a system with a common discharge header. Valves discharging into a common collection pipe may be affected by the discharge of other valves by the corrosion of parts in the outlet portion of the valve or the buildup of products discharged from those valves;

g) Ability to coordinate with planned system shutdowns. The shutdown of a system for other maintenance or inspection activities is an ideal time for the operational inspection and test of a pressure relief valve;

h) Critical nature of the system. Systems that are critical to plant operation or where the effects of the discharge of fluids from the system are particularly detrimental due to fire hazard, environmental damage, or toxicity concerns all call for more frequent inspection intervals to ensure devices are operating properly; and

i) Where the effects of corrosion, blockage by system fluid, or ability of the valve to operate under given service conditions are unknown (such as in a new process or installation), a relatively short inspection interval, not to exceed one year or the first planned shutdown, whichever is shorter, shall be established. At that time the device shall be visually inspected and tested. If unacceptable test results are obtained, the inspection interval shall be reduced by 50% until suitable results are obtained.

### 2.5.8.2 ESTABLISHMENT OF SERVICE INTERVALS

a) The above intervals are guidelines for periodic inspection and testing. Typically if there are no adverse findings, a pressure relief valve would be placed back in service until the next inspection. Any unacceptable conditions that are found by the inspection shall be corrected immediately by repair or replacement of the device. Many users will maintain spare pressure relief devices so the process or system is not affected by excessive downtime.

b) Pressure relief valves are mechanical devices that require periodic preventive maintenance even though external inspection and test results indicate acceptable performance. There may be wear on internal parts, galling between sliding surfaces or internal corrosion, and fouling which will not be evident from an external inspection or test. Periodic re-establishment of seating surfaces and the replacement of soft goods such as o-rings and diaphragms are also well advised preventive maintenance activities that can prevent future problems. If the valve is serviced, a complete disassembly, internal inspection, and repair as necessary, such that the valve's condition and performance are restored to a like new condition, should be done by a National Board "VR" Certificate Holder.

c) Service records with test results and findings should be maintained for all overpressure protection devices. A service interval of no more than three inspection intervals or ten years, whichever is less, is recommended to maintain device condition. Results of the internal inspection and maintenance findings can then be used to establish future service intervals.

# PART 2, SECTION 3
# INSPECTION — CORROSION AND FAILURE MECHANISMS



## 3.1 SCOPE

This section describes damage mechanisms applicable to pressure-retaining items. Further information concerning metallurgical properties of steels and nonferrous alloys are described in ASME Section II, Part D, of the Boiler and Pressure Vessel Code, Non Mandatory Appendix A.

A damage (or deterioration) mechanism is a process that induces deleterious micro and/or macro material changes over time that are harmful to the material condition or mechanical properties. Damage mechanisms are usually incremental, cumulative and, in some instances, unrecoverable. Common damage mechanisms include corrosion, chemical attack, creep, erosion, fatigue, fracture, and thermal aging.

## 3.2 GENERAL

Understanding the potential damage/deterioration mechanisms that can affect the mechanical integrity of a pressure-retaining item and knowledge of the inspection methods that can be used to find these damage mechanisms, are essential to an effective inspection. This section includes a general discussion of various damage mechanisms, and effective inspection methods are referenced in Section 4 of this part. In addition, some specific guidance is given on how to estimate the remaining life of a pressure-retaining item and determine the appropriate inspection frequencies as referenced in NBIC Part 2, Section 5.

## 3.3 CORROSION

All metals and alloys are susceptible to corrosion. Corrosion is deterioration that occurs when a metal reacts with its environment. Corrosion can be classified based on three factors:

a) Nature

   1) Wet — liquid or moisture present

   2) Dry — high-temperature gasses

b) Mechanism — electrochemical or direct chemical reactions

c) Appearance — either uniform or localized

### 3.3.1 MACROSCOPIC CORROSION ENVIRONMENTS

Macroscopic corrosion types are among the most-prevalent conditions found in pressure-retaining items causing deterioration. The following corrosion types are found.

a) Uniform Corrosion (General)

   The most common form of corrosion is uniform attack over a large area of the metal surface. Safe working pressure is directly related to the remaining material thickness, and failures can be avoided by regular inspection.

b) Galvanic Corrosion

   Two dissimilar metals in contact with each other and with an electrolyte (e.g., a film of water containing dissolved oxygen, nitrogen, and carbon dioxide) constitute an electrolytic cell, and the electric current flowing through the circuit may cause rapid corrosion of the less noble metal (the one having the

greater electrode potential). This corrosion mechanism is most active when there are large differences between the electrode potentials of the two metals, but galvanic corrosion may also exist with relatively minor changes of alloy composition (e.g., between a weld metal and the base metal). Natural (e.g., an oxide coating on aluminum) or protective coatings may inhibit galvanic corrosion, but in most instances the metals or alloys must be selected on the basis of intrinsic resistance to corrosion. In pressure vessels the effects of galvanic corrosion are most noticeable at rivets, welds, or at flanged and bolted connections.

c) Erosion Corrosion

Movement of a corrosive over a metal surface increases the rate of attack due to mechanical wear and corrosion. This corrosion is generally characterized as having an appearance of smooth bottomed shallow pits and may also exhibit a directional pattern related to the path taken by the corrosive.

d) Crevice Corrosion

Environmental conditions in a crevice can, with time, become different to those on a nearby clean surface. A more-aggressive environment may develop within the crevice and cause local corrosion. Crevices commonly exist at gasket surfaces, lap joints, bolts, rivets, etc. They are also created by dirt deposits, corrosion products, scratches in paint, etc. Crevice corrosion is usually attributed to one or more of the following:

1) Changes in acidity in the crevice;

2) Lack of oxygen in the crevice;

3) Buildup of detrimental ions in the crevice; and

4) Depletion of a corrosion inhibitor in the crevice.

e) Pitting Corrosion

Pitting corrosion is the formation of holes in an otherwise relatively unattacked surface. Pitting is usually a slow process causing isolated, scattered pits over a small area that does not substantially weaken the vessel. It could, however, eventually cause leakage.

f) Line Corrosion

This is a condition where pits are connected, or nearly connected, to each other in a narrow band or line. Line corrosion frequently occurs in the area of intersection of the support skirt and the bottom of the vessel or liquid-vapor interface.

g) Exfoliation

Exfoliation is a subsurface corrosion that begins on a clean surface but spreads below it. It differs from pitting in that the attack has a laminated appearance. These attacks are usually recognized by a flaky and sometimes blistered surface.

h) Selective Leaching

Selective leaching is the removal of one element in an alloy. This corrosion mechanism is detrimental because it yields a porous metal with poor mechanical properties.

i) Grooving

Grooving is a form of metal deterioration caused by localized corrosion and may be accelerated by stress concentration. Grooving may be found adjacent to riveted lap joints or welds and on flanged surfaces, particularly the flanges of unstayed heads.

### 3.3.2 MICROSCOPIC CORROSION ENVIRONMENTS



Microscopic corrosion environments are not visible to the naked eye. The following corrosion types are among the most prevalent conditions found in pressure-retaining items causing deterioration.

a) Intergranular Corrosion

Corrosion attack by a corrosive usually related to the segregation of specific elements or the formation of a compound in the grain boundary. It usually attacks the grain boundary that has lost an element necessary for adequate corrosion resistance. In severe cases entire grains are dislodged causing the surface to appear rough co the naked eye and feel sugary because of the loose grains. Susceptibility to intergranular corrosion is usually a by-product of heat treatment.

b) Stress Corrosion Cracking (SCC)

1) The action of tensile stress and a corrosive result in the cracking of metals. This is very serious because periods of time (often years) may pass before cracks become visible. The cracks then propagate quite rapidly and result in unexpected failures. Stresses that cause cracking arise from cold working, welding, thermal treatment, or may be externally applied during service. The cracks can follow intergranular or transgranular paths and often have a tendency for branching.

2) The principal variables affecting stress corrosion cracking are tensile stress, service temperature, solution chemistry, duration of exposure, and metal properties. Modifying any one of these parameters sufficiently can reduce or eliminate the possibility of stress corrosion cracking occurring in service. As an example, austenitic stainless steels used in water wetted service are susceptible to stress corrosion cracking.

c) Corrosion Fatigue

This is a special form of stress corrosion cracking caused by repeated cyclic stressing. When fatigue occurs in the presence of a corrodent, the result is corrosion fatigue. Such damage is common to pressure-retaining items subjected to continuous vibration.

d) Microbiologically Induced Corrosion

Microbiologically induced corrosion (MIC) is caused by bacteria, algae or fungi and is often associated with the presence of tubercles or slimy organic substances. MIC is usually found in services where stagnant water is present.

### 3.3.3 CONTROL OF CORROSION

There are many ways to control and avoid corrosion, such as control of process variables, engineering design, protection, material selection, and coatings.

#### 3.3.3.1 PROCESS VARIABLES

Some of the more common process variables that influence corrosion are listed below:

a) Concentration of major constituents;

b) Impurities;

c) Temperature;

d) pH;

e) Velocity;

f) Inhibitors; and

g) Start-up and downtime operations.



### 3.3.3.2 PROTECTION

Protective methods such as cathodic and anodic corrosion control can minimize attack and thereby reduce replacement costs or permit the use of less-expensive or thinner materials.

### 3.3.3.3 MATERIAL SELECTION

Chemical and physical properties of a material will enable selection of the best one for a specific application. The final choice will often be a compromise between the desired physical properties and economic factors. A checklist for material selection would include:

a) Evaluating requirements to be met (properties, design, appearance, mechanical, physical);

b) Material selection considerations;

c) Corrosive variables;

d) Application of equipment; and

e) Experience of materials.

### 3.3.3.4 COATINGS

Metallic and inorganic materials are typical coatings for controlling corrosion. Selection of materials depends on the corrosive, method of application, type of base material, and the nature of bonding between the base material and coating. The success or failure of a coating will often depend on the surface preparation.

a) Techniques for applying metallic coatings could include:

    1) Hot dipping;

    2) Metal spraying;

    3) Cladding;

    4) Cementation;

    5) Vapor deposition;

    6) Electroplating;

    7) Plating; and

    8) Welding.

b) Techniques for applying inorganic coatings would include:

1) Porcelain, ceramic;

2) Glass;

3) Cement;

4) Rubber;

5) Paint; and

6) Phosphates.



### 3.3.3.5 ENGINEERING DESIGN

Crevice, galvanic, erosion, and stress corrosion cracking are the types of corrosion most controllable by proper design of equipment. Procedures and situations such as welding, end-grain attack, and drainage are also controlled by proper design techniques.

### 3.3.3.6 CONCLUSION

a) By carefully selecting materials and protection methods, we can predict and control corrosive attack. However, there may be unexpected damage as a result of one or more of the following:

1) Poor choice of materials;

2) Operating conditions different from those anticipated;

3) Defective fabrication;

4) Improper design;

5) Inadequate maintenance; and

6) Defective material.

b) Corrective actions will depend on which factors caused the problems, making it important to diagnose the reason for damage. Early detection of corrosion problems is important to prevent further damage and can be achieved by performing regular inspections and encouraging employees to be observant and communicate their observations.

## 3.4 FAILURE MECHANISMS

The following failure mechanism information may assist inspectors in identifying service-induced deterioration and failure modes encountered in pressure-retaining items.

### 3.4.1 FATIGUE

Stress reversals (such as cyclic loading) in parts of equipment are common, particularly at points of high secondary stress. If stresses are high and reversals frequent, damage may occur because of fatigue. Fatigue damage in pressure vessels may also result from cyclic temperature and pressure changes. Locations where metals having different thermal coefficients of expansion are joined by welding may be susceptible to thermal fatigue.

### 3.4.2 CREEP

Creep damage may occur if equipment is subjected to temperatures above those for which the equipment is designed. Since metals become weaker at higher temperatures, such distortion may result in failure, particularly at points of stress concentration. If excessive temperatures are encountered, structural property and chemical changes in metals may also take place, which may permanently weaken equipment. Since creep is dependent on time, temperature and stress, the actual or estimated levels of these quantities should be used in any evaluations.



### 3.4.3 TEMPERATURE EFFECTS

At subfreezing temperatures, water and some chemicals handled in pressure vessels may freeze and cause damage. Carbon and low-alloy steels may be susceptible to brittle failure at ambient temperatures. A number of failures have been attributed to brittle fracture of steels that were exposed to temperatures below their transition temperature and that were exposed to pressures greater than 20% of the required hydrostatic test pressure. However, most brittle fractures have occurred on the first application of a particular stress level (that is, the first hydrostatic test or overload). Special attention should be given to low-alloy steels because they are prone to temper embrittlement. Temper embrittlement is defined as a loss of ductility and notch toughness due to postweld heat treatment or high-temperature service, above 700°F (371°C).

### 3.4.4 HYDROGEN EMBRITTLEMENT

a) The term hydrogen embrittlement (HE) refers to a loss of ductility and toughness in steels caused by atomic hydrogen dissolved in the steel. Hydrogen that is dissolved in carbon and low-alloy steels from steel making, welding, or from surface corrosion can cause either intergranular or transgranular cracking and “brittle” fracture behavior without warning.

b) Hydrogen embrittlement typically occurs below 200°F (93°C) because hydrogen remains dissolved within the steel at or below this temperature. One example of hydrogen embrittlement is underbead cracking. The underbead cracks are caused by the absorption of hydrogen during the welding process in the hard, high-strength weld heat affected zone (HAZ). Use of low-hydrogen welding practices to minimize dissolved hydrogen and/or the use of high preheat, and/or postweld heat treatment can reduce susceptibility to cracking from hydrogen embrittlement. The diffusivity of hydrogen is such that at temperatures above 450°F (232°C), the hydrogen can be effectively removed, eliminating susceptibility to cracking. Thus, hydrogen embrittlement may be reversible as long as no physical damage (e.g., cracking or fissures) has occurred in the steel.

c) Hydrogen embrittlement is a form of stress corrosion cracking (SCC). Three basic elements are needed to induce SCC: the first element is a susceptible material, the second element is environment, and the third element is stress (applied or residual). For hydrogen embrittlement to occur, the susceptible material is normally higher strength carbon or low alloy steels, the environment must contain atomic hydrogen, and the stress can be either service stress and/or residual stress from fabrication. If any of the three elements are eliminated, HE cracking is prevented.

d) In environments where processes are conducted at elevated temperature, the reaction of hydrogen with sulfur in carbon and low-alloy reactor vessel steels can produce hydrogen sulfide stress corrosion (SSC), which is a form of hydrogen embrittlement. Susceptibility to sulfide ($H_2S$) stress corrosion cracking depends on the strength of the steel. Higher-strength steels are more susceptible. The strength level at which susceptibility increases depends on the severity of the environment. Hydrogen sulfide, hydrogen cyanide, and arsenic in aqueous solutions, all increase the severity of the environment towards hydrogen embrittlement by increasing the amount of hydrogen that can be absorbed by the steel during the corrosion reaction. In hydrogen sulfide environments, susceptibility to cracking can be reduced by using steels with a strength level below that equivalent to a hardness of 22 on the Rockwell C scale.

e) Other forms of hydrogen embrittlement are wet hydrogen sulfide cracking, hydrogen stress cracking, hydrogen-induced cracking (HIC), and stress-oriented hydrogen-induced cracking (SOHIC). In each case, three basic elements are required for this damage mechanism — susceptible material, hydrogen generating environments, and stress (either residual or applied). Organic or inorganic coatings, alloy cladding or linings, are often used as a barrier to mitigate wet $H_2S$ corrosion and subsequent cracking.

### 3.4.5 HIGH-TEMPERATURE HYDROGEN ATTACK



a) Hydrogen attack is a concern primarily in refinery and petrochemical plant equipment handling hydrogen and hydrogen-hydrocarbon streams at temperatures above 450°F (232°C) and pressure above 100 psi (700 kPa). A guideline for selection of steels to avoid hydrogen attack is given in API Publication 941, “Steels for Hydrogen Service at Elevated Temperatures and Pressures in Petrochemical Refineries and Petrochemical Plants.” Also widely known as the “Nelson Curves,” API 941 shows that the severity of hydrogen attack depends on temperature, hydrogen partial pressure, exposure time, and steel composition. Additions of chromium and molybdenum increase resistance to hydrogen attack. It is important to understand that hydrogen attack is different from hydrogen embrittlement, which is discussed in NBIC Part 2, 3.4.4.

b) Hydrogen attack occurs in a high-temperature, high-pressure hydrogen environment that can degrade the mechanical strength of carbon and low alloy steels. The damage is caused by hydrogen permeating into the steel and reacting with carbon to form methane. Since carbon is an element that strengthens steel, its removal by the high-temperature reaction with hydrogen causes the steel to lose strength. In addition, methane can become trapped within the steel at high pressures, eventually forming bubbles, fissures (cracks), and/or blisters.

c) Damage caused by hydrogen attack is preceded by an incubation period with no noticeable change in properties. After the incubation period, decarburization and/or blistering and fissuring will occur. The length of the incubation period varies with service temperature, the partial pressure of hydrogen, and alloy content of the steel. Damage is reversible during the incubation period, during which no loss of mechanical properties will have occurred. Once permanent degradation begins, the damage is irreversible.

### 3.4.6 HYDROGEN DAMAGE

a) Hydrogen damage has been encountered in steam boilers that operate in the high-pressure range (1,200 psi [8.27 MPa] or higher), with relatively high-purity boiler feedwater. In boilers, the mechanism of hydrogen damage is initiated by underdeposit corrosion on water-touched surfaces. During operation of the boiler, waterwall tubing exposed to high heat flux can result in a departure from nucleate boiling (DNB) condition on the ID (waterside) surface due to small flow disturbances. Because of the increased tube metal temperature, low levels of contaminants in the boiler feedwater precipitate (e.g., plate out) on the hot tube surface. The intermittent wetting from flow, over time, results in the accumulation of deposits.

b) As the deposit begins to thicken, the tube metal beneath the deposit locally increases in temperature, causing oxidation of the tube metal. The oxidation/reduction corrosion mechanism creates atomic hydrogen, which permeates into the tube wall at boiler pressures greater than 1,200 psig (8.27 MPa).

c) The atomic hydrogen reacts with the carbon in the steel, forming methane gas that results in microfissures at grain boundaries and decarburization. The combination of decarburization and microcracks increases the susceptibility to brittle fracture in service. The typical appearance of hydrogen damage in boiler tubes is a thick-lipped, “window-type” blow out of tube metal.

d) Hydrogen damage in copper and copper alloys has also been observed and is sometimes known as steam embrittlement. This type of damage commonly occurs when the copper contains oxygen. Hydrogen entering the metal reacts with the oxygen to form water. At certain combinations of pressures and

temperatures steam forms and the pressure generated is sufficient to produce micro-cavity formation and cracking.

### 3.4.7 BULGES AND BLISTERS

a) A bulge may be caused by overheating of the entire thickness of the metal, thereby lowering the strength of the metal which is then deformed by the pressure. Bulges may also be caused by creep or temperature gradients.

b) A blister may be caused by a defect in the metal, such as a lamination, where the side exposed to the fire overheats but the other side retains its strength due to cooling effect of water or other medium. Blisters may also be caused by a hydrogen environment (See NBIC Part 2, 3.4.5).

### 3.4.8 OVERHEATING

a) Overheating is one of the most serious causes of deterioration. Deformation and possible rupture of pressure parts may result.

b) Attention should be given to surfaces that have either been exposed to fire or to operating temperatures that exceed their design limit. It should be observed whether any part has become deformed due to bulging or blistering. If a bulge or blister reduces the integrity of the component or when evidence of leakage is noted coming from those defects, proper repairs must be made.

### 3.4.9 CRACKS

a) Cracks may result from flaws existing in material or excessive cyclic stresses. Cracking can be caused by fatigue of the metal due to continual flexing and may be accelerated by corrosion. Fire cracks are caused by the thermal differential when the cooling effect of the water is not adequate to transfer the heat from the metal surfaces exposed to the fire. Some cracks result from a combination of all these causes mentioned.

b) Cracks noted in shell plates and fire cracks that run from the edge of the plate into the rivet holes of girth seams should be repaired. Thermal fatigue cracks determined by engineering evaluation to be self arresting may be left in place.

c) Areas where cracks are most likely to appear should be examined. This includes the ligaments between tube holes, from and between rivet holes, any flange where there may be repeated flexing of the plate during operation, and around welded connections.

d) Lap joints are subject to cracking where the plates lap in the longitudinal seam. If there is any evidence of leakage or other distress at this point, the Inspector shall thoroughly examine the area and, if necessary, have the plate notched or slotted in order to determine whether cracks exist in the seam. Repairs of lap joint cracks on longitudinal seams are prohibited.

e) Where cracks are suspected, it may be necessary to subject the pressure-retaining item to a pressure test or a nondestructive examination to determine their presence and location.

For additional information regarding a crack or determining extent of a possible defect, a pressure test may be performed per NBIC Part 2, 4.3.1.

f) Cracks shall either be repaired or formally evaluated by crack propagation analysis to quantify their existing mechanical integrity.

# PART 2, SECTION 4
# INSPECTION — EXAMINATIONS, TEST METHODS, AND EVALUATIONS

## 4.1 SCOPE

This section describes acceptable examination and test methods that are available to the Inspector during inspection of pressure-retaining items. This section also describes evaluation of test results and assessment methodologies.

## 4.2 NONDESTRUCTIVE EXAMINATION METHODS (NDE)

a) Listed below is a variety of nondestructive examination methods that may be employed to assess the condition of pressure-retaining items. The skill, experience, and integrity of the personnel performing these examinations are essential to obtain meaningful results. The Inspector should review the methods and procedures to be employed to ensure compliance with jurisdictional requirements.

b) Generally, some form of surface preparation will be required prior to use of these examination methods. When there is doubt as to the extent of a defect or detrimental condition found in a pressure-retaining item, the Inspector is cautioned to seek competent technical advice and supplemental NDE.

c) Personnel performing examination and test methods shall have proper training and certification, as required by the owner and acceptable to the Inspector and Jurisdiction, if required.

### 4.2.1 VISUAL

a) Visual examination is the basic method used when conducting an inservice inspection of pressure-retaining items. Additional examination and test methods may be required at the discretion of the Inspector to provide additional information to assess the condition of the pressure-retaining item.

b) Visual examination is an inspection method to ascertain the surface condition of the pressure-retaining item. The Inspector should be aware of recognizing various surface features and comparing these features with damage mechanisms listed in NBIC Part 2, Section 3 that could indicate exposure of the pressure-retaining item to harmful corrosion or elevated temperature service.

c) Remote Visual Inspection is an acceptable method of visual examination if the process is agreed upon by the owner and acceptable to the Inspector and Jurisdiction, if required.

1) For Remote Visual Inspection, plans are reviewed and approved by the Inspector.

2) The Inspector shall be present at time of data collection.

3) The Inspector will be provided a dedicated monitor that has a resolution at least equal to that obtainable by direct observation, care should be taken to minimize glare on the viewing screen.

4) The Inspector shall have direct communication with the operator of the remote visual camera.

5) For Remote Visual Inspections, the final report is acceptable to the Inspector / Jurisdiction and all raw data is available to the Inspector / Jurisdiction as needed.

6) For Remote Visual Inspections, the inspection procedure shall reference a validated qualification of the equipment, including verification that the equipment is safe for use in the environment it will be operating in. Equipment validation will refer to ASME BPVC Section V. As a minimum the equipment shall meet:

a. 1/32 in. (0.8 mm) simulated defect identification

b. Minimum light intensity of 100 fc (1076 lux)

c. Not less than 30deg offset to the surface to be examined

d. Resolution at least equal to that obtainable by direct observation

7) All equipment used must produce results acceptable to the Inspector.

### 4.2.2 MAGNETIC PARTICLE

a) The magnetic particle examination method can be used only on ferromagnetic materials to reveal surface discontinuities and to a limited degree, those located below the surface. It uses the principle that magnetic lines of force will attract magnetizable material. The sensitivity of this method decreases rapidly with depth below the surface being examined and, therefore, it is used primarily to examine for surface discontinuities.

b) In order to use this method, a magnetic field has to be established within the material to be examined. This can be done directly by bringing a strong magnetic field into close proximity of the item being examined or by inducing a magnetic field in the object by passing electric current through the object.

c) If there is a discontinuity at or near the surface, it will deflect the magnetic lines of force out of the object, thus creating a north pole (magnetic lines leave the north pole of a magnet). The magnetic lines of force will re-enter the test object on the other side of the discontinuity, thereby creating a south pole (magnetic lines enter the south pole of a magnet). Since a north and a south pole have been created, they will attract magnetizable objects. Iron powder placed on the discontinuity is held in place by the lines of force and will be visible on the surface of the test object.

### 4.2.3 LIQUID PENETRANT

a) The liquid penetrant examination method is used to detect discontinuities that are open to the surface of the material being examined. This method may be used on both ferrous and nonferrous materials. Liquid penetrant examination may be used for the detection of surface discontinuities such as cracks, seams, laps, cold shuts, laminations, and porosity.

b) Liquid penetrant examination works by applying a colored liquid (penetrant) to the object to be examined. Time is allowed for the liquid to fill any voids that are open to the surface. Excess penetrant is then removed and a “developer” is applied in a uniform, thin coating. The developer acts as a blotter and draws the penetrant out of the discontinuity. The developer is usually of a contrasting color to the penetrant. The penetrant indications will appear as colored figures on a background of the developer.

c) Liquid penetrant examination is portable, fast, and requires minimal operator training.

### 4.2.4 ULTRASONIC

Ultrasonic testing is used for volumetric examination of welds and base materials (metallic and nonmetallic) for detection of flaws. This method depends on sound waves of very high frequency being transmitted through metal and reflected at any boundary, such as a metal to air boundary at the surface of the metal or metal crack boundary at a discontinuity. High-frequency sound waves can detect small irregularities but are easily absorbed, particularly by coarse-grained materials. Sound waves can be introduced into a part either normal to the surface or at predetermined angles. Factors such as material composition, surface condition, choice of equipment, and ability of the operator affect the results of ultrasonic inspection. Ultrasonic testing can also be used to measure material thickness.

### 4.2.5 RADIOGRAPHY

a) Radiography is a volumetric method that can detect discontinuities throughout a material. This method is commonly used to examine for surface and subsurface discontinuities. The use of this method may be restricted due to the configuration of the welded joint or the limitations of the radiographic equipment. Radiography will not give an indication of the depth of discontinuity unless special procedures are used.

b) The method uses a high-energy gamma ray or x-ray source to penetrate the material to be examined. The rays are absorbed, reflected, and refracted by the material, but some of the energy passes completely through. The energy of rays that pass completely through is determined by the thickness and other physical properties of the material.

c) Radiography uses film to detect the rays that penetrate the material. The higher the energy of the rays, the darker the film will become, similar to exposing photographic film to sunlight.

d) Most discontinuities (cracks, porosity, and inclusions) reduce the amount of base material available to absorb (attenuate) x-rays or gamma rays, thus allowing more energy to pass through the material. Most discontinuities will appear as dark shapes on the radiographic film.

e) The technique used for radiography depends largely on the equipment used and what experience has shown will produce the best results. It is not the function of the technician to indicate the procedure to be followed, provided the procedure and films satisfy all requirements of the applicable code of construction. The radiographic film provides a permanent record of the results of the examination.



### 4.2.6 EDDY CURRENT

Eddy current is an examination method that measures changes in a magnetic field caused by discontinuities. Eddy current can also detect a loss of material on inaccessible surfaces and be used to detect changes in hardness of a material. There are three general types of eddy current coils: the concentric coil, which surrounds the part to be tested (e.g., tubing); the probe coil, which is brought adjacent to the part to be tested; and the bobbin coil, which is inserted into the part to be tested (e.g., tubing).

### 4.2.7 METALLOGRAPHIC

Metallographic examination is a method of locally polishing, etching, and viewing the surface of a pressure-retaining item with either acetate tape (e.g., replication) or a field microscope to determine the condition of the metal microstructure.

### 4.2.8 ACOUSTIC EMISSION

Acoustic emission is a method of detecting and monitoring discontinuities in a pressure-retaining item or load-bearing structure. This method utilizes wave guides, transducers, cables, and a sophisticated data acquisition system to collect transient acoustic emissions generated by the rapid release of energy from localized sources within the material being tested. Signal amplitude, frequency, and location are collected for many hours of operation at various loads or pressures. Analysis of the data can determine if any part of the system requires additional nondestructive examination with a more sensitive test method.

## 4.3 TESTING METHODS

All testing methods should be performed by experienced personnel using written procedures acceptable to the Inspector.

### 4.3.1 PRESSURE TESTING

a) During an inspection, there may be certain instances where inservice conditions have adversely affected the leak tightness or the inspection discloses unusual, hard to evaluate forms of deterioration that may affect the pressure-retaining capability of the pressure retaining item. In these specific instances, a pressure test using an incompressible liquid, water, or other suitable test medium may be required at the discretion of the Inspector to assess pressure boundary integrity of the pressure-retaining item.

b) The Inspector is cautioned that a pressure test will not provide any indication of amount of remaining service life or the future reliability of a pressure-retaining item. The pressure test only serves to determine if the item contains defects that will not allow the item to retain pressure. In certain instances, pressure tests of inservice items may reduce remaining service life due to causing permanent deformation.

c) Use of pressure test methods written or otherwise, shall be in agreement between the owner or user and Inspector.

All instrumentation, including pressure and temperature gages, used to monitor a test shall be properly calibrated.

When contamination of vessel contents by water is prohibited or when a liquid pressure test is not practical due to weight or other considerations, alternate test media may be used provided precautionary requirements of the applicable section of the original construction code or other standards are followed. In such cases, there shall be agreement as to the testing procedure between the owner or user and the Inspector.
Pressure testing shall not be conducted using flammable or toxic fluids.

**NOTE:** The requirements of NBIC Part 3 shall be followed when performing a liquid pressure test following repair or alteration of a pressure-retaining item.

#### 4.3.1.1 ALL PRESSURE TESTING

Careful design of test procedure can limit potential damage. For testing of pressure-retaining items, parameters that should be considered are the test media, test pressure, materials of construction and material temperature and temperature of test media. Some carbon steel and low-alloy steel materials that were manufactured prior to 1970 may not have sufficient notch toughness to prevent brittle fracture during pressure testing conducted at, or even above, the generally acceptable temperature of 60°F (16°C).

For thick-walled pressure-retaining items, it is recommended to seek technical guidance in establishing notch toughness characteristics of steel plate prior to pressure testing so that the material temperature may be warmed above 60˚F (16˚C) to avoid brittle fracture.

The organization making any pressure test shall determine pressure-retaining item material has adequate notch toughness at the minimum temperature of the material and test media during pressure test.

#### 4.3.1.2 LIQUID PRESSURE TESTING

Test pressure should be selected or adjusted in agreement between the Inspector and owner or user.

The test pressure shall not exceed the liquid test pressure of the original code of construction.

During a liquid pressure test where test pressure will exceed 90% of set pressure of a pressure relief device, the device shall be removed whenever possible. If removal of valve-type devices is not possible or practical, a spindle restraint such as a gag may be used provided that the valve manufacturer’s instructions

and recommendations are followed. Extreme caution should be employed to ensure only enough force is applied to contain pressure. Excessive mechanical force applied to the spindle restraint may result in damage to the seat and/or spindle and may interfere with proper operation of the valve. The spindle restraint shall be removed following the test.

The organization that performs the liquid pressure test and applies a spindle restraint shall attach a metal tag that identifies the organization with the date the work was performed to the pressure relieving device. If the seal was broken, the organization shall reseal the adjustment housing with a seal that identifies the responsible organization. The process shall be acceptable to the Jurisdiction where pressure-retaining items are installed.

Metal temperature shall not be more than 120°F (49°C) unless the owner or user specifies the requirement for a higher test temperature. If the owner or user specifies a test temperature higher than 120°F (49°C), then precautions shall be taken to afford the Inspector close examination without risk of injury.

Hold-time for liquid pressure tests shall be for a minimum of 10 minutes prior to examination by the Inspector. Test pressure shall be maintained for the time necessary for the Inspector to conduct inspection.



#### 4.3.1.3 PNEUMATIC PRESSURE TESTING

A pressure test using a compressible gas should not be considered due to potential hazard unless a liquid pressure test cannot be performed without damaging the pressure-retaining item or causing contamination of internal surfaces of the pressure-retaining item.

Concurrence of the owner and Inspector shall be obtained and the Jurisdiction, where required, prior to conducting a pneumatic test. The test pressure shall be the minimum required to verify leak tightness integrity but shall not exceed maximum pneumatic test pressure of the original code of construction. Precautionary requirements of the original code of construction shall be followed.

**WARNING**: Adequate safety precautions shall be taken to ensure personnel safety when a compressible gas is used due to volumetric expansion potential upon release of pressure test gas. Consideration shall be given to possible asphyxiation hazards.

Properly calibrated instrumentation shall be used to detect leakage of testing medium. Instrumentation selected shall be appropriate for the test medium. Instrumentation may detect changes in pressure or chemical concentrations and shall be sensitive enough to detect leakage.

## 4.4 METHODS TO ASSESS DAMAGE MECHANISMS AND INSPECTION FREQUENCY FOR PRESSURE-RETAINING ITEMS

### 4.4.1 SCOPE

a) This section provides guidelines and alternative methods to assess materials and pressure-retaining items subject to degradation or containing flaws identified during inservice inspections or examinations. New pressure-retaining items are placed in service to operate within their intended design parameters for a period of time determined by service conditions, which can include exposure to corrosion, exposure to elevated temperature (creep), or other forms of damage. If the pressure-retaining item is to remain safe in operation, the service conditions and the length of time before the next inspection must be identified. There are various methods that can be used to assess the condition of a pressure-retaining item to establish remaining service life and to ultimately determine the inspection interval. In some cases, a visual inspection of the pressure-retaining item will suffice. However, more comprehensive condition assessment methods may be required, including an engineering evaluation performed by a competent technical source.

b) Various assessment methods (see NBIC Part 2, 1.3), including those mentioned in this section (an example of guidelines for performing fitness for service assessments are referenced in API recommended practice API-579 “Fitness-for-Service”), can be used to establish the next inspection interval of a pressure-retaining item and to ensure safe operation. Condition assessment methods shall be subject to review and acceptance by the Jurisdiction.

c) Safe and adequate implementation of Fitness for Service Assessment (FFSA) programs is the responsibility of the owner or user. Responsibility includes verifying and understanding jurisdictional rules/ regulations and inservice inspection requirements. Application of these programs may result in decisions that will deviate from or conflict with jurisdictional requirements (e.g., frequency or types of inspections, repairs and alterations, etc.). The Inspector and Jurisdiction shall be contacted for acceptance, as appropriate, prior to implementing decisions that deviate from or conflict with established requirements.

d) If required by the Jurisdiction, FFSA shall be documented on a Report of FFSA Form NB-403, as shown in NBIC Part 2, 5.3.4. Preparation of the Report of FFSA shall be the responsibility of the owner or user. An Inspector shall indicate acceptance by signing the Report of FFSA. Legible copies of the FFSA report shall be distributed to the Jurisdiction, and the Authorized Inspection Agency responsible for the inservice inspection. The owner or user shall maintain a copy of the FFSA report in the relevant equipment inspection history file.



### 4.4.2 GENERAL REQUIREMENTS

a) Organizations or qualified individuals with experience in inspection, design, construction, repairs, or failure analysis of pressure-retaining items should be consulted to assist in identifying damage mechanisms, and to evaluate condition assessment results of pressure-retaining items. Documentation and inspection data used for fitness for service assessment should be evaluated for compliance, with codes, industry standards/experience or good engineering practices, and shall be acceptable to the Jurisdiction. Understanding the operation of equipment or systems and interaction with their internal or external service environment is necessary to correctly identify damage mechanisms.

b) There are various condition assessment and fitness for service methods that can be used to determine inspection intervals, based on calculating the remaining service life of the pressure-retaining item. For items subject to corrosion or erosion, the method to determine or adjust inspection intervals is identified in NBIC Part 2, 4.4.7. Methods for assessing other types of inservice damage that affect remaining service life of pressure-retaining items are identified in NBIC Part 2, 4.4.8.

### 4.4.3 RESPONSIBILITIES

a) Owner or User

The owner or user of the pressure-retaining item is responsible for the selection and application of a suitable fitness for service or condition assessment methodology described in this section, subject to review and approval by the Jurisdiction, if required.

b) Inspector

The Inspector shall review the condition assessment methodology and ensure inspection data and documentation are in accordance with this section.

### 4.4.4 REMAINING SERVICE LIFE ASSESSMENT METHODOLOGY

a) An evaluation of inservice damage using one or more condition assessment methods is not intended to provide a precise determination of the actual time to failure for a pressure-retaining item. Instead, the extent of inservice damage should be estimated based on the quality of available information,

established engineering assessment guidelines or methodology and appropriate assumptions used for safety, operation, and inspection.

b) If inspection and engineering assessment results indicate that a pressure-retaining item is safe for continued operation, future monitoring and inspection intervals should be determined and submitted to the Jurisdiction for review and approval. If an engineering assessment indicates that a pressure-retaining item is not suitable for service under current operating conditions, new operating conditions should be established (i.e., de-rate), or the item could be repaired subject to revised inspection intervals, or the item could be replaced.

c) Determination of the extent of inservice damage life requires the following:

1) Understanding applicable damage and failure mechanisms;

2) Developing inspection plans that can monitor the extent of inservice damage;

3) Performing an assessment of the damage including estimation of remaining life;

4) Considerations needed to minimize risk of failure;

5) Determination of root cause; and

6) Corrective measures.



### 4.4.5 DATA REQUIREMENTS FOR REMAINING SERVICE LIFE ASSESSMENTS

Evaluating the extent of inservice damage to a pressure-retaining item requires an understanding of known and potential damage mechanisms. Information that can be used to evaluate service life can be divided into three categories: inspection history, operating and maintenance history, and equipment information. Examples of types of data are listed below:

a) Inspection history

1) Summary/records of repairs and alterations;

2) Test records including pressure tests;

3) Results of prior inservice examinations (NDE methods, thickness measurements, and corrosion rate); and

4) Physical measurements or inspections.

b) Operating history/conditions

1) Operating logs including pressure, temperature, startups/shutdowns, cycles;

2) Consultation with operating personnel to determine operating history;

3) Date of installation;

4) Identification of internal and external environmental conditions to include pressure, temperature, age, design, chemical and mechanical environment, loadings, processes, etc.;

5) List of damage mechanisms identified in the past and that may be present based on materials, contaminants, and operating conditions;

6) Identification of the damage mechanisms presently active or which may become active; and

7) Identification of the failure modes associated with the identified damage mechanisms, (e.g., leaks, cracks, bursts, etc.).

c) Equipment information

1) Manufacturer's Data Reports;

2) Material Test Reports;

3) Drawings; and

4) Original design calculations/specifications.

### 4.4.6 IDENTIFICATION OF DAMAGE MECHANISMS

a) There are a variety of damage mechanisms that may affect the remaining service life of a pressure-retaining item. Damage mechanisms will cause either micro or macro changes to the material, affecting its conditions or properties. Damage mechanisms may be difficult to assess, therefore, detailed methods of evaluation for each damage mechanism should be performed in accordance with established industry practices or other acceptable standards should be followed (See NBIC Part 2, 1.3). These results should be evaluated and the inspection interval reviewed for possible adjustment. Various failure modes are described in NBIC Part 2, Section 3.

b) Common forms of damage and damage mechanisms that affect remaining service life evaluations are listed below:

1) Bulging;

2) Sagging;

3) Stress corrosion cracking;

4) Corrosion (local or general);

5) Creep;

6) Thermal or mechanical fatigue;

7) Hydrogen damage;

8) Metallurgical changes; and

9) Erosion.

c) Damage may also be caused by mechanical forces such as thermal shock, cyclic temperature changes, vibration, pressure surges, excessive temperature, external loading, and material and fabrication defects.

### 4.4.7 DETERMINING INSPECTION INTERVALS

a) The maximum period between internal inspections or a complete inservice evaluation of pressure-retaining items shall not exceed one-half of the estimated remaining service life of the vessel or ten years, whichever is less. The method for estimating inspection intervals of pressure-retaining items subject to internal erosion or corrosion is discussed in NBIC Part 2, 4.4.7.1 and 4.4.7.2.

b) Inspection intervals can be revised beyond the maximum period stated above, provided the owner or user has submitted technical justification for revising the inspection interval, subject to review and acceptance by the Jurisdiction, where required.

c) Data used in engineering assessment methods to develop revised inspection intervals for pressure-retaining items shall be re-evaluated every five years, when a change in operation occurs, or after discovery of new and/or altered damage mechanisms.

### 4.4.7.1 METHOD FOR ESTIMATING INSPECTION INTERVALS FOR PRESSURE-RETAINING ITEMS SUBJECT TO EROSION OR CORROSION

Assessment guidelines for pressure-retaining items subject to corrosion or erosion are provided in this Section. These guidelines are based on actual thickness measurements within the area of concern. Minimum required wall thickness shall be based on allowable stress of the material. Applicability and limitations of this guideline are as follows:

a) Original design criteria are known;

b) Item is not operating in the creep range;

c) Item does not contain crack-like indications;

d) Service stresses are known; and

e) Maintenance and operating history are known.



### 4.4.7.2 METHOD FOR ESTIMATING INSPECTION INTERVALS FOR EXPOSURE TO CORROSION

a) When the pressure-retaining item is exposed to service temperatures below the creep range, and the corrosion rate controls the remaining wall thickness of the pressure-retaining item, the inspection interval shall be calculated by the formula below or by other industry methods as accepted by the Jurisdiction.

$$\text{remaining life (years)} = (t_{(actual)} - t_{(required)}) / \text{corrosion rate}$$

$t_{(actual)}$ = thickness in inches (mm) measured at the time of inspection for the limiting section used in the determination of $t_{(required)}$.

$t_{(required)}$ = minimum allowable thickness in inches (mm) for the limiting section of the pressure-retaining item or zone. It shall be the greater of the following:

1) The calculated thickness, exclusive of the corrosion allowance, required for the pressure relieving device set pressure, static head, or other loading and design temperature; or

2) The minimum thickness permitted by the provision of the applicable section of the original code of construction.

Corrosion Rate = inches (mm) per year of metal removal as a result of corrosion.

b) Any suitable nondestructive examination method may be used to obtain thickness measurements, provided the instruments employed are calibrated in accordance with the manufacturer's specification or an acceptable national standard.

1) If suitably located existing openings are available, measurements may be taken through the openings.

2) When it is impossible to determine thickness by nondestructive means, a hole may be drilled through the metal wall and thickness gage measurements taken.

c) For new pressure-retaining items or PRIs for which service conditions are being changed, one of the following methods shall be employed to determine the probable rate of corrosion from which the remaining wall thickness, at the time of the next inspection, can be estimated:

1) The corrosion rate as established by data for pressure-retaining items in the same or similar service; or

2) If the probable corrosion rate cannot be determined by the above method, on-stream thickness determinations shall be made after approximately 1,000 hours of service. Subsequent sets of thickness measurements shall be taken after additional similar intervals until the corrosion rate is established.

d) Corrosion-Resistant Lining

When part or all of the pressure-retaining items have a corrosion-resistant lining, the interval between inspections of those sections so protected may be based on recorded experience with the same type of lining in similar service, but shall not exceed ten years, unless sufficient data has been provided to establish an alternative inspection interval. If there is no experience on which to base the interval between inspections, performance of the liner shall be monitored by a suitable means, such as the use of removable corrosion probes of the same material as the lining, ultrasonic examination, or radiography. To check the effectiveness of an internal insulation liner, metal temperatures may be obtained by surveying the pressure-retaining item with temperature measuring or indicating devices.

e) Two or More Zones

When a pressure-retaining item has two or more zones of pressure or temperature and the required thickness, corrosion allowance, or corrosion rate differ so much that the foregoing provisions give significant differences in maximum periods between inspections for the respective zones (e.g., the upper and lower portions of some fractionating towers), the period between inspections may be established individually for each zone on the basis of the condition applicable thereto, instead of being established for the entire vessel on the basis of the zone requiring the more frequent inspection.

f) Above-Ground Pressure Vessels

All pressure vessels above ground shall be given an external examination after operating the lesser of five years, or one quarter of remaining life, preferably while in operation. Alternative intervals resulting in longer periods may be assigned provided the requirements of this section have been followed. Inspection shall include determining the condition of the exterior insulation, the supports, and the general alignment of the vessel on its supports. Pressure vessels that are known to have a remaining life of over ten years or that are prevented from being exposed to external corrosion (such as being installed in a cold box in which the atmosphere is purged with an inert gas, or by the temperature being maintained sufficiently low or sufficiently high to preclude the presence of water), need not have the insulation removed for the external inspection. However, the condition of the insulating system and/or the outer jacketing, such as the cold box shell, shall be observed periodically and repaired if necessary.

g) Interrupted Service

1) The periods for inspection referred to above assume that the pressure-retaining item is in continuous operation, interrupted only by normal shutdown intervals. If a pressure-retaining item is out of service for an extended interval, the effect of the environmental conditions during such an interval shall be considered.

2) If the pressure-retaining item was improperly stored, exposed to a detrimental environment or the condition is suspect, it shall be given an inspection before being placed into service.

3) The date of next inspection, which was established at the previous inspection, shall be revised if damage occurred during the period of interrupted service.

h) Circumferential Stresses

For an area affected by a general corrosion in which the circumferential stresses govern the MAWP, the least thicknesses along the most critical plane of such area may be averaged over a length not exceeding:

1) The lesser of one-half the pressure vessel diameter, or 20 in. (500 mm) for vessels with inside diameters of 60 in. (1.5 m) or less; or

2) The lesser of one-third the pressure vessel diameter, or 40 in. (1 m), for vessels with inside diameters greater than 60 in. (1.5 m), except that if the area contains an opening, the distance within which thicknesses may be averaged on either side of such opening shall not extend beyond the limits of reinforcement as defined in the applicable section of the ASME Code for ASME Stamped vessels and for other vessels in their applicable codes of construction.

i) Longitudinal Stresses

If because of wind loads or other factors the longitudinal stresses would be of importance, the least thicknesses in a length of arc in the most critical plane perpendicular to the axis of the pressure vessel may be averaged for computation of the longitudinal stresses. The thicknesses used for determining corrosion rates at the respective locations shall be the most critical value of average thickness. The potential for buckling shall also be considered.

j) Local Metal Loss

Corrosion pitting shall be evaluated in accordance with NBIC Part 2, 4.4.8.7. Widely scattered corrosion pits may be left in the pressure-retaining item in accordance with the following requirements:

1) Their depth is not more than one-half the required thickness of the pressure-retaining item wall (exclusive of corrosion allowance);

2) The total area of the pits does not exceed 7 sq. in. (4,500 sq mm) within any 50 sq. inches (32,000 sq. mm); and

3) The sum of their dimensions (depth and width) along any straight line within this area does not exceed 2 in. (50 mm).

k) Weld Joint Efficiency Factor

When the surface at a weld having a joint efficiency factor of other than one is corroded as well as surfaces remote from the weld, an independent calculation using the appropriate weld joint efficiency factor shall be made to determine if the thickness at the weld or remote from the weld governs the maximum allowable working pressure. For the purpose of this calculation, the surface at a weld includes 1 in. (25 mm) on either side of the weld, or two times the minimum thickness on either side of the weld, whichever is greater.

l) Formed Heads

1) When evaluating the remaining service life for ellipsoidal, hemispherical, torispherical or toriconical shaped heads, the minimum thickness may be calculated by:

   a. Formulas used in original construction; or

   b. Where the head contains more than one radii of curvature, the appropriate strength formula for a given radius.

2) When either integral or non-integral attachments exist in the area of a knuckle radius, the fatigue and strain effects that these attachments create shall also be considered.

m) Adjustments in Corrosion Rate

If, upon measuring the wall thickness at any inspection, it is found that an inaccurate rate of corrosion has been assumed, the corrosion rate to be used for determining the inspection frequency shall be adjusted to conform with the actual rate found.

n) Riveted Construction

For a pressure-retaining item with riveted joints, in which the strength of one or more of the joints is a governing factor in establishing the maximum allowable working pressure, consideration shall be given as to whether, and to what extent, corrosion will change the possible modes of failure through such joints. Also, even though no additional thickness may have originally been provided for corrosion allowance at such joints, credit may be taken for the corrosion allowance inherent in the joint design.

### 4.4.7.3 ESTIMATING INSPECTION INTERVALS FOR PRESSURE-RETAINING ITEMS WHERE CORROSION IS NOT A FACTOR

When the corrosion rate of a pressure-retaining item is not measurable, the item need not be inspected internally provided all of the following conditions are met and complete external inspections, including thickness measurements, are made periodically on the vessel.

a) The non-corrosive character of the content, including the effect of trace elements, has been established by at least five years comparable service experience with the fluid being handled.

b) No questionable condition is disclosed by external inspection.

c) The operating temperature of the pressure-retaining item does not exceed the lower limits for the creep range of the vessel metal. Refer to NBIC Part 2, Table 4.4.8.1.

d) The pressure-retaining item is protected against inadvertent contamination.

### 4.4.8 EVALUATING INSPECTION INTERVALS OF PRESSURE-RETAINING ITEMS EXPOSED TO INSERVICE FAILURE MECHANISMS

Pressure-retaining items are subject to a variety of inservice failure mechanisms that are not associated with corrosion. The following provides a summary of evaluation processes that may require a technical evaluation to assess resultant inspection intervals.

### 4.4.8.1 EXPOSURE TO ELEVATED TEMPERATURE (CREEP)

a) The owner or user of the pressure-retaining item and the Inspector are cautioned to seek competent technical advice to determine which of the condition assessment methods can be used to ensure safe operation and determination of the next inspection interval for the pressure-retaining item when elevated service temperature is a consideration.

b) When creep damage is suspected in a pressure-retaining item, an assessment of remaining service life should be determined either by the owner or user of the pressure-retaining item or a competent engineer. This assessment may include, but is not limited to, the following methods:

1) Dimensional measurements of the item to check for creep;

2) Measurement of oxide scale and wall thickness for use in engineering analysis to determine remaining service life. Creep life can be predicted through an empirical approach that uses available data for the pressure-retaining component; total number of operating hours to the present is needed. Oxide scale thickness (steam side) can be measured directly from material samples or be

measured in situ using ultrasonic techniques;

3) Metallographic examination to determine the extent of exposure to creep damage; and

4) After removal of a material sample for creep rupture testing, a test matrix is selected to yield the most meaningful results from the sample. Test specimens are machined from the sample and tested under representative loads and temperatures (as selected in the test matrix). Creep strain vs. time and temperature vs. time to rupture data are recorded.

**TABLE 4.4.8.1**
TEMPERATURES ABOVE WHICH CREEP BECOMES A CONSIDERATION

| | |
|---|---|
| Carbon steel and C-1/2 Mo and ferritic stainless steels | 750°F (400°C) |
| Low alloy steels (Cr-Mo) | 850°F (455°C) |
| Austenitic stainless Steel | 950°F (510°C) |
| Aluminum alloys | 200°F (93°C) |



### 4.4.8.2 EXPOSURE TO BRITTLE FRACTURE

a) Determining susceptibility to brittle fracture should be required as part of the overall assessment for evaluating remaining service life or to avoid failure of the pressure-retaining item during a pressure test. In order to carry out brittle fracture assessment, mechanical design information, materials of construction and materials properties are to be determined. This information is required for pressure-retaining components in order to identify the most limiting component material that governs brittle fracture. Design information, maintenance/operating history, and information relating to environmental exposure shall be evaluated to determine if there is a risk of brittle fracture.

b) When brittle fracture is a concern, methods to prevent this failure shall be taken. These methods could include changes to operating conditions and further engineering evaluations to be performed by a qualified engineer (metallurgical/corrosion/mechanical). Engineering evaluation methods to prevent brittle fracture shall be reviewed and accepted by the owner or user, Inspector, and Jurisdiction, as required.

### 4.4.8.3 EVALUATING CONDITIONS THAT CAUSE BULGES/BLISTERS/LAMINATIONS

a) Blistering in pressure-retaining items can result from laminations, inclusions in the metal, or damage mechanisms that occur in service. Procedures for evaluating bulges/blisters/laminations are referenced in applicable standards (see NBIC Part 2, 1.3).

b) An engineering evaluation shall be performed to ensure continued safe operation when bulges/blisters/laminations are identified. If a bulge/blister/lamination is within the specified corrosion allowance, further assessment shall be performed to evaluate any crack-like indications in surrounding base material.

**Note**: Proximity of crack-like indications in welds and HAZ is important. Cracks and blisters should be evaluated separately.

### 4.4.8.4 EVALUATING CRACK-LIKE INDICATIONS IN PRESSURE-RETAINING ITEMS

a) Crack-like indications in pressure-retaining items are planar flaws characterized by length and depth with a sharp root radius. Cracks may occur within material or on the surface and may be individual or multiple in nature. In some cases, a conservative approach is to treat aligned porosity, inclusions, undercuts, and overlaps as crack-like indications. It is important that the cause of cracking be identified prior to any further determination of inspection intervals.

b) If crack-like indications are on the surface and within the specified corrosion allowance, removal by blend grinding or air arc gouging can be performed. Measurements shall be taken to ensure minimum thickness is met, and effective monitoring techniques should be established. If a crack-like flaw is not completely removed and repaired, then an engineering fracture mechanics or other evaluation must be performed to verify continued safe operation.

c) There are various methods or approaches for evaluating crack-like indications, some of which are referenced in applicable standards (see NBIC Part 2, 1.3).

### 4.4.8.5 EVALUATING EXPOSURE OF A PRESSURE-RETAINING ITEM TO FIRE DAMAGE

a) The extreme heat of a fire can produce visual structural damage and less apparent degradation of mechanical properties (decrease in yield strength or fracture toughness). Potential damage includes changes in mechanical properties, decrease in corrosion resistance, distortion, and cracking of pressure boundary components. Distortion of equipment extremities such as ladders and platforms does not necessarily mean that the pressure equipment is no longer suitable for continued service. Process fluid inside the vessel may serve as a cooling medium, thus preserving mechanical properties of the equipment. Instrumentation and wiring are commonly damaged during a fire. Data requirements and history information should be obtained as identified in NBIC Part 2, 4.4.5.

b) Recommended measurements and collection of data for evaluation of fire damage shall include but are not limited to:

1) Concentrated areas of fire damage versus overall fire damage as it relates to normal operation;

2) Determination of cause and origin of fire;

3) Temperature extremes;

4) Nature of the fuel;

5) Source of ignition;

6) Time at temperature;

7) Cooling rate;

8) Photographs taken;

9) Plant personnel interviewed; and

10) Actual strength and toughness properties of the material.

**Note**: It is important that evidence be maintained in order to perform a proper evaluation.

c) Components subjected to fire damage can exhibit altered mechanical properties, and should be evaluated to determine if the material has retained necessary strength and toughness as specified in the original code of construction. Heating above the lower critical temperature results in a phase transformation that, upon rapid cooling, can dramatically affect material properties. Evaluation methods may consist of:

1) Portable hardness testing;

2) Field metallography or replication;

3) Liquid pressure testing;

4) Magnetic particle testing;

5) Liquid penetrant testing;

6) Visual examination; or

7) Dimensional verification checks.

d) If visual distortion or changes in the microstructure or mechanical properties are noted, consider replacing the component, or a detailed engineering analysis shall be performed to verify continued safe operation.

e) Techniques for evaluating fire damage are referenced in applicable standards. See NBIC Part 2, 1.3.

### 4.4.8.6 EVALUATING EXPOSURE OF PRESSURE-RETAINING ITEMS TO CYCLIC FATIGUE

a) A fatigue evaluation should be performed if a component is subject to cyclic operation. The allowable number of cycles (mechanical or thermal) at a given level of stress should be adequate for the specified duration of service to determine suitability for continued operation.

b) Data requirements and history information should be obtained as identified in NBIC Part 2, 4.4.5.

c) Techniques for evaluating fatigue are referenced in applicable standards. See NBIC Part 2, 1.3.

### 4.4.8.7 EVALUATING PRESSURE-RETAINING ITEMS CONTAINING LOCAL THIN AREAS

a) Local thin areas can result from corrosion/erosion, mechanical damage, or blend/grind techniques during fabrication or repair, and may occur internally or externally. Types of local thin areas are grooves, gouges, and pitting. When evaluating these types of flaws, the following should be considered:

1) Original design and current operating conditions;

2) Component is not operating in the creep range;

3) Material has sufficient toughness;

4) Not operating in cyclic service;

5) Does not contain crack-like indications;

6) Flaws are not located in knuckle regions of heads or conical transitions;

7) Applied loads; and

8) The range of temperature or pressure fluctuation.

b) Where appropriate, crack-like indications should be removed by blend/grinding, and evaluated as a local thin area.

c) Data requirements and history information should be obtained as identified in NBIC Part 2, 4.4.5.

d) Required measurements for evaluation of local thin areas shall include:

1) Thickness profiles within the local region;

2) Flaw dimensions;

3) Flaw to major structural discontinuity spacing;

4) Vessel geometry; and

5) Material properties.

e) Required measurements for evaluation of pitting corrosion shall include:

1) Depth of the pit;

2) Diameter of the pit;

3) Shape of the pit; and

4) Uniformity.

f) Widely scattered corrosion pits may be left in the pressure-retaining item in accordance with the following requirements:

1) Their depth is not more than one-half the required thickness of the pressure-retaining item wall (exclusive of corrosion allowance);

2) The total area of the pits does not exceed 7 in.$^2$ (4,500 mm$^2$) within any 50 in.$^2$ (32,000 mm$^2$); and

3) The sum of their dimensions (depth and width) along any straight line within this 50 in.$^2$ (32,000 mm$^2$) area does not exceed 2 in. (50 mm).

g) If metal loss is less than specified, corrosion/erosion allowance and adequate thickness is available for future corrosion, then monitoring techniques should be established. If metal loss is greater than specified corrosion/erosion allowance and repairs are not performed, and a detailed engineering evaluation shall be performed to ensure continued safe operation.

h) Techniques for evaluating local thin areas and pitting are referenced in applicable standards. See NBIC Part 2, 1.3.

## 4.5 RISK-BASED INSPECTION ASSESSMENT PROGRAMS

### 4.5.1 SCOPE

a) This section describes the basic elements, principles, and guidelines of a risk-based inspection (RBI) program. This section does not address any one method but is intended to clarify the elements associated with a RBI program. Risk assessment is a process to evaluate continued safe operation of a pressure-containing component. This process is based on sound engineering practices, proven risk assessment experience, and management principles. There are numerous risk-based assessment methods being applied throughout many industries. Details for developing and implementing risk-based inspection programs are defined in other referenced standards.

b) Implementation of a (RBI) assessment program allows an owner or user to plan inspection frequencies based on assessing probability of failure (POF) and consequence of failure (COF) (risk = POF x COF). Risk assessment programs involve a team concept based on knowledge, training, and experience between engineers, inspectors, operators, analysts, financial, maintenance, and management personnel. Appropriate and responsible decisions must be made from input by all team members to ensure safe operation of systems and their components. Organizational commitment and cooperation is required to successfully implement and maintain a RBI program.

### 4.5.2 DEFINITIONS

*COF* — Consequence of failure. Outcome from a failure. There may be one or more outcomes from a single failure.

*POF* — Probability of failure. Extent to which a failure is likely to occur within a specific time frame.

*Risk* — A combination of probability of an event occurring and the consequences associated with the event. Risk = (POF x COF).

*Risk Assessment* — A process of risk analysis and evaluation.

*Risk Analysis* — Identification and use of information such as historical data, opinions, and concerns to evaluate, treat, and accept risk.

*Risk-Based Inspection* — Inspection managed through risk assessment.

*Risk Criteria* — Terms used whereby the significance of risk is assessed, such as personnel safety, cost benefits, legal/statutory requirements, economic/environmental aspects, stakeholders concerns, priorities, etc.

*Risk Evaluation* — Process to compare risk with given criteria to determine the significance of risk to assist in accepting or mitigating the risk.

*Uncertainty* — A measure of confidence in the expected value.



### 4.5.3 GENERAL

Risk-based inspection assessment programs can provide the following benefits for organizations:

a) An overall reduction in risk of equipment failure;

b) Identification of items not requiring inspection or mitigation;

c) An acceptable understanding of the current risk for specific items under consideration;

d) Process safety improvements by concentrating inspections, maintenance and associated expenditures on items of high risk and reducing efforts on low-risk items;

e) Improved record retention for items by retaining both historical and latest essential data and information needed for assessment;

f) Provides a management tool to continually:

   1) Maintain an effective inspection and maintenance program;

   2) Improve reliability and safety for operation;

   3) Define staffing needs;

   4) Evaluate and define funds required;

   5) Adjust risk assessment program based on desired results; and

   6) Manage uncertainty.

### 4.5.4 CONSIDERATIONS

Effective risk-based inspection programs should consider the following:

a) Significance of failure to personnel safety;

b) Identifying and obtaining accurate and appropriate information on system or component;

c) Using appropriate inspection methods and types (internal, external, inservice, etc.), frequencies, and understanding limitations;

d) Design requirements;

e) Installation requirements;

f) Operational requirements and limitations;

g) Proper execution of plans;

h) Qualifications and training requirements for personnel;

i) Use and development of procedures;

j) Sound engineering and operating judgment;

k) Effective communication among all affected areas of management and personnel;

l) Jurisdictional and Inspector involvement as required;

m) Human error;

n) Consequential and secondary effects; and

o) Impact of failure on personnel or operations.



### 4.5.5 KEY ELEMENTS OF AN RBI ASSESSMENT PROGRAM

The following key elements should be included when establishing an RBI program:

a) Establish objectives and goals;

b) Understand risk of operation by identifying effects of inspection, maintenance, operating parameters, and mitigating actions;

c) Defining roles, responsibilities, training, and qualifications;

d) Define risk criteria;

e) Managed actions for acceptable levels of risk;

f) Understanding and meeting safety and environmental requirements;

g) Optimizing expenditures;

h) Assessing mitigation alternatives;

i) Data and information collection;

j) Identifying deterioration mechanisms (see NBIC Part 2, Section 3);

k) Assessing POF and COF;

l) Determining an acceptable risk matrix;

m) Reassessing and updating RBI assessments; and

n) Required documentation and retention.

### 4.5.6 RBI ASSESSMENT

Assessments provide a systematic approach to screen risk, identify areas of concern, and develop a list for needed inspections or analysis. (POF) and (COF) must first be evaluated separately. Risk is then determined as (POF x COF) to develop a risk ranking measure or estimate.

#### 4.5.6.1 PROBABILITY OF FAILURE

Probability of failure can be expressed in terms of number of events occurring during a specific time frame. There are three main considerations when analyzing POF.

a) Evaluate deterioration mechanisms based on materials and the item's operating environment.

b) Evaluate the impact of deterioration mechanisms on the integrity of the PRI(s).

c) Determine the effectiveness of the inspection program to quantify and monitor deterioration mechanisms either on-or off-line, so that mitigation can be effective prior to failure.

#### 4.5.6.2 CONSEQUENCE OF FAILURE

Consequence analysis involves logic modeling to depict combinations of events to represent effects of failure. These models usually contain one or more failure scenarios. Consequence categories for consideration include the following:

a) Personnel safety;

b) Business/production effects, including cost related to downtime or collateral damage to surrounding equipment;

c) Affected area;

d) Environmental damage;

e) Volume of fluid or gas released;

f) Toxic or flammable events; and

g) Maintenance/repairs/replacement.

#### 4.5.6.3 RISK EVALUATION

Once POF and COF are assessed and assigned, categories of risk can be calculated and evaluated. A risk matrix or plot is helpful to display or present risk without using numerical values with categories such as low, medium, and high typically assigned to identify POF and COF. POF and COF categories can be presented easily to understand and manage risk. Using the risk evaluation, an inspection plan, including proposed inspection frequencies and appropriate inspection methods, is developed and implemented.

#### 4.5.6.4 RISK MANAGEMENT

Based on risk ranking and identifying acceptable thresholds, risk management or mitigation can proceed. When risk is considered unacceptable, the following action should be taken to minimize POF or COF. These may include, but are not limited to, the following:

a) Decommissioning;

b) Increased monitoring/inspection;

c) Repair/replace/maintain;

d) De-rate equipment — needs/limits/cycles;

e) Modifications/redesign;

f) Training; and

g) Enhance process control.

### 4.5.7 JURISDICTIONAL RELATIONSHIPS

Jurisdictions mandate specific codes/standards with rules or laws that may differ between jurisdictions. Frequency and types of inspections are examples of requirements that may vary. Owners and users implementing RBI assessment plans should understand jurisdictional requirements, so deviations from the mandated types of inspection and frequency of inspection can be requested. Methods used to develop and implement RBI assessment methods and the RBI program developed from those methods shall be acceptable to the Jurisdiction and the Inspector as required.

## 4.6 QUANITITATIVE ENGINEERING ASSESSMENTS INCLUDING FINITE ELEMENT ANALYSIS (FEA)

### 4.6.1 CALCULATIONS

This section describes criteria to be considered by the Inspector in the review of calculations prior to acceptance of quantitative engineering assessments per industry standards (such as fitness-for-service) for in-service equipment, repairs, and alterations.

### 4.6.2 ENGINEER EXPERIENCE

For quantitative engineering used in assessments, repairs and alterations, all calculations shall be completed prior to the start of any physical work or fitness-for-service acceptance. All design calculations shall be completed by an engineer (as designated by the manufacturer, R-stamp organization, owner or user) experienced in the design portion of the code used for construction of the item. Refer to NBIC Part 3, 3.2.4, 3.2.5, and 3.2.6 for design and calculations requirements for repairs and alterations.

### 4.6.3 FINITE ELEMENT ANALYSIS (FEA) ENGINEER EXPERIENCE

Finite Element Analysis (FEA) may be used to support quantitative engineering assessments or design for repairs and alterations as follows:

a) When quantitative engineering analysis is used to demonstrate the structural integrity of an in-service component containing a flaw or damage.

b) Where the configuration is not covered by the available rules in the code used for construction.

c) When there are complicated loading conditions or when a thermal analysis is required.

Because the FEA method requires more extensive knowledge of, and experience with, pressure equipment design and the FEA software package involved, the analysis and report submitted to the Inspector for review shall be completed and certified by a Professional Engineer (PE) licensed and registered as required by the manufacturer, R-stamp organization, owner or user and the jurisdiction if applicable.

The Inspector may require an initial explanation of why the FEA is applicable before the analysis is performed. The Inspector should verify the validity of the FEA report: that it has been certified by a licensed and registered Professional Engineer and that it is available for review by the manufacturer, R-stamp organization, owner or user and the jurisdiction. Owing to the specialized nature of FEA, the report must be clear and concise. Further guidelines are found in NBIC Part 2, Supplement 11, *Inspector Review Guidelines for Finite Element Analysis*.

# PART 2, SECTION 5
# INSPECTION — STAMPING, DOCUMENTATION, AND FORMS

## 5.1 SCOPE

This section provides requirements and guidelines for stamping and documentation (forms) for in-service inspections of PRIs. This section also describes evaluation of inspection results and assessment methodologies.

## 5.2 REPLACEMENT OF STAMPING OR NAMEPLATE

### 5.2.1 INDISTINCT STAMPING OR NAMEPLATE IS LOST, ILLEGIBLE, OR DETACHED.

a) When the stamping on a pressure –retaining item becomes indistinct or the nameplate is lost, illegible or detached, but traceability to the original pressure-retaining item is still possible the Inspector shall instruct the owner or user to have the nameplate or stamped data replaced. All re-stamping shall be done in accordance with the original code of construction, except as modified herein. Request for permission to re-stamp data or replace nameplates shall be made to the Jurisdiction in which the nameplate or stamping is reapplied for approval. Application shall be made on the *Replacement of Stamped Data Form,* NB-136 (see 5.3.2) which is available on the National Board website (www.nationalboard.org). Proof of traceability to the original nameplate or stamping and other such data, as is available, shall be furnished with the request. The manufacturer of the pressure-retaining item, if available, shall be contacted prior to replacing a nameplate or stamped data in order to verify applicable code requirements.

b) When there is no Jurisdiction, documentation used to verify traceability, and the *Replacement of Stamped Data Form,* NB-136 shall be submitted to a National Board Commissioned Inspector for approval.

c) All re-stamping or replacement of nameplates shall be witnessed by a National Board Commissioned Inspector.

d) When the nameplate is welded to the pressure retaining boundary, the welding must be done by a National Board “R” Stamp Holder.

e) Permission from the Jurisdiction or National Board Commissioned Inspector is not required for the reattachment of nameplates that are partially attached.

f) The re-stamping or replacement of a code symbol stamp shall be performed only as permitted by the governing code of construction.

g) Replacement nameplates or stamped data shall be clearly marked “Replacement”.

h) When traceability cannot be established, the Jurisdiction where the pressure retaining item is installed shall be contacted for approval prior to replacing a nameplate or re-applying stamping.

### (23) 5.2.2 REPORTING

a) The completed Form NB-136, *Replacement of Stamped Data Form*, with a facsimile of the replacement stamping or nameplate applied and appropriate signatures shall be filed with the Jurisdiction, if applicable and the National Board by the owner, user, original manufacturer, or “R” Certificate Holder.

b) The owner or user shall retain all documentation provided for traceability with the completed form NB-136 for as long as the pressure-retaining item is in their ownership or use. If the pressure-retaining item is sold, Form NB-136 along with the supporting documentation shall be provided to the new owner.

### 5.2.3 REPLACEMENT OF DUPLICATE NAMEPLATES

Replacement or re-attachment of duplicate nameplates is exempt from meeting the requirements in Part 2, 5.2.1, provided the information on the nameplate is identical to the original data existing on the pressure-retaining item. The duplicate nameplate shall be marked duplicate. The jurisdiction where the pressure-retaining item is located and the original manufacturer of the item shall be contacted for additional guidance and direction.

### 5.2.4 TEMPORARY REMOVAL OF NAMEPLATE FOR EXTERNAL INSPECTION, CLEANING, OR PAINTING OF VESSEL WITH NAMEPLATE STAND-OFF BRACKETS (23)

a) Some older vessels may have their nameplate attached on stand-off brackets which prevents, without complete removal of the nameplate, easy inspection of the area under the nameplate (for possible corrosion); preparation and/or cleaning of the area under the nameplate for re-painting or coating; and/or re-painting or coating of the area under the nameplate. To accomplish these tasks on these older vessels, it may be desirable to remove the nameplate from the stand-off brackets and re-attach after the required tasks have been completed on the vessel.

b) Temporary removal and re-attachment of nameplates is permitted when either requirement below is met:

   1) A National Board Commissioned Inspector witnesses the removal and re-attachment of the nameplate in accordance with NBIC Part 3, 5.11; or

   2) Temporary removal and re-attachment is by a National Board “R” Certificate Holder who has the following controls in place to ensure re-attachment of the nameplate to the correct vessel. Documented written procedure, approved by the “R” Certificate Holder’s Authorized Inspection Agency, and the Jurisdiction (if applicable), that clearly identifies: how the vessel will be marked, prior to removal of the nameplate, to identify traceability to the correct nameplate; and how it will be ensured that the correct nameplate is re-attached to the corresponding vessel. (One example that meets this marking requirement could be an engraving of the vessel serial number on lug or support.)

c) An alternative to complete removal of the nameplate is to partially detach the nameplate from the stand-off brackets, maintaining attachment of the nameplate to the vessel at all times, until required tasks are completed. In accordance with NBIC Part 2, 5.2.1.e), permission from the Jurisdiction or National Board Commissioned Inspector is not required for the reattachment of nameplates that are partially attached.

## 5.3 NATIONAL BOARD INSPECTION FORMS

### 5.3.1 SCOPE

Forms specified in 5.3.2 may be used for documenting specific requirements as indicated on the top of each form. These forms can also be found on the National Board website, www.nationalboard.org.

**Note**: Jurisdictions may have adopted other forms for the same purpose and may not accept these forms.

### 5.3.2 FORMS

a) **REPLACEMENT OF STAMPED DATA FORM (NB-136)**, see Pg. 89

b) **FORM NB-4 NEW BUSINESS OR DISCONTINUANCE OF BUSINESS**, see Pg. 91

c) **FORM NB-6 BOILER-FIRED PRESSURE VESSELS REPORT OF INSPECTION**, see Pg. 92

d) **FORM NB-7 PRESSURE VESSELS REPORT OF INSPECTION**, see Pg. 94

e) **FORM NB-403 REPORT OF FITNESS FOR SERVICE ASSESSMENT**, see Pg. 97

### (23) 5.3.3 INSTRUCTIONS FOR COMPLETING THE FORM NB-136, REPLACEMENT OF STAMPED DATA FORM

Items 1-13 shall be completed by the owner, user, original manufacturer, or “R” Certificate Holder making the request.

1) Enter purchase order number, job number, or other identifying number used by your company if applicable.

2) The name, address, and phone number of the Jurisdiction, Authorized Inspection Agency (when there is no Jurisdiction) to which the form is being submitted for approval.

3) Enter the name and address of the requester’s company or organization.

4) Enter the name, email, and phone number of the person within the requester’s company or organization who can be contacted if there are any questions concerning this request.

5) Enter the name and address of the location where the pressure-retaining item is installed. If this is the same as number 3, check the box “Same as # 3”. If the pressure-retaining item is being refurbished and the final installation location is unknown, check the box “Stock Item-Unknown”.

6) Enter the date the pressure-retaining item was installed. If unknown check the box “Unknown.”

7) Enter the name of the manufacturer of the pressure-retaining item for whom the request is being submitted.

8) Is the Manufacturer’s Data Report attached to the form? Check the appropriate box.

9) Is the pressure-retaining item registered with the National Board? Check the appropriate box. If yes, provide the National Board Registration Number.

10) Provide as much information as known to help identify the pressure-retaining item.

11) Provide a true facsimile of the legible part of the nameplate or stamping.

12) Attach any other documentation that helps provide traceability of the vessels to the original stamping, such as purchase orders, blueprints, inspection reports, etc.

13) Provide the name of the owner, user, original manufacturer, or “R” Certificate Holder making the request. If an “R” Certificate Holder is making the request, provide the “R” Certificate Number. Provide the signature of the requester and date requested.

14) To be completed by the Jurisdiction or Authorized Inspection Agency’s authorized representative.

If the original manufacturer is currently in business, concurrence shall be obtained by the owner or user.

The requester shall submit the form along with any attachments to the jurisdiction where the pressure-retaining item is installed for approval. If there is no jurisdiction or the pressure-retaining item is a stock item, the requester shall submit the form to a National Board Commissioned Inspector for approval.

After authorization, the form will be returned to the owner, user, original manufacturer, or "R" Certificate Holder who made the request. The requester is required to contact the jurisdiction or an Authorized Inspection Agency to provide a National Board Commissioned Inspector to witness the re-stamping or installation of the new nameplate. If the nameplate is being welded to the pressure-retaining boundary of the vessel, the welding shall be done by an "R" Certificate Holder. The requester will provide the new nameplate or have on hand the tools to do the re-stamping in accordance with the original code of construction.

15) Once the re-stamping is completed, or the new nameplate is attached, the requester shall provide a true facsimile of the replacement stamping.

16) The owner, user, original manufacturer, or "R" Certificate Holder shall fill in their name (and "R" Certificate Number if an "R" Certificate Holder), signature, and date.

17) To be completed by the National Board Commissioned Inspector who witnessed the re-stamping or installation of the new nameplate.

**Note:** Once the form is completed, the requester shall file a copy with the jurisdiction where the pressure-retaining item is installed, the National Board, and the owner or user of the vessel (if the request was made by the original manufacturer or the "R" Certificate Holder), and upon request to the Authorized Inspection Agency who witnessed the re-stamping or attachment of the new nameplate.



### 5.3.4 GUIDE FOR COMPLETING FITNESS FOR SERVICE ASSESSMENT REPORTS (23)

1) For tracking and reference purposes, indicate the sequential Fitness for Service Assessment number.

2) Name and address of the owner of the equipment that is being assessed for Fitness for Service.

3) Name and address of the organization or individual performing the Fitness for Service Assessment.

4) Name and address of the facility where the equipment being assessed for Fitness for Service is located.

5) Name of the Jurisdiction where the assessed equipment is located.

6) Identification of equipment, including manufacturer, manufacturer's serial number, National Board number, Jurisdiction-assigned registration number, and year built. Also include equipment/component material specification/grade, design and operating pressures, design and operating temperatures, if applicable.

7) Indicate the name, section, division, edition, and addenda of the original code of construction.

8) Name of the standard used to perform the Fitness for Service Assessment.

9) Description of the equipment / component damage mechanism or flaw types considered in the Fitness for Service Assessment.

10) Description of the Fitness for Service Assessment level and technique. Attach all relevant Fitness for Service Assessment procedures and detailed documentation.

11) Description of the Inspection and NDE results as prescribed in the Fitness for Service Assessment analysis.

12) Description of the failure, damage and/or deterioration modes identified in the Fitness for Service Assessment.

13) Indicate the results of the Fitness for Service Assessment, including remediation recommendations.

14) Indicate if the equipment can continue current operation.

15) Indicate if repairs are required.

16) Indicate if equipment replacement is required.

17) Indicate if continued operation has a finite date.

18) Indicate finite date of continued operation (if applicable).

19) Indicate the required Inspection intervals as determined by the Fitness for Service Assessment.

20) Indicate the required inservice monitoring methods and intervals for the equipment as defined by the Fitness for Service Assessment.

21) Describe any operating or inservice limitations for the equipment. This would include any reductions / changes in operating pressures or temperatures.

22) Type or print the name of the representative of the Organization or individual performing the Fitness for Service Assessment.

23) Name of the owner of the equipment.

24) Signature of owner.

25) Indicate the month, day, and year of the owner review and acceptance of Fitness for Service Assessment.

26) Indicate the name of the organization performing the Fitness for Service Assessment (this may be the same name as in line 22).

27) Signature of the responsible engineer performing the Fitness for Service Assessment.

28) Indicate the month, day, and year of the completion of the Fitness for Service Assessment by the Organization responsible.

29) Type or print the name of the Inspector.

30) Name of the Accredited Inspection Agency employing the Inspector.

31) Signature of the Inspector.

32) Indicate the month, day, and year of the review and acceptance by the Inspector of the Fitness for Service Assessment.

33) National Board commission number of Inspector, Jurisdiction, and Certificate of Competency Numbers.

(23)

THE NATIONAL BOARD OF BOILER AND PRESSURE VESSEL INSPECTORS

NB-136, Rev. 10, (01/20/19)

# REPLACEMENT OF STAMPED DATA FORM, NB-136

in accordance with provisions of the *National Board Inspection Code*

1. _____
(P.O. no., job no., etc.)

2. SUBMITTED TO: _____
(Name of Jurisdiction)

_____
(Address)

_____
(Telephone no.)

3. SUBMITTED BY: _____
(Name of Owner, User, Original Manufacturer, or "R" Certificate Holder)

_____
(Address)

4. _____ _____ _____
(Name of contact) (Email) Telephone no.)

5. LOCATION OF INSTALLATION: ☐ SAME AS #3 ☐ STOCK ITEM-UNKNOWN

_____
(Name)

_____
(Address)

6. DATE INSTALLED: _____ ☐ UNKNOWN

7. MANUFACTURER: _____
(Name)

8. MANUFACTURER'S DATA REPORT ATTACHED: ☐ NO ☐ YES

9. ITEM REGISTERED WITH NATIONAL BOARD: ☐ NO ☐ YES, NB NUMBER _____

10. ITEM IDENTIFICATION: _____ _____ _____ _____
(Type) (Mfg. serial no.) (Jurisdiction no.) (Year built)

_____ _____ SAFETY RELIEF VALVE SET AT: _____
(Dimensions) (MAWP psi) (psi)

11. PROVIDE A TRUE FACSIMILE OF THE LEGIBLE PORTION OF THE NAMEPLATE: ☐ ATTACHED

THE FOLLOWING IS A TRUE FACSIMILE OF THE LEGIBLE PORTION OF THE ITEM'S ORIGINAL NAMEPLATE (IF AVAILABLE). PLEASE PRINT. WHERE POSSIBLE, ALSO ATTACH A RUBBING OR PICTURE OF THE NAMEPLATE.

12. TRACEABILITY DOCUMENTATION – PROVIDE ANY DOCUMENTATION THAT WILL HELP THE JURISDICTION OR INSPECTOR VERIFY THE REQUESTED RE-STAMPING OR REPLACEMENT NAMEPLATE IS IN ACCORDANCE WITH THE ORIGINAL CODE OF CONSTRUCTION FOR THIS PRESSURE-RETAINING ITEM. ☐ ATTACHED

THE NATIONAL BOARD OF BOILER AND PRESSURE VESSEL INSPECTORS

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13. I REQUEST AUTHORIZATION TO REPLACE THE STAMPED DATA OR NAMEPLATE ON THE ABOVE DESCRIBED PRESSURE-RETAINING ITEM IN ACCORDANCE WITH THE RULES OF THE *NATIONAL BOARD INSPECTION CODE* (NBIC).

NAME: _____ NUMBER: _____
(Owner, User, Original Manufacturer, "R" Certificate Holder) ("R" Certificate Holder only)

SIGNATURE: _____ DATE: _____
(Authorized Representative)

14. BASED ON THE TRACEABILITY PROVIDED, AUTHORIZATION IS GRANTED TO REPLACE THE STAMPED DATA OR TO REPLACE THE NAMEPLATE OF THE ABOVE DESCRIBED PRESSURE-RETAINING ITEM.

SIGNATURE: _____ DATE: _____
(Authorized Jurisdictional Representative or Inspector)

NATIONAL BOARD COMMISSION NO.: _____ JURISDICTIONAL NUMBER: _____
(If available)

15. THE FOLLOWING IS A TRUE FACSIMILE OF THE ITEM'S REPLACEMENT STAMPING OR NAMEPLATE.
(Must clearly state "replacement")

16. I CERTIFY THAT TO THE BEST OF MY KNOWLEDGE AND BELIEF, THE STATEMENTS IN THIS REPORT ARE CORRECT, AND THAT THE REPLACEMENT INFORMATION, DATA, AND IDENTIFICATION NUMBERS ARE CORRECT AND IN ACCORDANCE WITH PROVISIONS OF THE *NATIONAL BOARD INSPECTION CODE* (NBIC).

NAME: _____ NUMBER: _____
(Owner, User, Original Manufacturer, "R" Certificate Holder) ("R" Certificate Holder only)

SIGNATURE: _____ DATE: _____
(Authorized Representative)

17. WITNESSED BY: _____ EMPLOYER: _____
(Name of Inspector)

SIGNATURE: _____ DATE: _____ NB COMMISSION NO.: _____
(Name of Inspector)

# FORM NB-4
# NEW BUSINESS OR DISCONTINUANCE
# USED BY AUTHORIZED INSPECTION AGENCIES

To: _____ _____
JURISDICTION 1. DATE OF SERVICE

2. Notice of: ☐ New insurance business ☐ Discontinuance or cancellation ☐ Refusal to insure 3. Effective date _____ 4. Type of object: ☐ High-pressure boiler ☐ Low-pressure boiler ☐ Pressure vessel

| 5. OBJECT | 6. OWNER'S NO. | 7. JURISDICTION NO. | 8. NATIONAL BOARD NO. | 9. NAME OF MANUFACTURER |
|---|---|---|---|---|
| | | | | |

10. NAME OF OWNER

11. NAME OF OWNER INCLUDING COUNTY

12. LOCATION OF OBJECT INCLUDING COUNTY

13. USER OF OBJECT (IF SAME AS OWNER SHOW "SAME")

| 14. DATE OF LAST CERTIFICATE INSPECT., IF ANY | 15. CERTIFICATE ISSUED ☐ Yes ☐ No | 16. REASON FOR DISCONTINUANCE OR CANCELLATION ☐ Phys. condition ☐ Out of use ☐ Other |
|---|---|---|
| | | |

17. REMARKS (USE REVERSE SIDE)

18. By: _____
CHIEF INSPECTOR BRANCH OFFICE

This form may be obtained from The National Board of Boiler and Pressure Vessel Inspectors, 1055 Crupper Ave., Columbus, OH 43229 NB-4 Rev. 2

THE NATIONAL BOARD OF BOILER AND PRESSURE VESSEL INSPECTORS

NB-6, Rev.7, (03/14/23)

# FORM NB-6 BOILER-FIRED PRESSURE VESSEL REPORT OF INSPECTION

**Standard Form for Jurisdictions Operating Under the ASME Code**

1. DATE INSPECTED: _____ (Month/Day/Year) CERTIFICATE EXPIRATION DATE: _____ (Month/Day/Year) CERTIFICATE POSTED: ☐ YES ☐ NO

   USER NUMBER: _____ NAT'L BD NUMBER ☐ OR SERIAL # (IF CAST IRON) ☐ _____

   FIRST INSPECTION: YES ☐ NO ☐ JURISDICTION NUMBER: _____

   NATIONAL BOARD NUMBER: _____ OTHER NUMBER: _____

2. EQUIPMENT LOCATION NAME: _____

   EQUIPMENT LOCATION ADDRESS: _____ (Equipment Location Street) _____ (Equipment Location City)

   _____ (Equipment Location State) _____ (Equipment Location Zip Code)

   NATURE OF BUSINESS: _____

   KIND OF INSPECTION: ☐ INTERNAL ☐ EXTERNAL CERTIFICATE RENEWAL: ☐ YES ☐ NO

3. CERTIFICATE BUSINESS NAME: _____

   CERTIFICATE CONTACT: _____ (NAME) _____ (Email)

   CERTIFICATE MAILING ADDRESS: _____ (Certificate Mailing Street) _____ (Certificate Mailing City)

   _____ (Certificate Mailing State) _____ (Certificate Mailing Zip Code)

4. INVOICE BUSINESS: _____ (Name)

   CERTIFICATE INVOICE CONTACT: _____ (Name) _____ (Email)

   INVOICE ADDRESS: _____ (Invoice Address Street) _____ (Invoice Address City)

   _____ (Invoice Address State) _____ (Certificate Mailing Zip Code)

5. TYPE: ☐ FT ☐ WT ☐ CI ☐ OTHER: _____ ASME/OTHER CODE: _____

   MANUFACTURER: _____ YEAR BUILT: _____

   MANHOLE ☐ HANDHOLE ☐ NEITHER ☐ CERTIFICATE DURATION (MONTHS): _____

6. USE: ☐ POWER ☐ PROCESS ☐ STEAM HEATING ☐ HWH ☐ HWS ☐ OTHER

   FUEL TYPE: _____ METHOD OF FIRING: _____

   LOCATION IN PLANT: _____

This form may be obtained from The National Board of Boiler and Pressure Vessel Inspectors • 1055 Crupper Avenue, Columbus, Ohio 43229-1183

Page 1 of 2

7. LOW WATER CUTOFF INSTALLED: YES ☐ NO ☐ TESTED: YES ☐ NO ☐

   HIGH LIMIT TEMP/PRESSURE INSTALLED: YES ☐ NO ☐ WAS BOILER FIRED: YES ☐ NO ☐

   COMBUSTION CONTROLS: CSD-1 ☐ NFPA ☐ OTHER ☐ _____

   COMBUSTION AIR VERIFIED: YES ☐ NO ☐

8. ARE THERE ANY KNOWN OUTSTANDING (OPEN) VIOLATIONS FOR THIS EQUIPMENT? ☐ YES ☐ NO (IF YES, EXPLAIN FULLY UNDER ADVERSE CONDITIONS FOUND)

   LOG/RECORD REVIEW: YES ☐ NO ☐

   PRESSURE TEST: ☐ YES PSI: _____ DATE: _____ ☐ NO

9. STAMPED MAWP: _____ MINIMUM PRD REQUIRED CAPACITY: _____

   NUMBER OF PRD'S: _____ TOTAL CAPACITY: _____

   SET PRESSURE: _____ CAPACITY: _____

   SET PRESSURE: _____ CAPACITY: _____

   SET PRESSURE: _____ CAPACITY: _____

10. INSPECTORS COMMENTS: (Verify any repairs were completed by a qualified repair company, and when applicable, the proper repair/alterations forms are completed.)

    _____
    _____
    _____
    _____
    _____
    _____

11. ADVERSE CONDITIONS FOUND: _____

    _____
    _____
    _____
    _____
    _____
    _____

12. REQUIREMENTS: _____

    _____
    _____
    _____
    _____

13. PERSON TO WHOM REQUIREMENTS WERE EXPLAINED: _____ (Name) _____ (Title)

    _____ (Email) _____ (Phone Number)

14. I HEREBY CERTIFY THIS IS A TRUE REPORT OF MY INSPECTION:

    NB COMMISSION NUMBER: _____ EMPLOYED BY: _____

    IDENTIFICATION NUMBER: _____ SIGNATURE OF INSPECTOR: _____

THE NATIONAL BOARD OF BOILER AND PRESSURE VESSEL INSPECTORS

NB-7, Rev.8, (03/14/23)

# FORM NB-7 PRESSURE VESSELS
# REPORT OF INSPECTION

**Standard Form for Jurisdictions Operating Under the ASME Code**

1. DATE INSPECTED: _____ (Month/Day/Year) CERTIFICATE EXPIRATION DATE: _____ (Month/Day/Year) CERTIFICATE POSTED: ☐ YES ☐ NO

   USER NUMBER: _____ JURISDICTION NUMBER: _____

   NATIONAL BOARD NUMBER: ☐ OR SERIAL NUMBER: (IF CAST IRON) ☐ _____

   FIRST INSPECTION: YES ☐ NO ☐

2. EQUIPMENT LOCATION NAME: _____

   NATURE OF BUSINESS: _____

   KIND OF INSPECTION: ☐ INTERNAL ☐ EXTERNAL CERTIFICATE RENEWAL: ☐ YES ☐ NO

3. EQUIPMENT LOCATION ADDRESS: _____ (Equipment Location Street) _____ (Equipment Location City)

   _____ (Equipment Location State) _____ (Equipment Location Zip Code)

4. CERTIFICATE BUSINESS NAME: _____

   CERTIFICATE CONTACT: _____ (NAME) _____ (Email)

5. CERTIFICATE MAILING ADDRESS: _____ (Certificate Mailing Street) _____ (Certificate Mailing City)

   _____ (Certificate Mailing State) _____ (Certificate Mailing Zip Code)

6. INVOICE BUSINESS: _____ (Name)

   CERTIFICATE INVOICE CONTACT: _____ (Name) _____ (Email)

7. INVOICE ADDRESS: _____ (Invoice Address Street) _____ (Invoice Address City)

   _____ (Invoice Address State) _____ (Certificate Mailing Zip Code)

8. TYPE: AIRTANK ☐ WATER TANK ☐ OTHER: ☐ _____ ASME/OTHER CODE: _____

   MANUFACTURER: _____ YEAR BUILT: _____

   MANHOLE ☐ HANDHOLE ☐ NEITHER ☐ CERTIFICATE DURATION (MONTHS): _____

9. USE: ☐ STORAGE ☐ PROCESS ☐ HEAT EXCHANGE ☐ OTHER: _____

   HORIZONTAL ☐ VERTICAL ☐ LENGTH: _____ DIAMETER: _____

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10. STAMPED MAWP: _____ MINIMUM PRD REQUIRED CAPACITY: _____

NUMBER OF PRD'S: _____ TOTAL CAPACITY: _____

SET PRESSURE: _____ CAPACITY: _____

SET PRESSURE: _____ CAPACITY: _____

SET PRESSURE: _____ CAPACITY: _____

OVERPRESSURE PROTECTION BY SYSTEM DESIGN: ☐ SIZE ($ft^3$ or Gallons): _____

11. ARE THERE ANY KNOWN OUTSTANDING (OPEN) VIOLATIONS FOR THIS EQUIPMENT? ☐ YES ☐ NO (IF YES, EXPLAIN FULLY UNDER ADVERSE CONDITIONS FOUND)

PRESSURE TEST: YES ☐ PSI _____ Date _____ NO ☐

12. INSPECTORS COMMENTS: (Verify any repairs were completed by a qualified repair company, and when applicable, the proper repair/alterations forms are completed.)

_____

_____

_____

_____

_____

_____

13. ADVERSE CONDITIONS FOUND: _____

_____

_____

_____

_____

_____

_____

14. REQUIREMENTS: _____

_____

_____

_____

_____

15. PERSON TO WHOM REQUIREMENTS WERE EXPLAINED: _____ (Name) _____ (Title)

_____ (Email) _____ (Phone Number)

16. I HEREBY CERTIFY THIS IS A TRUE REPORT OF MY INSPECTION:

NB COMMISSION NUMBER: _____ EMPLOYED BY: _____

IDENTIFICATION NUMBER: _____ SIGNATURE OF INSPECTOR: _____

The National Board of Boiler and Pressure Vessel Inspectors

NB-7, Rev.8, (03/14/23)

## PRESSURE VESSEL — REPORT OF INSPECTION — (EXTENSION SHEET)

| DATE INSPECTED | | OWNER-USER | | | | | | LOCATION | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| OWNER'S NO. | JURISDICTION NO. | NB ASME OR STD. NO. | INT | EXT | *CERT – NO. OF YEARS | TYPE OF OBJECT | YEAR BUILT | MADE BY | ALLOW. PRESS. | TEMP. OF | R.V.S.V. SETTING |
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* In this column show the number of years for which the inspector authorizes the issuance of the certificate.

THE NATIONAL BOARD OF BOILER AND PRESSURE VESSEL INSPECTORS

NB-403, Rev. 1, (06/25/15)

# FORM NB-403 REPORT OF FITNESS FOR SERVICE ASSESSMENT

in accordance with provisions of the *National Board Inspection Code*

F.F.S ASSESMENT NO. (1) _____

1. EQUIPMENT OWNER INFORMATION: (2) _____
(name)

_____
(address)

2. FFS ASSESSMENT PERFORMED BY: (3) _____
(Name of Organization or Individual)

_____
(address)

3. LOCATION OF EQUIPMENT INSTALLATION: (4) _____
(Name of Company)

_____ (5) _____
(address) (Jurisdiction)

4. EQUIPMENT OR COMPONENT INFORMATION: (6) _____
(MFG SR#, NB#, JURISDICTION# , YEAR BUILT, OTHER)

_____
(Equipment Material Specification, Grade)

_____
(Design & Operating Pressures, Design & Operating Temperatures)

5. ORIGINAL CODE OF CONSTRUCTION: (7) _____ _____ _____ _____ _____
(Name) (Section) (Division) (Edition) ( Addendum)

FITNESS FOR SERVICE STANDARD USED FOR ASSESSMENT (8) _____

6. FLAW TYPE(S) AND / OR DAMAGE MECHANISMS CONSIDERED IN FFS ASSESSMENT: (9) _____

_____

_____

_____

_____

7. FFS ASSESSMENT PROCEDURES (ATTACH FFS ASSESSMENT REFERENCE DOCUMENTS WITH DETAILS IF APPLICABLE):
(10) _____

_____

_____

INSPECTION RESULTS: (11) _____
(Type of NDE Performed, Pressure Tests, Thickness Measurements, etc.)

_____

_____

_____

FAILURE MODES IDENTIFIED: (12) _____
(Crack-Like Flaws, Pitting, Bulges/Blisters, General or Localized Corrosion, etc.)

_____

_____

8. FFS ASSESSMENTS RESULTS / RECOMMENDATIONS (CHECK BOXES THAT APPLY AND PROVIDE DETAILS): (13)

(14) ☐ CONTINUED OPERATION (15) ☐ REPAIR (16) ☐ REPLACE (17) ☐ CONTINUE OPERATION UNTIL:

(18) _____

DETAILS (IF APPLICABLE) _____

9. OWNERS INSPECTION INTERVALS (BASED ON ASSESSMENT): (19) _____
(Months/Years)

10. IN SERVICE MONITORING METHODS AND INTERVALS: (20) _____
(Methods, Months/Years)

11. OPERATING LIMITATIONS (IF APPLICABLE): (21) _____

**CERTIFICATE OF COMPLIANCE**

I, (22) _____ certify that to the best of my knowledge and belief the statements in this report are correct and that the information, data, and identification numbers are correct and in accordance with provisions of the *National Board Inspection Code*, Part 2, 4.4. Applicable documentation is attached to support this assessment

Owner Name (23) _____ (Printed)

Signature (24) _____ (Owner) Date (25) _____

Organization Performing Assessment (26) _____ (Name)

Signature (27) _____ (Responsible Engineer) Date (28) _____

Verified By (29) _____ (Inspector, Printed) Employer (30) _____ (Accredited Inspection Agency)

Signature (31) _____ (Inspector) Date (32) _____

NB Commission # (33) _____ (National Board & Jurisdiction Number)

# PART 2, SECTION 6
# INSPECTION — SUPPLEMENTS

## SUPPLEMENT 1
## STEAM LOCOMOTIVE FIRETUBE BOILER INSPECTION AND STORAGE

### S1.1 SCOPE

This supplement provides requirements and guidelines for inspection and storage of steam locomotive firetube boilers operating on tracks gaged 24 in (610 mm) or greater or for steam locomotives under the requirements of the Federal Railroad Administration (FRA). These rules shall be used in conjunction with the applicable rules of the NBIC. See NBIC Part 2, Figures S1.1-a and S1.1-b.

**FIGURE S1.1-a**

LOCOMOTIVE BOILER GENERAL ARRANGEMENT

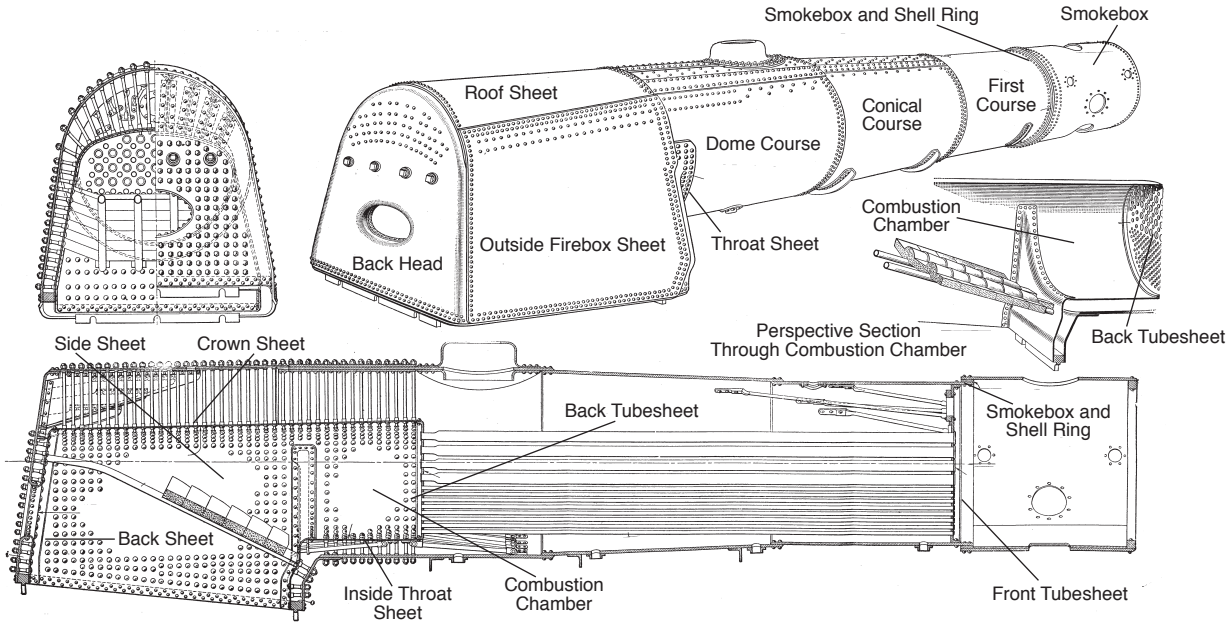
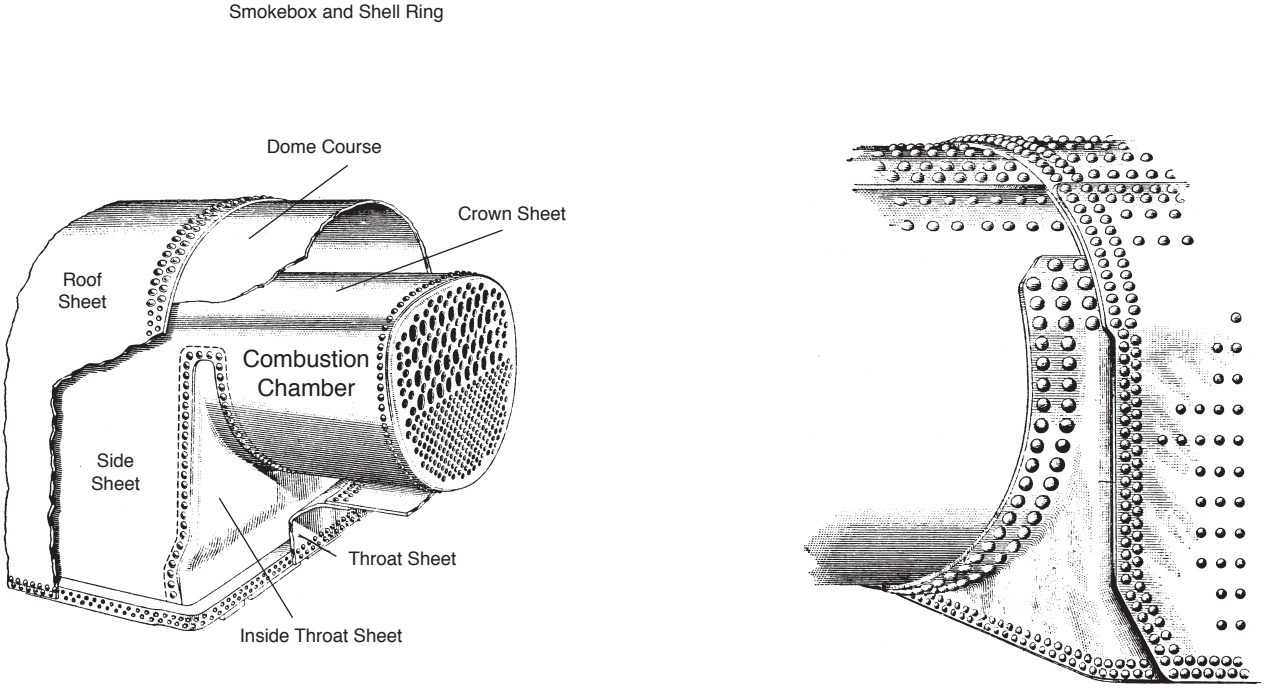


**FIGURE S1.1-b**
ARRANGEMENT OF FIREBOX SHEETS (STAYBOLTS DELETED FOR CLARITY)






## S1.2 SPECIAL JURISDICTIONAL REQUIREMENTS

Many Jurisdictions have special requirements for locomotive boilers. Such requirements shall be considered in addition to those in this supplement.

## S1.3 FEDERAL RAILROAD ADMINISTRATION (FRA)

The FRA rules for steam locomotive boilers are published in the *Code of Federal Regulations* (CFR) 49CFR Part 230, dated November 17,1999. All locomotives under FRA Jurisdiction are documented on FRA Form 4 as defined in 49CFR Part 230. This document is the formal documentation of the steam locomotive boiler and is required to be completed prior to the boiler being placed in service. This document shall be used as the data report for the boiler, applicable to all repairs and alterations performed. National Board "R" Certificate Holders shall document their repairs and/or alterations on National Board Forms R-1 or R-2. These reports shall be distributed to the owner or user of the boiler, who is required to incorporate them into the FRA Form 19, which becomes an attachment to the FRA Form 4. The design margin for all such repairs or alterations shall not be less than four, based on ultimate tensile strength of the material.

## S1.4 LOCOMOTIVE FIRETUBE BOILER INSPECTION

### S1.4.1 INSPECTION METHODS

a) Plate thickness and depth of corrosion may be determined by use of the ultrasonic thickness testing process.

b) Where access is possible, the depth of pitting may be determined by use of a depth micrometer or a pit gage.

c) On stayed sections, the plate thickness readings should be taken on a grid not exceeding the maximum staybolt pitch at the center of each section of four staybolts. Additional readings may be taken close to each staybolt to determine if localized thinning has occurred. Particular attention should be given to the joint between the staybolt and the plate.

d) On unstayed sections, the plate thickness readings should be taken on a grid not exceeding 12 inch (305 mm) centers. Additional readings should be taken if conditions warrant.

e) Cracks in plates may be located by the use of appropriate Nondestructive Examination (NDE) methods.

f) Separation of plates at riveted seams may be detected by use of a feeler gage and magnifying glass or other applicable method.

g) Varying the intensity of inspection lights may facilitate discovery of defects. Placement of the light to shine parallel to the surface is one method of detecting pits and surface irregularities.

h) When inspecting internal stayed surfaces, placement of a light source within the stayed zone will aid the inspection.

i) Broken staybolts may be detected by leakage through telltale holes and by hammer testing. Both methods are most effective when the boiler is under hydrostatic pressure of at least 95% MAWP. If a hydrostatic test cannot be applied, the hammer test may be performed alone with the boiler drained.

j) Visual inspection shall be performed as a supplement to all of the above.

### S1.4.2 INSPECTION ZONES

#### S1.4.2.1 RIVETED SEAMS AND RIVET HEADS

Riveted seams and rivet heads shall be inspected for:

a) Grooving;

b) Corrosion;

c) Cracks;

d) Pitting;

e) Leakage;

f) Separation of the plates;

g) Excessive or deep caulking of the plate edges and rivet head;

h) Seal welding of the plate edges and rivet heads;

i) Rivet heads that have been built up by, or covered over completely by, welding;

j) Rivets replaced by patch bolts;

k) Defective components of the seam; and

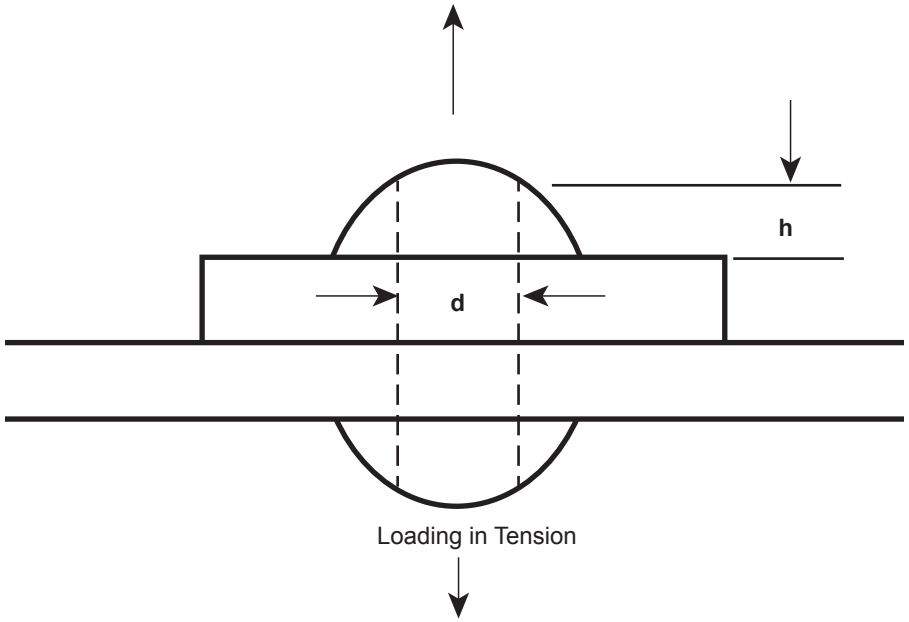
**Notes**: Broken rivet heads or cracked plates may result from sodium hydroxide cracking (caustic embitterment). Riveted longitudinal lap seams should be given careful examination, using NDE if necessary, because this type of construction is prone to cracking. When determining the extent of corrosion to rivet heads, it is important to know the rivet size and the type of rivet head used for the original construction. Corrosion can alter the appearance of these items and disguise the full extent of the damage. Fire cracks extending to the rivet holes in riveted lap seams of firebox sheets may be acceptable under NBIC Part 2, 3.4.9.

l) Rivet head wastage for rivet joint in tension.
Rivet head wastage for riveted joints in tension shall not exceed 0.250d. In NBIC Part 2, Figure S1.4.2.1, h shall be equal to or greater than 0.250d where:

h= average height of rivet head on circumference of diameter d
d= shank diameter of driven rivet

**Note:** This calculation is independent of the type and style of the rivet head.

**FIGURE S1.4.2.1**






### S1.4.2.2 WELDED AND RIVETED REPAIRS

Welded and riveted repairs shall be inspected for:

a) Correct application of welded patches or weld application;

b) Correct application of riveting;

c) Cracks;

d) Separation of the plates;

e) Dents or other mechanical damage; and

f) Leakage.

### S1.4.2.3 BOILER SHELL COURSE

The boiler shell course shall be inspected for:

a) Grooving or cuts;

b) Corrosion;

c) Cracks;

d) Pitting;

e) Separation of the plates;

f) Dents or other mechanical damage; and

g) Leakage.

**Note**: An accurate inspection often cannot be performed until the interior has been cleaned, since mud and scale make it difficult to detect defects.

### S1.4.2.4 DOME AND DOME LID

The dome and dome lid shall be inspected for:

a) Grooving;

b) Corrosion, especially at the interior section attached to the boiler course;

c) Cracks;

d) Pitting;

e) Separation of plates;

f) Dents or other mechanical damage;

g) Leakage;

h) Stretched, bent, or corroded dome studs; and

i) Damage to the steam dome cover sealing surfaces.

**Notes**: Close inspection should be made to the interior section at the joint attached to the boiler course. If the dome studs are bent, a careful evaluation should be made of the lid for leakage and mechanical damage.

### S1.4.2.5 MUDRING

The mudring and mudring rivets shall be inspected for:

a) Mud and scale on the waterside;

b) Debris on the waterside;

c) Corrosion;

d) Grooving;

e) Cracks;

f) Separation of the firebox plates from the mudring;

g) Dents or other mechanical damage; and

h) Leakage.

### S1.4.2.6 FLUE SHEETS

Flue sheets shall be inspected for:

a) Grooving around flue holes, rivet seams and braces;

b) Pitting;

c) Fireside and waterside corrosion;

d) Fire cracks at riveted lap seams;

e) Cracks;

f) Bulges;

g) Leakage; and

h) Excessive or deep caulking of the plate edges.

**Note**: Corrosion is common at the bottom section of the front flue sheet. Close inspection of the joint between the front flue sheet and shell shall be made.



### S1.4.2.7 FLANGED SHEETS

The flanged section of all flanged sheets shall be inspected for:

a) Pitting;

b) Corrosion;

c) Cracks;

d) Grooving;

e) Scale and mud deposits; and

f) Correct fit up and alignment of the flanged sheet to the adjacent sheets.

**Notes**: Corrosion is common at the bottom section of the front flue sheet. The flanges should have a smooth, uniform curvature and should make a smooth transition to the flat sheets.

### S1.4.2.8 STAYED SHEETS

Stayed sheet shall be examined for:

a) Scale and mud deposits;

b) Grooving around staybolt holes;

c) Deterioration of the joint between the staybolt and the sheet;

d) Grooving on the waterside section;

e) Pitting;

f) Fireside and waterside corrosion;

g) Overheating;

h) Fire cracks at riveted lap seams;

i) Cracks; and

j) Bulges.

**Notes**: Close inspection for fireside corrosion should be given to sections located behind refractory or grate bars.

Close inspection should be made for grooving on waterside surfaces of the stayed sheets just above the mudring.

Fire cracks extending to the rivet holes in riveted lap seam firebox sheets may be acceptable under NBIC Part 2, 3.4.9.

### S1.4.2.8.1 BULGED STAYED SHEETS

a) The maximum depth of the bulged section of the firebox sheet shall not exceed the firebox sheet thickness. The bulged section depth is defined as the protrusion of the firebox sheet beyond its original position. Where sheets are bulged more than one quarter inch within one staybolt pitch, the thickness of the plate shall be verified. If the thickness is less than required the sheet shall be replaced. If the thickness of the sheet is adequate for the pressure, it shall be ensured that there is complete thread engagement between the staybolts and the sheet in the bulged area. If any deficiency is found in the thread engagement that impedes the holding power of the staybolt to a level below what is required for the operating pressure, the defective area shall be repaired or replaced.

b) If the maximum depth of the bulge exceeds the firebox sheet thickness, the bulged section of the firebox sheet shall be replaced. All staybolts within and/or contacting the bulged firebox sheet section shall be replaced. The adjacent sections of the firebox sheet shall be inspected to determine the cause of the bulge such as scale or mud accumulation prior to completing the repair.

c) If the bulged firebox sheet will remain in service, the conditions that caused the bulge shall be identified and corrected prior to placing the boiler back into operation.

d) If the bulged firebox sheet will remain in service the bulged sheet section and the sheet sections adjacent to the bulge shall be inspected for cracking and thinning (wastage) by use of NDE in order to confirm their suitability for service prior to placing the boiler back into operation.

### S1.4.2.9 STAYBOLTS

Staybolts shall be inspected for:

a) Cracks in or breakage of the body;

b) Erosion of the driven head from corrosion or combustion gases;

c) Staybolt head flush with or below the surface of the sheet (see Figure S1.4.2.9-a);

d) Plugging of telltale holes except as permitted by 49 CFR Part 230.41;

e) Waterside corrosion (see Figure S1.4.2.9-b); and

f) Staybolt heads that have been covered over by welding.

Un-threaded fillet welded staybolts shall be inspected for corrosion wear of more than two tenths of the original dimensions of the head and shaft and leakage or signs of leakage. If leakage in excess of sweat porosity is indicated, the weld shall be removed and the staybolt rewelded, in accordance with NBIC Part 3.

**Notes**: An indicator of waterside corrosion on threaded staybolts is the lack of threads on the section of the staybolt body adjacent to the sheet.

Broken staybolts may be detected by leakage through telltale holes and by hammer testing. Both methods are most effective when the boiler is under hydrostatic pressure of at least 95% MAWP. If a hydrostatic test cannot be applied, the hammer test may be performed alone with the boiler drained.

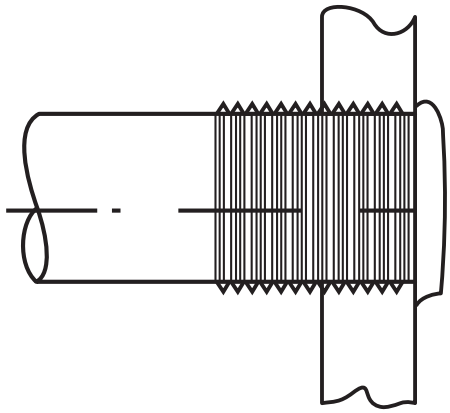
When a broken staybolt is found, the staybolts adjacent to it should be examined closely because these may have become overstressed by addition of the load from the broken staybolt.

A telltale hole plugged by installation of a nail or pin may indicate the staybolt is broken and requires replacement.

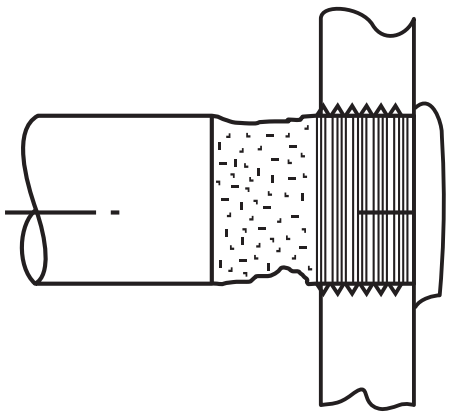
The plugging of telltale holes by refractory to prevent buildup of foreign matter in the telltale hole is permitted for locomotives operating under FRA Jurisdiction per 49 CFR Section 230.41.

(23) **FIGURES 1.2.4.9-a.**





(23) **FIGURES 1.2.4.9-b.**



### S1.4.2.10 FLEXIBLE STAYBOLTS AND SLEEVES

Flexible staybolt sleeves and caps shall be inspected for:

a) Corrosion;

b) Cracks;

c) Dents or other mechanical damage;

d) Leakage;

e) Damaged threads or welds;

f) Scale and mud accumulations inside the sleeve that could restrict bolt movement;

g) Correct application of welding to welded sleeves and welded caps; and

h) Seal welding of threaded sleeves or threaded caps.

**Notes**: An indicator of waterside corrosion on threaded staybolts is the lack of threads on the section of the staybolt body just above the sheet.

Broken staybolts may be detected by leakage through telltale holes and by hammer testing. Both methods are most effective when the boiler is under hydrostatic pressure of at least 95% MAWP. If a hydrostatic test cannot be applied, the hammer test may be performed alone with the boiler drained.

On ball head flexible staybolts, one method of testing the stay for cracks or breakage is to strike the ball head using a pneumatic hammer or hand hammer. Another method is to twist the ball head using a long- handled wrench. Access to the ball head is gained by removing the cap from the sleeve.

When a broken stay is found, the stays adjacent to it should be examined closely because these may have become overstressed by addition of the load from the broken stay.

A telltale hole plugged by installation of a nail or pin may indicate the staybolt is broken and requires replacement.

The plugging of telltale holes by refractory to prevent buildup of foreign matter in the telltale hole is permitted for locomotives operating under FRA Jurisdiction per 49 CFR Section 230.41.

One indication that a threaded staybolt leaks during service is when the head of it is found to have been re-driven repeatedly.

### S1.4.2.11 GIRDER STAY AND CROWN BARS

Girder stays, crown bars, and their associated fasteners including stays, rivets, pins, washers, nuts, thimbles, spacers, and the adjacent sections of the firebox plates shall be inspected for:

a) Corrosion;

b) Cracks;

c) Mud and scale;

d) Correct fit and alignment of the girder stay or crown bar to the firebox plate surface, including flanged sections;

e) Correct fit and alignment of the thimbles, spacers, and pins to the girder stay or crown bar, and the firebox plates;

f) Dents or other mechanical damage;

g) Stays or rivets built up by or covered over completely by welding;

h) Leakage from the stay heads;

i) Seal welding of rivet heads;

j) Correct application of retainers to all nuts and fasteners; and

k) Missing fasteners, nuts or retainers.

**Notes**: An accurate inspection often cannot be performed until the girder stay or crown bar has been cleaned, since mud and scale will make it difficult to detect defects.

When a broken stay is found, the stays adjacent to it should be examined closely because these may have become overstressed by addition of the load from the broken stay.

### S1.4.2.12 SLING STAYS

Sling stays and their associated fasteners including the pins, retainers, washers, nuts, and their associated attachment at eyes, girder stays, or crown stays shall be inspected for:

a) Corrosion;

b) Cracks;

c) Dents, wear or other mechanical damage;

d) Mud and scale;

e) Wear to the pinhole or expansion slot of the sling stay and mating component;

f) Correct application of retainers to the pins;

g) Missing fasteners, nuts, or retainers; and

h) Any of the above that would restrict movement of the sling stays.

**Notes**: An accurate inspection often cannot be performed until the sling stay has been cleaned, since mud and scale will make it difficult to detect defects.

When a broken or loose stay is found, the stays adjacent to it should be examined closely because these may have become overstressed by addition of the load from defective stays.

Special attention should be given to the row of sling stays adjacent to the flue sheet to ensure that these stays are not loose.

### S1.4.2.13 CROWN STAYS AND EXPANSION STAYS

Crown stays and expansion stays shall be inspected for:

a) Cracks in or breakage of the body;

b) Dents, wear, or other mechanical damage;

c) Erosion of the driven head from corrosion or combustion gases;

d) Stay head flush with or below the surface of the sheet;

e) Plugging of telltale holes, except as permitted by 49 CFR Part 230.41;

f) Waterside corrosion;

g) Stay heads that have been covered over by welding;

h) Correct application of seal welding to stay heads;

i) Correct application of retainers to the pins;

j) Missing fasteners, nuts, or retainers;

k) Correct fit and alignment of the stay assembly; and

l) Any of the above that would restrict movement of the stay.

**Notes**: An indicator of waterside corrosion on threaded stays is the lack of threads on the section of the stay body just above the sheet.

Broken stays may be detected by leakage through telltale holes and by hammer testing. Both methods are most effective when the boiler is under hydrostatic pressure of at least 95% MAWP. If a hydrostatic test cannot be applied, the hammer test may be performed alone with the boiler drained.

When a broken stay is found, the stays adjacent to it should be examined closely because these may have become overstressed by addition of the load from broken stays.

A telltale hole plugged by installation of a nail or pin may indicate the stay is broken and requires replacement.

The plugging of telltale holes by refractory to prevent buildup of foreign matter in the telltale hole is permitted for locomotives operating under FRA Jurisdiction per 49 CFR Part 230.41.

One indication that a threaded stay leaks during service is when the head of it is found to have been re-driven repeatedly.

Special attention should be given to the row of stays adjacent to the flue sheet to ensure that these stays are not loose.



### S1.4.2.14 DIAGONAL AND GUSSET BRACES

Diagonal and gusset braces, and their attachments, shall be inspected for:

a) Looseness;

b) Corrosion;

c) Cracks;

d) Welded repairs;

e) Missing pins or pin retainers;

f) Defective rivets; and

g) Scale and mud deposits.

**Notes**: Diagonal and gusset braces should be under tension.

The brace pins should fit the brace clevis and eye securely and be retained from coming out by some type of fixed or keyed retainer.

Diagonal braces having loop-type ends should be given close inspection for cracks and corrosion. The loop-type end is formed by the brace body being split, looped around, and forged to the body. Some versions of it have a low margin of material to provide the required strength.

### S1.4.2.15 FLUES

All boiler and super heater flues shall be inspected for:

a) Fire cracks;

b) Pitting;

c) Corrosion;

d) Erosion;

e) Obstructions in the flue interior;

f) Mud or scale buildup on the waterside;

g) Erosion or cracking of the flue ends, flue beads and/or seal welds;

h) Leakage;

i) Number of circumferential welded joints on flues repaired by re-ending; and

j) Correct application including expanding/rolling and belling, beading, or seal welding of the flue end.

**Notes**: Erosion (cinder cutting) generally occurs to the firebox end of the flue.

Galvanic corrosion of the flue in the flue sheet may occur if flues are installed with copper ferrules.



### S1.4.2.16 SUPERHEATER UNITS AND HEADER

Superheater units and the superheater header shall be inspected for:

a) Pitting;

b) Cracks;

c) Erosion;

d) Corrosion;

e) Bulges;

f) Leakage;

g) Missing shields;

h) Missing or broken bands or supports on the superheater units;

i) Missing, damaged, or welded attachment bolts, nuts, clamps, studs, and washers; and

j) Adequate structural bracing and support of the superheater header.

### S1.4.2.17 ARCH TUBES, WATER BAR TUBES, AND CIRCULATORS

Arch tubes, water bar tubes, and circulators shall be inspected for:

a) Erosion;

b) Corrosion;

c) Fire cracks;

d) Pitting;

e) Cracking of tube ends;

f) Overheating and blistering;

g) Bulges;

h) Mud and scale buildup in the waterside;

i) Welded repairs; and

j) Correct application including expanding/rolling and belling, beading, or seal welding of the tube end.

**Note**: Weld buildup or welded patches are not permitted on arch tubes and water bar tubes of locomotives operating under FRA Jurisdiction per 49 CFR Section 230.61. The defective tubes must be replaced.

### S1.4.2.18 THERMIC SYPHONS

Thermic syphons shall be inspected for:

a) Erosion;

b) Corrosion;

c) Fire cracks;

d) Pitting;

e) Cracking of the siphon neck;

f) Overheating and blistering;

g) Bulges;

h) Mud and scale blockage in the waterside; and

i) Broken or damaged staybolts.

**Note**: Refer to inspection zones — Staybolts, Stayed Sheets, and Flanged Sheets - for additional inspection procedures.

### S1.4.2.19 FIREBOX REFRACTORY

Firebox refractory shall be inspected to ensure it is properly applied and maintained to prevent undesired flame impingement on the firebox sheets.

### S1.4.2.20 DRY PIPE

The dry pipe of boilers having dome mounted (internal) throttle valves shall be inspected for:

a) Erosion;

b) Corrosion;

c) Cracks;

d) Adequate structural bracing, support, and attachment to the boiler and dome; and

e) Loose, bent, or damaged rivets, nuts, bolts, and studs.

**Note**: A steam leak into the dry pipe of a dome mounted (internal) throttle valve will send an unregulated flow of steam to the cylinders.

### S1.4.2.21 THROTTLE AND THROTTLE VALVE

The throttle handle and its mechanism shall be inspected for:

a) Proper operation;

b) Lost motion or looseness;

c) Adequate structural bracing, support and attachment to the boiler, dome, and firebox; and

d) Loose, bent, or damaged nuts, bolts, and studs.

**Note**: The throttle handle shall be equipped with some type of locking mechanism to prevent the throttle from being opened by the steam pressure.

### S1.4.2.22 SCREW-TYPE WASHOUT PLUGS, HOLES, AND SLEEVES

Screw-type washout plugs, holes, and sleeves, especially those having square or Acme thread, shall be inspected for:

a) Damaged or cracked threads on the plug, hole, or sleeve;

b) Corrosion;

c) Cracks;

d) Distortion;

e) Looseness;

f) Leakage;

g) Steam cuts to threads and sealing surfaces; and

h) Twisting of the plug head or body.

**Note**: When washout plugs are threaded with USF or NPT thread, the minimum number of threads in good condition in the threaded hole shall be adequate for the service.

### S1.4.2.23 HANDHOLE WASHOUT DOORS

Handhole washout doors and their mating surfaces shall be inspected for:

a) Damaged or cracked threads on the door studs;

b) Corrosion of door sealing surfaces and studs;

c) Cracks;

d) Stretching or bending of the door stud or handhole door;

e) Looseness;

f) Leakage and steam cuts;

g) Damage to the clamp;

h) Damage to the clamp seating surface on the sheet;

i) Confirmation that the handhole door makes unbroken line contact along the entire circumference of the sheet at the opening;

j) Handhole doors and assembly components shall have proper fit assembly;

k) Distortion of any components at assembly is prohibited; and

l) Material of the handhole door gaskets shall be suitable for the pressure and temperature of service.

**Notes**: Confirmation that the handhole door has unbroken line contact against the sheet can be determined by performing a “blue check.” This requires applying a light coating of “contact blue” or “Prussian Blue” to the handhole door sealing surfaces. The door then is held against the sheet and removed. The transfer of the bluing will show the areas that contact the sheet surfaces.

The material of the handhole door gaskets should be reviewed with the operator to confirm that it meets the pressure and temperature requirements of the boiler.

### S1.4.2.24 THREADED AND WELDED ATTACHMENT STUDS

Threaded and welded attachment studs shall be inspected for:

a) Corrosion, especially at the sheet;

b) Cracks;

c) Damaged threads;

d) Stretching or bending;

e) Looseness; and

f) Leakage.

### S1.4.2.25 FUSIBLE PLUGS

Fusible plugs shall be inspected for:

a) Corrosion;

b) Scale buildup on the waterside;

c) Damage;

d) Tampering;

e) Leakage from the threads;

f) Height of the plug above waterside of crown sheet;

g) Evidence of melting or overheating; and

h) Proper marking.

### S1.4.2.26 WATER GLASS, WATER COLUMN, AND GAGE COCKS

The water glass, water column, and gage cock boiler connections and piping shall be inspected for:

a) Mud and scale blockage;

b) Kinks or sharp, restricted, or flattened bends in the piping;

c) Sags in the piping horizontal runs;

d) Condition of tubular or reflex water glass;

e) Correct type and material of piping and fittings;

f) Correct location, size, and installation of the connections to the sheets;

g) Correct installation of the safety shield (if used);

h) Correct installation of the viewing light (if used);

i) Correct installation of the test and drain valves;

j) Proper installation;

k) Proper bracing to prevent vibration; and

l) Loose, bent, or damaged nuts, bolts, and studs.

### S1.4.2.27 STEAM PRESSURE GAGE

The steam pressure gage, gage cock boiler connections, and piping shall be inspected for:

a) Kinks or sharp, restricted, or flattened bends in the piping;

b) Correct installation of the shutoff valve and siphon;

c) Proper size, type, and material of piping and fittings;

d) Proper installation;

e) Proper lighting for viewing;

f) Proper bracing to prevent vibration; and

g) Calibration.

### S1.4.2.28 BOILER FITTINGS AND PIPING

The boiler fittings and associated piping shall be inspected for:

a) Cracks;

b) Corrosion;

c) Pitting;

d) Leakage;

e) Looseness;

f) Loose, bent, or damaged nuts, bolts, and studs;

g) Adequate structural bracing, support, attachment, and provision for expansion; and

h) Proper size, type, and material.

### S1.4.2.29 BOILER ATTACHMENT BRACKETS (23)

The boiler attachment brackets and associated components and fasteners used to secure the boiler to the frame shall be inspected for:

a) Correct installation;

b) Damaged or missing components;

c) Looseness;

d) Leakage;

e) Loose, bent, broken, or damaged rivets, nuts, bolts and studs;

f) Defective rivets; and

g) Provision for expansion and free movement of sliding supports.

### S1.4.2.30 FIRE DOOR

The fire door, the locking mechanism, and the operating mechanism shall be inspected for:

a) Safe and suitable operation;

b) Cracked, damaged, or burned parts; and

c) Loose, damaged, or bent rivets, nuts, bolts, and studs.

**Note**: The locking mechanism should be inspected for correct operation to confirm it will not allow the door to open in the event the firebox becomes pressurized.

### S1.4.2.31 GRATES AND GRATE OPERATING MECHANISM

The grates shall be inspected for:

a) Cracked, damaged, burned, or missing segments; and

b) The grate operating mechanism of rocking grates shall be checked for:

1) Uniform operation of all segments;

2) Corrosion;

3) Worn or cracked linkage;

4) Correct fit of the shaker bar on the linkage;

5) Missing pins or pin retainers; and

6) Loose, bent, or damaged nuts, bolts, and studs.

### S1.4.2.32 SMOKEBOX

The smokebox shall be inspected for:

a) Erosion;

b) Corrosion;

c) Leakage;

d) Holes;

e) Looseness; and

f) Loose, bent, or damaged nuts, bolts, and studs.

### S1.4.2.33 SMOKEBOX STEAM PIPES

The smokebox steam pipes shall be inspected for:

a) Erosion;

b) Corrosion;

c) Pitting;

d) Leakage;

e) Looseness; and

f) Loose, bent, or damaged nuts, bolts, and studs.

**Note**: Pitting from the casting process may be evident on cast thick wall steam pipes, but may not constitute a defect.

### S1.4.2.34 ASH PAN AND FIRE PAN

The ash pan or fire pan shall be inspected for:

a) Corrosion;

b) Holes;

c) Looseness;

d) Loose or damaged rivets, nuts, bolts, and studs;

e) Secure attachment to the frame or firebox;

f) Proper operation of the slides, clean out doors, dumping mechanism, and dampers; and

g) Proper sealing of the slides, clean out doors, and dampers.

## S1.4.3 METHOD OF CHECKING HEIGHT OF WATER GAGE GLASS

The height of the bottom gage cock and water glass or water column above the highest section of the crown sheet should be checked to confirm it meets the height requirements for the service intended and those of the regulatory agency. It is especially important this be checked if the water glass location or piping was changed, or if a new crown sheet or complete firebox is installed.

### S1.4.3.1 WATER HEIGHT MEASUREMENT METHOD

The following method is intended for use where it is possible to enter the boiler shell interior to measure the water level at the highest section of the crown sheet. (See NBIC Part 2, Figure S1.4.3.1)

a) Level the locomotive in the longitudinal and transverse planes so that it is in the position used for normal operation.

b) Place a measurement gage or ruler on the longitudinal centerline of the highest section of the crown sheet. The measurement gage or ruler must be placed vertical and tangent to the highest section of the crown sheet.

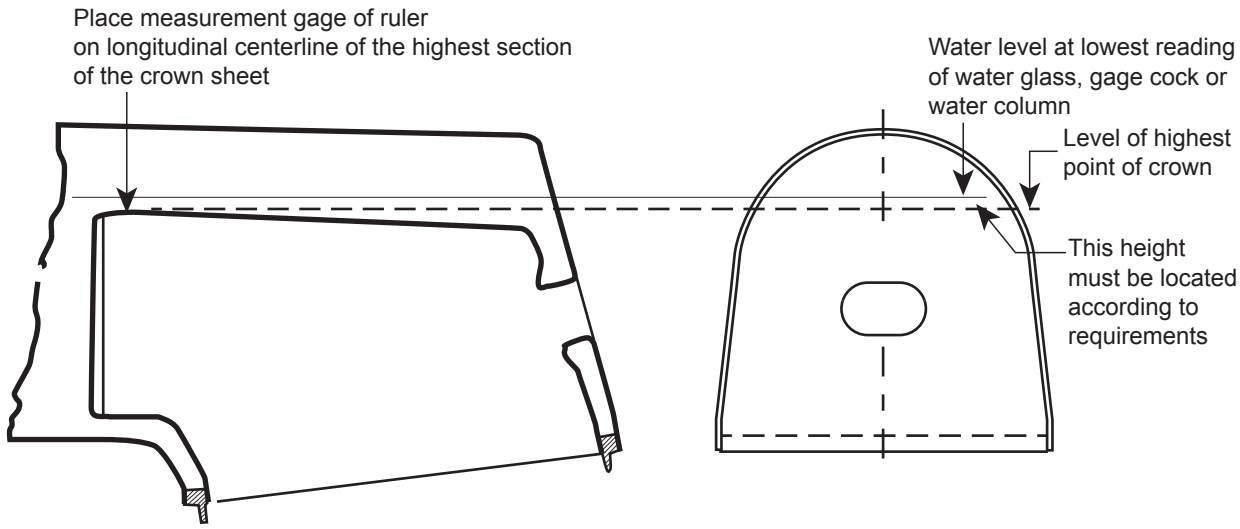
c) Fill the boiler with water until water exits the lowest gage cock and/or is just visible at the bottom of the water glass or water column.

d) Measure the height of water over the crown sheet using the ruler or gage.

e) Record the height reading and compare it to the required height. Repeat Steps 3 to 5 and compare the readings of the first and second tests.

### FIGURE S1.4.3.1

**Water Height Measurement Method**




### S1.4.3.2 FLEXIBLE SPIRIT LEVEL METHOD

The following method is intended for use where it is difficult to enter the boiler shell interior to measure the water level. The method is based on use of a flexible spirit level made from flexible rubber hose and clear plastic tubing. The measurements are taken from the fireside of the crown sheet.

a) The flexible spirit hose is made from a suitable length of flexible rubber tubing, such as garden hose, with a minimum internal diameter of 5/8 in. (16 mm). The tubing must be long enough to extend from the front of the firebox to the back head without kinks or sharp bends. At each end of the hose fasten an 8 in. (200 mm) long piece of clear plastic tube using hose clamps. The upper end of each piece of tubing must have four 1/8 in. (3.2 mm) deep x 1/8 in. (3.2 mm) wide air openings (slots) cut into it in order to allow the air to be vented out when held against the crown sheet. (See NBIC Part 2, Figure S1.4.3.2)

b) Fill the hose with water and bring the clear plastic tubes side by side vertically to observe the water level. If the level is not the same, there is an air bubble or other obstruction in the hose. Repair it and retest the water level before proceeding.

c) Level the locomotive in the longitudinal and transverse planes so that it is in the position used for normal operation.

d) Locate the approximate longitudinal centerline of the fireside of the crown sheet and the highest section of the crown sheet using a ruler and chalk.

e) Place one end of the hose against the approximate center of crown sheet at the highest point with the plastic tube held vertically.

f) Place the other end of the hose and tube against the back head exterior vertical centerline and hold vertically in a position slightly lower than the crown sheet.

g) Slowly raise the end of the hose held against the back head until water is discharged from the tube held against the crown sheet. Hold both tubes in position until the water stops flowing. At this point the level of water in the tube held at the back head will show the height of the bottom side of the crown sheet. Mark this water level position on the back head.

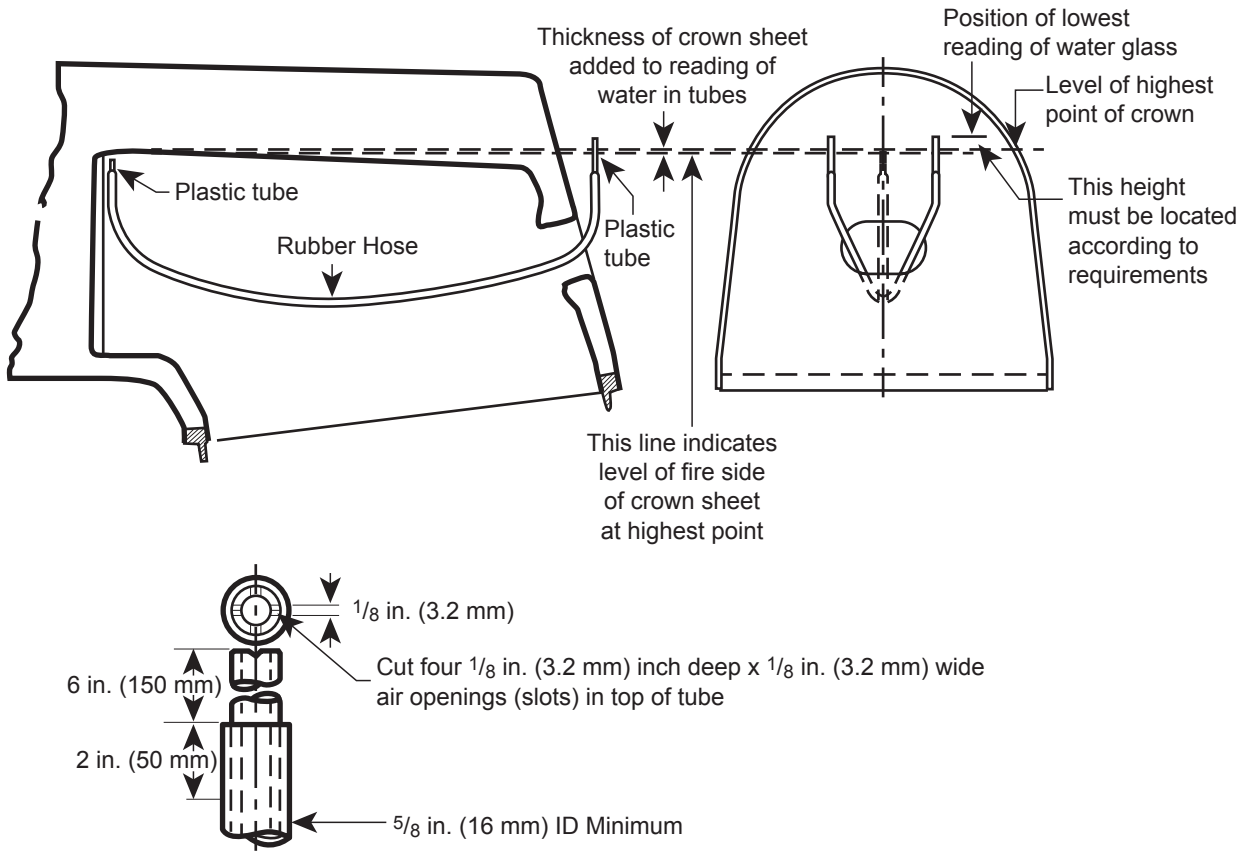
h) Repeat the measuring procedure several times, each time moving the tube held against the crown sheet laterally to another position to confirm the highest location of the crown sheet has been located. Mark the level position of each measurement on the back head.

i) Above the line on the back head obtained by the spirit level measurement make a second line of the same curvature but higher by a height equal to the crown sheet thickness plus the 1/8” deep slots cut into the tubing. This second line represents the top (waterside) of the crown sheet at the highest point.

j) Use the second line as the reference point for measurements to determine whether the water glasses and/or water column are located at the required height above the crown sheet. To simplify taking the measurements the second line can be extended across the back head by use of a long ruler and precision spirit level.

**FIGURE S1.4.3.2**

**Flexible Spirit Level Method**




## S1.5 GUIDELINES FOR STEAM LOCOMOTIVE STORAGE

The steam locomotive guidelines published herein list the general recommendations for storage of locomotive boilers and locomotives. The exact procedures used by the owner/operator must be reviewed by the railroad mechanical officers/engineers and be based on the conditions and facilities at the railroad shop or storage facility.

### S1.5.1 STORAGE METHODS

a) The methods for preparing a steam locomotive for storage depend upon several factors, including:

1) The anticipated length of time the locomotive will be stored;

2) Whether storage will be indoors or outdoors;

3) Anticipated weather conditions during the storage period;

4) The availability of climate-controlled storage;

5) Type of fuel used; and

6) Equipment available at the storage site.

b) Indoor storage can be categorized into two types: indoor with climate control, and indoor without climate control.

c) Outdoor storage can also be categorized into two types: outdoors during a warm time of year or in a geographic location where it can reasonably be expected to be above freezing during storage, and outdoors during a time period or in a geographic location where it can be expected that freezing temperatures will occur during storage.

d) Locomotive boilers may be stored using the “wet method” or the “dry method.”

e) Before any method of storage, the boiler must be thoroughly washed out, with mud and scale removed from the mudring, crownsheet, bottom of the barrel, and the top of the firing door.

### S1.5.2 WET STORAGE METHOD

a) When utilizing the “wet storage method” the boiler is completely filled with treated water to exclude air.

**Note**: This method cannot be used if the locomotive is exposed to freezing weather during storage.

b) Chemicals may be added to the storage water to further inhibit corrosion. However, depending on the chemical used, the treated water may have to be disposed of as a hazardous waste to prevent chemical contamination of the surrounding property.

c) The procedure applies only to the sections of the boiler that contain water. The firebox interior, cylinders, piping, and auxiliary equipment of the locomotive still require draining, preservation, and dry storage.



### S1.5.3 DRY STORAGE METHOD

a) When utilizing the “dry storage method” the boiler is completely emptied of water, dried out, and allowed to stand empty. Several variations of the “dry method” may be used. These include but are not limited to:

1) Airtight storage with a moisture absorbent placed in trays in the boiler;

2) Airtight storage with the boiler filled with inert gas to exclude oxygen; and

3) Open-air storage with the mudring washout plugs removed to enable air circulation for evaporation of formed moisture.

b) Each variation has positive and negative points that must be taken into account before use. If the boiler is filled with inert gas such as nitrogen, care must be taken because this method can result in asphyxiation of personnel if the gas escapes the boiler through a leaking valve or washout plug and enters a pit, sump, or enclosed room. In addition, the boiler must be completely vented to remove gas, then tested and declared gas-free before personnel may enter.

c) Although the use of dry storage with several washout plugs removed for air circulation is the most common method, there are some potential drawbacks. The boiler interior may be subject to moisture forming from condensation created from humidity changes in the ambient air. Small animals may take up residence inside if screens are not used to cover handholes and washouts.

d) Before storage, the boiler must be thoroughly washed out with mud and scale removed from the mudring, crownsheet, bottom of the barrel, and top of the firing door. Any mud or loose scale left in the boiler will retain moisture, leading to corrosion. After washing, water must be removed and the boiler dried before storage. A portable gas or electric heater placed in the firebox to aid evaporation and drying, along with a vacuum used to siphon water out via the lower washout plugs, is recommended.

**Note**: Use of the common railroad drying-out procedure of building a small wood fire in the firebox is not recommended because of the danger of overheating the firebox sheets.

e) The typical railroad dry storage method required blow down of the boiler until empty while steam pressure registered on the gage and removal of the washout plugs while the shell plates were hot and there was no steam pressure. This allowed the heat remaining in the boiler plates to evaporate remaining water in the boiler. However, this method may result in staybolt damage from temperature change and requires extreme care, if used.

f) Oil should not be applied to the interior surfaces of the boiler because it is difficult to remove. Further, the oil must be removed before steaming or it will form scale and contribute to foaming.

## S1.5.4 RECOMMENDED GENERAL PRESERVATION PROCEDURES

a) When the locomotive is under steam, inspect piping, fittings, and appliances for steam and water leaks that may introduce moisture into the lagging. Repair leaks as necessary and remove wet lagging. Wet lagging can accelerate corrosion of the boiler external surfaces, especially staybolt sleeves and caps.

b) Thoroughly wash the boiler and firebox and remove mud and scale from the mudring, crownsheet, bottom of the barrel, and top of the firing door. Any mud or loose scale left in the boiler will retain moisture, leading to corrosion. Wash out thermic siphons, arch tubes, and circulators.

c) To protect the boiler interior during storage, dry the boiler by using compressed air to blow out as much water as possible. A portable heater placed in the firebox to warm the boiler to 200°F (93°C), along with a vacuum used to siphon water out via the lower washout plugs, can aid evaporation and drying of any moisture that collects in low or impossible-to-drain locations without harming the sheets.

**Caution**: To prevent a buildup of steam pressure during the drying process, the steam dome cover or top washout plugs should be removed to enable the moisture to escape. In addition, the driving wheels should be blocked and the throttle and cylinder cocks should be opened to permit any steam that forms in the superheater units to escape.

d) Superheater units, by nature of design, can be difficult to drain and dry out. Typical methods include:

1) Pressurize the boiler with compressed air with the locomotive stationary and blocked in place. Using the throttle to regulate the airflow, allow the air to blow through the entire bank of superheater units and dry pipe and discharge into the cylinders. The cylinder cocks must be open.

2) Pressurize the boiler with compressed air and then operate the locomotive under air pressure over a short distance of track. The cylinder cocks should be opened during the initial operation to prevent damaging the cylinders by hydraulic lock.

3) If the air pressure draining procedure is not practical or cannot be accomplished correctly, the superheater units can be protected against trapped moisture by filling the entire superheater bundle with a standard antifreeze/water mixture or with diesel fuel.

**Notes**: The air pressure dry-out methods “1” or “2” may have to be performed several times to discharge all of the moisture. Refer to NBIC Part 2, S1.5.5, *Use of Compressed Air to Drain Locomotive Components*, for additional information on compressed-air drying.

If the locomotive is operated under air pressure, the air brake system should be made operational to provide safe stopping or other steps taken to control and stop the locomotive.

e) After drying, it will be necessary to either vent the boiler or place containers of desiccant inside the boiler through the dome cap to absorb any condensation that may occur during storage. Venting the boiler to allow air circulation is accomplished by leaving two or more of the lower washout plugs out and opening the vent valve on the top of the boiler. A vent line consisting of two 90° elbows and pipe nipples

should be installed in the vent valve to locate the opening to the downward direction in order to keep rain or snow from entering the open valve.

f) If the locomotive will be stored outdoors, the following should be completed:

1) Inspect the boiler jacket and confirm it is tight with no gaps leading into the lagging or shell. Pay close attention to areas at shell openings such as for studs, safety valves, etc. Repair all gaps or damaged jacket sections as necessary. Consideration should be given to covering the entire locomotive and tender with a tarp. Otherwise, all jacket openings should be covered to prevent the entrance of rain or snow. Where necessary, apply a waterproof covering over the exposed or open sections;

2) The smokestack should be sealed by applying a wood and sheet rubber cover held in place by clamps or a through bolt;

3) The safety valves should either be covered or removed, with plugs or caps installed in the holes if the valves are removed;

4) The dynamo, air pump, and feedwater heater exhausts should also be covered;

5) Empty and clean the smokebox, front tubesheet, superheater units, steam pipes, and front end plates of all coal, ash, or burnt oil. This work is especially critical at the bottom section of the smokebox and front tubesheet rivet flange. The smokebox door should be sealed by applying a gasket or sealant and any other air openings in the smokebox sealed. The exhaust nozzle should be sealed by applying a wood and sheet rubber cover held in place by clamps;

6) The potential for corrosion of the smokebox interior can be further minimized by applying a coating of outdoor paint or primer. All inspection of the smokebox and front tubesheet must be accomplished before painting since it will cover up many types of defects. The coating will burn off quickly when the locomotive is returned to service;

7) Thoroughly clean the firebox sheets, flues, and superheater return bends of all ash and clinker;

8) On coal burners, empty and clean the grates and ash pan of all coal and ash completely. This work is especially critical at the sections between the grate bearers, the mudring rivets, and firebox sheets; and from the grate segment air openings. On oil burners, care should be taken to remove ash from between the flash wall refractory and the firebox sheets;

9) If the locomotive will be out of service for longer than 12 months, removal of the brick arch or flash wall refractory that extends above the mudring should be considered to prevent condensation and corrosion from occurring between the brick and the steel. Temporary removal of the brick arch or flash wall to permit application of a preservative to firebox sides, arch tubes, or siphons should be considered for shorter storage periods;

10) All appliances and piping that might contain water or condensation should be drained and blown dry using dry compressed air. This includes the air and equalizing reservoirs, dirt collectors, injectors, cylinders, stoker engine cylinders, dynamos, the steam and water sides of feedwater heaters and pumps, the steam side of air pumps, the steam side of lubricators, atomizers, oil tank heaters, gage siphons, tank hoses, and cab heater piping. A small quantity of valve oil should be sprayed into the valve chambers, cylinders and the steam side of all appliances to protect against corrosion. Refer to S1.5.5, *Use of Compressed Air To Drain Locomotive Components*, for details;

11) The cylinder castings, exhaust cavities, and steam lines must be drained of all moisture and blown dry. Typical methods include:

a. Pressurizing the boiler with compressed air, with the locomotive stationary and blocked in place. Using the throttle to regulate the airflow, allow the air to blow through the dry pipe and discharge into the cylinders. The cylinder cocks must be open;

b. Pressurizing the boiler with compressed air, then operate the locomotive under air pressure over a short distance of track. The cylinder cocks should be opened during the initial operation to prevent damaging the cylinders by hydraulic lock;

**Note:** Methods "1" or "2" may have to be performed several times to discharge all of the moisture from the cylinders, and steam pipes. If the locomotive is operated under air pressure, the air brake system should be made operational to provide safe stopping or other steps taken to control and stop the locomotive.

Refer to NBIC Part 2, S1.5.5, *Use of Compressed Air to Drain Locomotive Components*, for additional information;

g) Drain and wash tender water spaces. The tank should be inspected afterward and any remaining water removed by siphon or vacuum. When dry, spray the water space with outdoor paint or a commercial rust preventative. Drain and dry tender tank hoses and clean screens;

h) On coal or wood burners, spray any exposed surfaces of the tender fuel space with outdoor paint or a commercial rust preventative. If the locomotive is to be stored outdoors for a long term, remove all coal and spray the surfaces as above or cover the coal space with a tarp or a roof;

i) On oil burners, drain and blow out all fuel lines, tank heater and blowback lines, and the burner itself. Drain sludge and water from the bottom of the fuel tank. Ensure that tank hatches are secure and the tank is vented to prevent condensation. Draining the oil tank is recommended if the fuel oil is known to lose its volatile content during storage;

j) After cleaning thoroughly, coat all side and main rods, cross heads, valve gear, guides, piston rods, brake pistons, feedwater pump pistons, and air pump pistons with water-resistant grease or a rust preventative. Grease should be applied to the junction of each axle and driving box and journal box to prevent water entering. Grease should be applied to junction of rod and pin in valve gear and rods to prevent water entering;

k) If the locomotive is moved after grease is applied, it will be necessary to reapply the coating to piston rods and guides;

**Note:** Heavy oil or unrefined oil such as any of the Bunker types (e.g., Bunker 6, etc.) should not be used for preservation of any components because the sulfur contained in it can accelerate corrosion. Standard motor oil or journal oil will not stick to and preserve wetted surfaces. All surfaces, to be so coated, must be dry. If moisture is a problem, steam cylinder oil should be applied.

l) Plain journal bearings should be inspected for water and repacked. Roller bearing boxes should have all moisture drained and the boxes filled with lubricant. Grease plugs should be screwed down so that the threads are not exposed;

m) If the locomotive is to be stored outdoors with questionable or no security, remove and store all cab gages, water glasses, lubricators, brass handles, seatboxes, and any other items that thieves or vandals might attack. Remove the whistle, bell, headlight and marker, and/or classification lights. Remove tools, radios, and spare parts. Secure wood or metal covers over all windows and doors, and board up the back of the cab. Secure all manholes on the top of the tender; and

n) Inspect stored locomotives regularly for signs of rust, corrosion, damage, deterioration, or vandalism and immediately take any corrective measures necessary.

## S1.5.5 USE OF COMPRESSED AIR TO DRAIN LOCOMOTIVE COMPONENTS

a) The process of using air pressure to drain and empty auxiliary components such as the cylinders, superheater units, and piping completely of water offers several advantages over other methods.

b) The air compressor must be equipped with a suitable filter to enable it to supply oil-free air because the introduction of air that contains oil into the water/steam parts of the boiler and superheater will promote the formation of scale and water foaming when the locomotive is returned to service.

c) The air compressor must be large enough to provide the volume and pressure of air required.

d) If the boiler is pressurized with compressed air, the air pressure must be raised slowly to prevent distorting or overstressing the firebox sheets or staybolts because the normal expansion of the boiler that occurs under steam pressure is not present when air pressure is used.

e) Auxiliary components such as the stokers, air compressors, turbo generators, and power reverse are drained by pressurizing the boiler to between one-half and three-quarters of the rated boiler pressure with compressed air from the stationary air compressor, then operating each component individually until the exhaust from it contains no moisture.

f) When necessary, specific pipe lines can be drained by breaking the line at each end, attaching the air line to it directly then blowing the line out.

### S1.5.6 RETURN TO SERVICE

a) When returning a locomotive to service, the boiler, firebox, and tender tank shall be ventilated to remove a potentially hazardous atmosphere from the boiler interior before personnel enter it. In addition, the atmosphere in the boiler shall be verified to be safe for human occupancy before personnel enter it. For the boiler this can be accomplished by removing the washout plugs and placing a fan or air blower on top of the steam dome opening to force air into the boiler. For the firebox this can be accomplished by opening the smokebox door and firebox door and placing a fan or air blower at either location to force air through. Failure to do this could result in asphyxiation of the personnel entering the boiler or firebox.

b) If possible, the locomotive should be moved into a heated engine house and the boiler allowed to warm up in the air for several days until it is the same temperature as the air.

c) The initial fire-up should be done slowly to allow even heating of the boiler.

d) Before movement, the cylinders should be warmed up by allowing a small quantity of steam to blow through them and out the cylinder cocks and exhaust passages. This is necessary to reduce the stress in the casting from thermal expansion of the metal.

e) Steam should be discharged through the cylinder cocks for several minutes to aid removal of any solvent, debris, or rust that may have formed in the superheater units, steam pipes, and dry pipe.

f) All appliances should be tested under steam pressure before the locomotive is moved.

## (23) S1.6 SAFETY VALVES

a) The minimum safety valve capacity in pounds per hour (kilograms per hour) shall be calculated by multiplying the boiler heating surface area by the factor from the appropriate chart in NBIC Part 2, Table S1.6 (1 pound steam/hr/ft$^2$ = 4.88 kg steam/hr/m$^2$).

b) Pressure relief valves shall be selected with a total rated capacity equal to or greater than the required capacity.

c) Where non-capacity valves are used on an existing boiler part, an accumulation test may be used to verify that the installed capacity is adequate.

1) Accumulation testing may be hazardous because the boiler is being run at maximum fire, and pressure relief valve capacity has not been verified. It should be done only under carefully controlled conditions by trained and knowledgeable personnel.

2) Boiler pressure shall be continuously monitored by both an operating gage and a calibrated test gage.

3) The pressure relief valves shall first have been set in accordance with the operational verification test requirements in accordance with NBIC Part 2, S1.6 d).

4) The accumulation test shall be performed by shutting off all other steam-discharge outlets from the boiler and forcing the fire to the maximum.

5) The locomotive shall be secured from movement, cylinder and valve vents blocked open, and throttle unsecured so that it may be opened if necessary to relieve excess pressure.

6) Should the pressure approach the limits specified in NBIC Part 2, S2.10, the throttle shall be opened enough to relieve the pressure and the fire reduced to prevent further accumulation of pressure. Corrective action to supply additional capacity shall then be taken.

7) The safety relief valves shall be sufficient to prevent an excess pressure beyond that specified in NBIC Part 2, S2.10.

8) Where the pressure relief valve capacity has been verified by an accumulation test, the valves shall be used only on the boiler on which they were tested. The valve identification numbers and set pressures shall be recorded on the data report for that specific boiler by the boiler manufacturer.

d) Operational verification of steam locomotive pressure relief valves may be accomplished by either 1) or 2):

1) Testing the valves on a steam test stand.

2) Setting the valves on the locomotive boiler per the following:

a. A calibrated test gage shall be used in addition to the boiler operating gage.

b. The boiler pressure shall be brought up at a controlled rate and the valves alternately set until the lowest set valve is set to open at MAWP (for MAWP less than or equal to 70 psi, applicable tolerance is +/- 2 psi of the set pressure; for MAWP greater than 70 psi and less than 333 psi, applicable tolerance is +/- 3% of the set pressure) with a blowdown not less than 2% of MAWP.

c. The low set valve may then be gagged, and the higher set valve(s) shall then be set to open within the set tolerances (for MAWP less than or equal to 70 psi, set tolerance is +/- 2 psi of the set pressure; for MAWP greater than 70 psi and less than 333 psi, set tolerance is +/- 3% of the set pressure). The blowdowns for the higher set valves shall be set such that the blowdown is greater than 2% of MAWP, and the valves will close below the lowest set valve set pressure. No valve shall be set to a lift pressure greater than 6 psi above MAWP.



**TABLE S1.6**

MINIMUM POUNDS OF STEAM/HR./SQ. FT. OF STEAM HEATING SURFACE

| **Firebox Heating Surface** | |
|---|---|
| Type | Factor |
| Hand-Fired | 8 (39) |
| Stoker-Fired | 10 (49) |
| Oil-Fired | 14 (68) |
| **Flue Heating Surface** | |
| Type | Factor |

| | |
|---|---|
| Hand-Fired | 5 (24) |
| Stoker-Fired | 7 (34) |
| Oil-Fired | 8 (39) |
| **Superheater Heating Surface** | |
| Type | Factor |
| Hand-Fired | 5 (24) |
| Stoker-Fired | 7 (34) |
| Oil-Fired | 8 (39) |

## S1.7 TABLES AND FIGURES

a) FIGURE S1.1-a Locomotive Boiler General Arrangement

b) FIGURE S1.1-b Arrangement of Firebox Sheets

c) FIGURE S1.4.2.1 Loading in Tension

d) FIGURE S1.4.3-a Water Height Measurement Method

e) FIGURE S1.4.3-b Flexible Spirit Level Method

f) TABLE S1.6 Minimum Pounds of Steam/hr./sq. ft. of Steam Heating Surface

# SUPPLEMENT 2
# HISTORICAL BOILERS

## S2.1 SCOPE

This supplement provides requirements and guidelines for inspection of historical steam boilers of riveted and/or welded construction not falling under the scope of NBIC Part 2, Supplement 1. These historical steam boilers would include: steam tractors, traction engines, hobby steam boilers, portable steam boilers, certain steam locomotive boilers, and other such boilers that are being preserved, restored, and maintained for demonstration, viewing, or educational purposes. (See Note below)

**Note**: This supplement is not to be used for steam locomotive boilers operating on tracks gaged 24 in. (610 mm) or greater or for steam locomotive boilers falling under the requirements of the Federal Railroad Administration (FRA). FRA rules for steam locomotive boilers are published in 49 CFR 230. Specific rules and special requirements for inspection, repairs, alterations, and storage of steam locomotive boilers are identified in NBIC Part 2, Supplement 1.

The rules specified in this supplement shall be used in conjunction with the applicable rules in this code. References specified or contained in this supplement may provide additional information to assist the user when applying the requirements of this supplement.

## S2.2 INTRODUCTION

a) The following inspection rules are minimum requirements for safe and satisfactory operation of historical boilers. Users of this supplement are cautioned that where complete details are not provided, the user is advised to seek technical guidance to provide sound engineering evaluations and practices.

b) Where adopted by a Jurisdiction, these requirements are mandatory. Where a Jurisdiction establishes different requirements for historical boilers or where a conflict exists, the rules of the Jurisdiction prevail.



## S2.3 RESPONSIBILITIES

The owner or user and/or operator are responsible for ensuring that the boiler meets the requirements of the Jurisdiction where the boiler is operated, including inspections, repairs, licensing, operating certificates, permits, and operator training.

**Note**: It should be recognized that safety of these boilers is dependent upon the knowledge and training of the operator in proper use, repair, maintenance, and safe operation of each specific boiler proposed to be operated. (See NBIC Part 2, S2.4.3.)

## S2.4 GENERAL INSPECTION REQUIREMENTS

The owner or user and Inspector should refer to NBIC Part 2, 1.4 *Personnel Safety*; NBIC Part 2, Section 3, *Corrosion and Failure Mechanisms*; and NBIC Part 2, Section 4, *Examinations, Test Methods, and Evaluations*, for additional information when performing inspections.

### S2.4.1 PRE-INSPECTION REQUIREMENTS

a) The owner or user has the responsibility to prepare the boiler for any required inspections needed to ensure safety as deemed necessary by the Inspector. Prior to performing any type of inspection, the owner and Inspector shall ensure safety precautions are taken to prevent personal injury.

b) Prior to conducting an inspection, the following shall be reviewed by the Inspector to the extent possible to aid in determining safe operation:

1) Operating and maintenance history and/or other information contained in the operator log book;

2) Inspection history;

3) Construction code/design;

4) Materials — types and thickness;

5) Certifications;

6) Operator knowledge and training as required by the Jurisdiction;

7) Repairs/Alterations performed;

8) Cleanliness of the boiler; and

9) Potential hazards to personnel.

**Note**: If a boiler has not been properly prepared for an inspection, the Inspector may decline to make the inspection.

### S2.4.2 POST-INSPECTION ACTIVITIES

a) Upon completion of inspection activities, the results of examinations and tests shall be documented by an Inspector, in a manner acceptable to the Jurisdiction.

b) Any defects or deficiencies in the condition, operation, and/or maintenance practice of the boiler and appurtenances shall be discussed and documented with the owner or user. Recommendations for correction and/or repair requirements (if required) shall be discussed and documented.



### S2.4.3 BOILER OPERATORS

a) The following guidelines should be understood by each historical boiler operator and demonstrated safely during jurisdictional inspection and testing for each boiler proposed to be operated:

1) Jurisdictional rules for construction, maintenance, repairs, operation, and certification;

2) Boiler functions and purpose of controls, appurtenances, and safety devices;

3) Proper operation, maintenance, types, use and testing of valves, including safety valves;

4) Fusible plugs including installation, maintenance, design, and purpose;

5) Performance of normal and emergency system operating procedures associated with blowdown of the boiler, feed, or water delivery system, steam system, water level control, and combustion of fuel;

6) Importance of maintenance, cleaning, and inspection of components and safety devices such as pressure gages, sight glass, governor, water column, firebox, etc.; and

7) Preparation and actions to be taken on emergency situations for fire, low water, foaming, overpressure, and excessive leakage.

b) Organizations/associations involved with historical boilers should verify operator knowledge by examination or practical testing or a combination of both. Some Jurisdictions may require specific operator qualifications or certifications. (See additional safety procedures in NBIC Part 2, S2.14)

### S2.4.4 EXAMINATIONS AND TESTS

The examinations and tests shall be as required by the Jurisdiction and verified by an Inspector. The Inspector shall accept and verify procedures and personnel qualifications when examinations and tests are performed.

#### S2.4.4.1 NONDESTRUCTIVE EXAMINATION METHODS

There are a variety of nondestructive examination methods that may be employed to assess the condition of historical boilers. Skill, experience, and integrity of personnel performing examinations are essential to obtaining meaningful results. Generally, some form of surface preparation will be required prior to the use of examination methods.

The nondestructive examination (NDE) requirements, including technique, extent of coverage, procedures, personnel qualification, and acceptance criteria, shall be in accordance with the original code of construction for the pressure-retaining item. Weld repairs and alterations shall be subjected to the same nondestructive examination requirements as the original welds. Where this is not possible or practicable, alternative NDE methods acceptable to the Inspector and the Jurisdiction where the pressure-retaining item is installed, where required, may be used.

#### S2.4.4.2 TESTING METHODS

Testing should be performed by experienced personnel using procedures acceptable to the Inspector. Typical test methods available to the Inspector during the inspection of historical boilers are listed below:

a) Hydrostatic testing/pressure testing;

b) Leak testing; and

c) Ultrasonic thickness testing.



### S2.5 SPECIFIC EXAMINATION AND TEST METHODS

### S2.5.1 SPECIFIC EXAMINATION METHODS

a) This part describes nondestructive examination and test methods that are typically available to the Inspector during inspection of historical boilers.

    1) Visual (VT)

    2) Ultrasonic (UT)

    3) Liquid Penetrant (PT)

    4) Magnetic Particle (MT)

    5) Radiographic (RT)

b) Additional examination or test methods may be performed if a deficiency is detected during initial or reoccurring inspection. Use of additional examination and testing methods shall be acceptable to the Inspector and the Jurisdiction, if required.

### S2.5.2 VISUAL EXAMINATION

Visual examination is the most widely used method to ascertain surface condition and recognize surface features typical of various damage mechanisms associated with historical boilers. Damage mechanisms such as corrosion or cracking may be due to operation, age of material, or improper maintenance.

#### S2.5.2.1 PREPARATION FOR VISUAL INSPECTION

The owner or user shall ensure the following areas, as a minimum, are prepared for visual examination, and are acceptable to the Inspector at the time of the examination:

a) Fireside open and grates removed;

b) Fireside tubesheets and tubes thoroughly cleaned of soot and ash;

c) Waterside drained and handholes, plugs, and inspection openings removed;

d) Sediment, scale, and mud flushed; and

e) Insulation or jackets removed, as appropriate.

**Note:** Where there is limited or no access for visual inspection, remote camera or fiber optic devices may be used.

#### S2.5.2.2 VISUAL EXAMINATION REQUIREMENTS

To the extent possible, the following areas and items shall be visually examined by the Inspector and results documented on the Boiler Inspection Guideline (NBIC Part 2, S2.11) provided in this supplement, or as required by the Jurisdiction. The Boiler Inspection Guideline should be used as a reference when performing visual inspections.

a) The fusible plugs shall be removed, inspected, and confirmed to meet requirements of NBIC Part 2, S2.8.4.

b) Threaded openings or connections in the boiler shall be inspected for wear or deterioration when there is evidence of leakage. ANSI standard plug and ring gages may be used to verify thread integrity.

c) Inspect the condition of boiler sheets, shell, tubesheets, fittings, staybolts, and other materials for thinning, pitting, cracks, or corrosion.

d) Verify that requirements of NBIC Part 2, S2.8 and S2.9, are in compliance, as applicable.

### S2.5.3 ULTRASONIC EXAMINATION

Ultrasonic examination is used as a volumetric examination of welds and base materials for detection of flaws. Factors such as material composition, surface condition, choice of equipment, and ability of the operator affect the results of ultrasonic examination.

### S2.5.4 LIQUID PENETRANT EXAMINATION

Liquid penetrant examination is used to detect discontinuities open to the surface, such as cracks, seams, laps, cold shuts, laminations, and porosity.

### S2.5.5 MAGNETIC PARTICLE EXAMINATION

Magnetic particle examination can be used to reveal surface discontinuities and, to a limited degree, discontinuities slightly below the surface. The sensitivity of this method decreases rapidly with depth below the surface and therefore is used primarily to examine surface discontinuities.

## S2.6 SPECIFIC TESTING METHODS

During inspection of historical boilers there may be instances where conditions have adversely affected the tightness of the boiler or the inspection discloses hard to evaluate forms of deterioration that may affect the safety of the vessel. In these specific instances, a pressure test using water or other suitable liquid test medium may be required at the discretion of the Inspector to assess leak tightness of the pressure-retaining item. For safety, pneumatic pressure tests shall not be performed.

### S2.6.1 HYDROSTATIC PRESSURE TESTING

When performing hydrostatic pressure testing for verification of leak tightness or when required by the Jurisdiction, the following requirements shall be met:

a) Hydrostatic pressure test shall be between the calculated maximum allowable working pressure and 1.25 times the calculated maximum allowable working pressure, and held for a minimum of 10 minutes or as required to perform a complete visual examination;

b) The metal and water temperature of the boiler shall be between 60°F to 120°F (16°C to 49°C) anytime a hydrostatic test is being performed;

c) A calibrated gage, acceptable to the Inspector, shall be used when hydrostatically pressure testing a boiler; and

d) During hydrostatic testing, safety valve(s) shall be removed.

### S2.6.2 ULTRASONIC THICKNESS TESTING

Ultrasonic thickness (UT) testing shall be performed to determine boiler plate thickness. UT testing shall be performed by personnel acceptable to the Jurisdiction and the Inspector. The following requirements shall be met, to the extent possible. Performance and results shall be acceptable to the Inspector and, if required, the Jurisdiction.

a) Equipment, operator, and calibration standards used shall be documented.

b) On initial UT of stayed sections, the plate thickness readings should be taken on a grid not exceeding the maximum staybolt pitch. Additional readings may be taken close to each staybolt to determine if localized thinning has occurred. Particular attention should be given to the joint between the staybolt and the plate.

c) On initial UT of unstayed sections, the plate thickness readings should be taken on a grid not exceeding 12 inch (350mm) centers. Additional readings should be taken if conditions warrant.

d) UT test results shall be documented so location of test results can be checked at subsequent UT tests to determine if material loss has occurred.

e) Recurring UT testing shall be performed by randomly checking 10% of original UT checks. Areas of thinning identified during previous inspections shall be given particular attention. If material loss is determined, additional testing may be requested by the Inspector.

f) Particular attention should be placed upon areas that typically exhibit thinning. These areas include the ogee curve, the mudlegs, the fusible plug, around feedwater inlets, and around the firebox door ring.

g) The owner/operator shall maintain the initial and recurring grid mapped UT readings in conjunction with the calculations in permanent boiler records. Documentation shall be available to the Inspector for review and acceptance.

h) Unstayed plain circular cylindrical components under external pressure shall require readings performed on a grid not exceeding 9 inch (229 mm) centers. Additional readings should be taken if conditions warrant.

### S.2.6.3 EVALUATION OF CORROSION

#### S2.6.3.1 LINE AND CREVICE CORROSION

Line and crevice corrosion may be disregarded for MAWP calculations when:

a) The thickness of the remaining material is at least 75% of the required thickness per the MAWP calculations.

b) The total length does not exceed 2 inches (50 mm).

#### S2.6.3.2 RANDOMLY SCATTERED PITS

Randomly scattered corrosion pits may be disregarded for MAWP calculations when:

a) The depths of the pits are such that the remaining material shall not be less than 50% of the required thickness per the MAWP calculations.

b) The total area of pits, below the required thickness per the MAWP calculations, does not exceed 7 sq. in. (4,500 sq. mm) within any 50 sq. in. (32,000 sq. mm) area.

c) Total length of pits in an 8 inch (200 mm) straight line cannot exceed 2 inches (50 mm).

(23) #### S2.6.3.3 LOCALLY THINNED AREAS

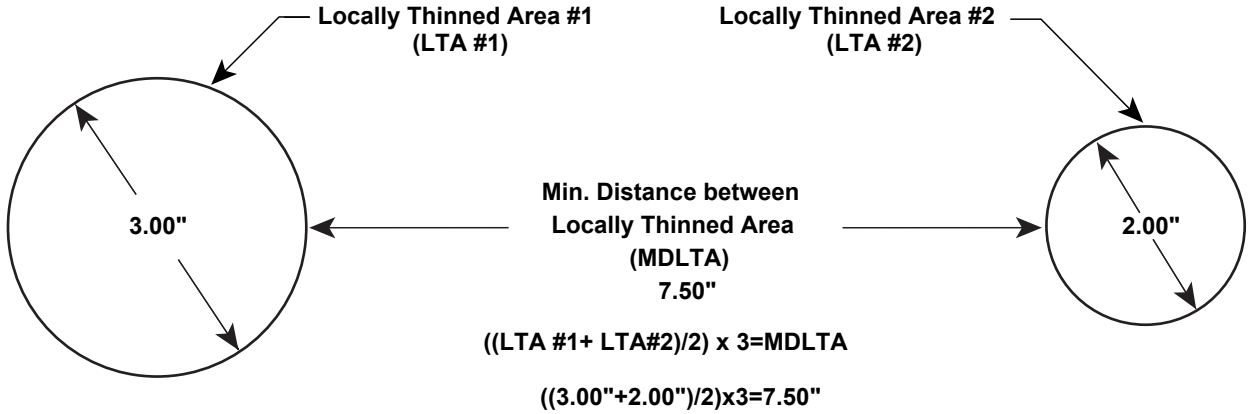
Locally thinned areas (LTA), 3 inch (75 mm) in diameter or less, may be disregarded for MAWP calculations when:

a) The average depth of the corrosion is such that remaining material shall not be less than 75% of the required thickness per the MAWP calculations.

b) The remaining thickness at the thinnest point shall not be less than 50% of the required thickness per the MAWP calculations.

c) The minimum distance between the boundaries of two locally thinned areas (MDLTA) must be greater than the average diameters of the two locally thinned areas (LTA) multiplied by 3.0. (See Figure S2.6.3.3)

**FIGURE S2.6.3.3**
LOCALLY THINNED AREA




### S2.6.3.4 GENERALIZED THINNED AREAS

a) For corroded areas exceeding the specifications in S2.6.3.1, S2.6.3.2, and S2.6.3.3, the remaining thickness may be averaged over an area not exceeding the UT-grid size specified in S2.6.2 b) or S2.6.2 c).

   1) The least measured remaining thickness within the grid indicated in S2.6.2 b) or S2.6.2 c) as applicable shall not be less than 50% of the required thickness per the calculation for MAWP.

   2) The average remaining thickness recognized from the grid indicated in S2.6.2 b) or S2.6.2 c) as applicable shall not be less than 75% of the required thickness per the calculation for MAWP.

b) When general corrosion exceeds the limits of S2.6.3.4 a), the conditions shall be presented and reviewed with the Inspector, and when required, the Jurisdiction for resolution.

   **Note**: The guidance presented at S2.6.3.1, S2.6.3.2, S2.6.3.3, and S2.6.3.4 is to be used to evaluate areas of thinning due to corrosion. Areas where plates have been formed to make corners whereby the radiuses may have thinned due to the forming process shall not be considered in calculating MAWP.

## S2.7 INSPECTIONS

The requirements of this section shall be used in conjunction with the general requirements identified in NBIC Part 2, S2.4.

### S2.7.1 INSERVICE INSPECTIONS

The following examinations and tests shall be performed while the boiler is in operation:

a) Two independent means of boiler feedwater delivery systems shall be demonstrated to the Inspector. Observance to be performed at an operating pressure no less than 90% of the safety valve set point of the boiler. If the boiler is equipped with more than one feedwater tank, each feedwater device must be

able to take water out of either feedwater tank. Pumped feedwater shall be preheated prior to entering the boiler;

b) Demonstration of operable try-cocks that show a level of water that correlates with that shown in the gage glass;

c) Demonstration of operating gage glass upper and lower shutoff valves;

d) Demonstration of an operating gage glass blowdown valve;

e) Check that the gage glass is visually clear and fully operational;

f) Visual inspection for leaks; and

g) Safety valves shall be tested by having the operator raise boiler pressure to the safety valve popping point. Popping point pressure and blowdown will be observed to ensure they are within tolerances (see NBIC Part 2, S2.8). Alternatively, a certification acceptable to the Jurisdiction may be used for verification of set pressures.

### S2.7.2 INSERVICE INSPECTION DOCUMENTATION

Inservice inspection shall be documented as required by the Jurisdiction where the boiler is operated, or Form NB-5 or similar form may be used.

### S2.7.3 INSPECTION INTERVALS



### S2.7.3.1 INITIAL INSPECTION

a) Initial inspections shall be performed to determine baseline criteria needed for the operating life of the boiler. The owner or user shall maintain documentation and inspection results, as required by this section. In addition to the required Jurisdiction inservice inspection report identified in NBIC Part 2, S2.7.2, Form C-1 (See NBIC Part 2, S2.12) may be used for the documentation of initial examinations and inspections.

b) Boilers initially evaluated in accordance with this inspection code shall be subject to the following examinations and tests:

   1) A visual internal examination per NBIC Part 2, S2.5.2;

   2) A visual inservice examination per NBIC Part 2, S2.7.1;

   3) Initial UT test requirements per NBIC Part 2, S2.6.2;

   4) MAWP calculation per NBIC Part 2, S2.10;

   5) Hydrostatic Pressure Testing per NBIC Part 2, S2.6.1; and

   6) Other examinations (UT, PT, MT) as required by the Jurisdiction or Inspector to determine boiler integrity.

c) For new boilers constructed to a design code acceptable to the Jurisdiction, the initial inspection shall be a visual inservice exam per NBIC Part 2, S2. 7. 1. Subject to jurisdictional acceptance, the other initial inspection items above may be omitted. These new boilers may be mounted on existing running gear or settings and may include the original appurtenances.

### S2.7.3.2 SUBSEQUENT INSPECTIONS (23)

a) Boilers that have completed the initial inspection requirements begin the subsequent inspection intervals. The following inspection intervals should be used unless other requirements are mandated by the Jurisdiction.

   1) Interval #1 — One year following initial inspection. Inservice inspection per NBIC Part 2, S2.7.1.

   2) Interval #2 — Two years following initial inspection. Visual inspection per NBIC Part 2, S2.5.2.2.

   3) Interval #3 — Three years following initial inspection. A pressure test per NBIC Part 2, S2.6.1.

b) After interval #3 is completed, the subsequent inspection cycle continues with interval #1.

c) UT thickness testing per NBIC Part 2, S2.6.2 shall be performed at 5 year intervals, or at a shorter interval if deemed necessary by the Jurisdiction.

   1) Recurring UT thickness testing may be extended by up to 1 cycle (5 years) where the owner can demonstrate the following:

      a. Two prior consecutive NDE reports following this cycle, spanning a minimum of 5 years, showing that current practice permits a longer NDE cycle;

      b. Storage and care of the boiler are in adherence with the applicable sections of S2.13.1 STORAGE METHODS; and

      c. Operating records (e.g., visual images and log book records showing correct water treatment) shall be reviewed annually during the extension period indicating no change to boiler condition.

   2) New construction ASME Section I boilers may not be required to be subjected to UT testing for 20 years from the date of manufacture, unless a shorter interval is deemed necessary by the Jurisdiction.



## S2.8 SAFETY DEVICES — GENERAL REQUIREMENTS

Each boiler shall be equipped with the following safety devices: safety valve(s), gage glass(es), try-cock(s), fusible plug(s), and pressure gage(s). These safety devices shall be verified by the owner and Inspector and documented on the Boiler Inspection Guideline, NBIC Part 2, S2.11, for proper installation and purpose during each inspection.

### S2.8.1 SAFETY VALVES

a) The following requirements shall be verified acceptable when performing inspections of safety valves:

   1) Set pressures of safety valves installed shall be verified by operation or certification acceptable to the Jurisdiction.

   2) Safety valve(s) shall be National Board capacity certified.

   3) Safety valve(s) shall be sealed by an ASME “V” Stamp holder or National Board “VR” repair firm.

   4) The required safety valve capacity in pounds per hour (kg per hour) shall be calculated by multiplying boiler heating surface area by the type of fuel factor used (see NBIC Part 2, Table S2.8.1, for fuel factors). Excessive safety valve capacity should be avoided. (Only heating surface area above the grates shall be used when calculating heating surface for safety valve required capacity.)

      **Note:** An additional pressure relief valve may be used in conjunction with the above required ASME safety valve if set at a lower pressure, although no credit for relieving capacity may be used.

5) Safety valve(s) shall have a test lever.

6) No isolation valve of any description shall be placed between the required safety valve(s) and the boiler, or on the discharge pipe between the valve and the atmosphere.

7) The piping connection between the boiler and the safety valve shall not be less than the inlet size of the safety valve, and the discharge pipe, if used, shall not be reduced between the safety valve and the point of discharge.

8) The safety valve(s) shall be connected so as to stand in an upright position with the spindle vertical.

9) The discharge from the safety valve(s) shall be arranged that there is no danger of scalding either the operator(s) or individuals who may be in the vicinity of the boiler. If the valve(s) is a top discharge design, no discharge piping is required. If a side discharge design valve(s) is used, an elbow should be attached to the outlet to assure a vertical discharge. The elbow must be located as close to the valve(s) as possible to minimize reaction moment stress.

10) Provision for ample gravity drain shall be made in the discharge pipe at or near each safety valve, and where water can collect.

11) If the boiler is equipped with a canopy, the elbow may be other than 90 degrees to direct the discharge out from under the canopy, while still directing the discharge to a safe location. The elbow must be located as close to the valve(s) as possible to minimize reaction moment stress.

12) If the boiler is equipped with a canopy, the discharge may be piped through the canopy. When the discharge piping is piped through a canopy, the elbow must be located as close to the valve as possible to minimize reaction moment stress. The discharge piping may be a larger pipe but in no case be smaller than the discharge size of the valve. Discharge piping shall be completely supported separate from the valve and elbow so no extra loading is transmitted to the safety valve(s).

b) To reduce cycling stress on the boiler, it is recommended that a safety valve with a blowdown between 2% and 4% be used. The blowdown, however, should never exceed 6%.



**TABLE S2.8.1**

MINIMUM POUNDS OF STEAM PER HOUR PER SQUARE FOOT OF HEATING SURFACE
(1 LB. STEAM/HR./SQ. FT. [4.88 KG/HR./SQ. M])

| Boiler Heating Surface | Firetube Boilers | Watertube Boilers |
|---|---|---|
| Hand-Fired | 5 (24) | 6 (29) |
| Stoker-Fired | 7 (34) | 8 (39) |
| Power Burner | 8 (68) | 10 (78) |
| Hand-Fired Waterwall | 8 (39) | 8 (39) |
| Stoker Waterwall | 10 (49) | 12 (59) |
| Power Burner Waterwall | 14 (68) | 16 (78) |

## S2.8.2 GAGE GLASS

Historical boilers shall be equipped with at least one gage glass meeting the following requirements:

a) The gage glass shall be fitted with a guard to protect the glass;

b) The gage glass shall indicate the minimum safe operating water level;

c) The gage glass shall be provided with a drain valve or petcock, piped to a safe location;

d) The gage glass shall be visually clear and fully operational; and

e) The distance from the highest point on the crown sheet to the top of the lowest packing nut of the gage glass shall be checked and documented documented in the boiler log. This distance shall be no less than 2 in. (50 mm).

### S2.8.3 TRY-COCKS

Historical boilers shall be equipped with try-cocks meeting the following requirements:

a) Try-cocks shall be correctly located in reference to the minimum required water level;

b) Try-cocks shall be open (unplugged) and fully operational; and

c) If the boiler was not originally fitted with try-cocks, a newly installed try-cock shall be located 3 in. (76 mm) above the crownsheet.

### S2.8.4 FUSIBLE PLUG

Historical boilers equipped with fusible plugs shall meet the following requirements:

a) The fusible plug shall be inspected to determine the condition of the threads in the crown sheet and on the fusible plug;

b) Boilers shall have a fusible plug unless equipped and operated with automatic controls;

c) Fusible plugs shall be constructed to meet the requirements of the ASME Code, and indicated as such by the ASME marking on the filler material;

d) Fireside fusible plugs must protrude a minimum of 3/4 inch (19 mm) into the water;

e) Fusible plugs may not protrude into the fire area more than 1 inch (25 mm);

f) Fusible plugs shall not be refilled;

g) Fusible plugs shall be replaced on initial jurisdictional inspection and after 500 hours of service, if hours of service can be proven. If hours of service cannot be proven they shall be replaced every three calendar years. Fusible plug life shall not exceed ten calendar years; and

h) Leaking fusible plugs shall be replaced.

### S2.8.5 PRESSURE GAGE

Historical boilers shall be equipped with at least one pressure gage meeting the following requirements:

a) Tested and proven accurate within plus or minus 5 psi (35 kPa) of the safety valve set point at the time of the inservice inspection pressure test. If the gage is found to be out of this specified range it shall be calibrated to a national standard using a master gage or dead weight tester traceable to a national standard;

b) Siphon, or water seal, shall be installed between pressure gage and boiler;

c) If a valve is installed between the gage and the boiler, the valve shall indicate the open position or be sealed open; and

d) The range of pressure gage shall be 1.5 to 3.5 times the set point of the safety valve.

## S2.9 APPURTENANCES — PIPING, FITTINGS, AND VALVES

Boiler piping and fittings shall meet the following requirements:

a) Threaded openings shall follow accepted standard piping practices and ANSI general pipe thread requirements;

b) Schedule 80, black pipe (SA-53 GR. A or B types ERW or Seamless; SA-106 GR A,B,C) shall be used for boiler pressure piping. Galvanized pipe and fittings and A-53 Type F and API-5L Grade A 25 pipe are prohibited on boiler pressure piping;

c) Steam piping components shall be used in the manner for which they were designed and shall not exceed manufacturer's pressure rating. Malleable iron Class 300 threaded fittings per ASME B16.3 are acceptable for use. The use of malleable iron class 150 is not recommended. Forged threaded fittings per ASME B16.11 classes 2,000-6,000 are acceptable for use;

d) The blowdown line shall be piped to a safe point of discharge during the time the boiler is operating;

e) Piping shall be properly supported;

f) Valves shall be used in the manner for which they were designed, and shall be used within the specified pressure-temperature ratings.

    1) Valves shall be rated at or above the pressure setting of the boiler safety valve, denoted by the general or primary pressure class identification on the valve body and/or by the initials "WSP" or "S" to indicate working steam pressure or steam rating. Valves in cold-water service may be designated by the initials "WOG" to indicate water, oil, or gas rating and/or by the pressure class identification on the valve body; and

    2) Valves shall operate freely and be in good working condition. Valves which are damaged, such as cracked or swelled from freezing, shall not be used.

    3) Each bottom blowoff pipe shall have at least one slow-opening valve. Blowoff valves may be Y-type globe valves, gate valves, or angle valves provided that they are so constructed and installed to prevent sediment collection. Ordinary globe valves, and other types of valves that have dams or pockets where sediment can collect, shall not be used on blowoff connections.

    4) A slow-opening valve is a valve that requires at least five 360 deg turns of the operating mechanism to change from fully closed to fully opened.

g) The boiler shall be equipped with two means of supplying feedwater while the boiler is under pressure.

### S2.9.1 PIPING, FITTINGS, AND VALVE REPLACEMENTS

The installation date should be stamped or stenciled on the replaced boiler piping. Alternatively, the installation date may be documented in permanent boiler records, such as the operator log book.

## S2.10 MAXIMUM ALLOWABLE WORKING PRESSURE (MAWP)

The MAWP of a boiler shall be determined by computing the strength of each boiler component. The computed strength of the weakest component using the factor of safety allowed by these rules shall determine the MAWP.

**Note:** The rules of ASME Section I may be used for determining specific requirements of design and construction of boilers and parts fabricated by riveting.

### S2.10.1 STRENGTH

a) In calculating the MAWP, when the tensile strength of the steel or wrought iron is known, that value shall be used. When the tensile strength of the steel or wrought iron is not known, the values to be used are 55,000 psi (379 MPa) for steel and 45,000 psi (310 MPa) for wrought iron. Original steel stamp marks, original material certifications, or current laboratory tests are acceptable sources for verification of tensile strength. Catalogs and advertising literature are not acceptable sources for tensile strength values.

b) In computing the ultimate strength of rivets in shear, the following values shall be used:

1) Iron rivets in single shear 38,000 psi (262 MPa)

2) Iron rivets in double shear 76,000 psi (524 MPa)

3) Steel rivets in single shear 44,000 psi (303 MPa)

4) Steel rivets in double shear 88,000 psi (607 MPa)

c) The resistance to crushing of mild steel shall be taken as 95,000 psi (655 MPa) unless otherwise known.

d) S = TS/FS. See definitions of nomenclature in NBIC Part 2,S2.10.6.

### S2.10.2 RIVETS AND RIVET HEADS

When the diameter of the rivet holes in the longitudinal joints of a boiler is not known, the diameter of rivets, after driving, shall be ascertained from the NBIC Part 2, Table S2.10.2.

**TABLE S2.10.2**
SIZES FOR RIVETS BASED ON PLATE THICKNESS

| Thickness of Plate, in. (mm) | Diameter of Rivet after Driving, in. (mm) |
|---|---|
| 1/4 (6) | 11/16 (17) |
| 9/32 (7) | 11/16 (17) |
| 5/16 (8) | 3/4 (19) |
| 11/32 (9) | 3/4 (19) |
| 3/8 (10) | 13/16 (21) |
| 13/32 (10) | 13/16 (21) |
| 7/16 (11) | 15/16 (24) |
| 15/32 (12) | 15/16 (24) |
| 1/2 (13) | 15/16 (24) |
| 9/16 (14) | 1-1/16 (27) |
| 5/8 (16) | 1-1/16 (27) |

### S2.10.2.1 RIVET HEAD TYPES

Common finished rivet heads are shown in NBIC Part 3, Figure S2.13.13.4-a, S2.13.4-b and S2.13.13.4-c. Note that a riveted seam may have more than one type of rivet, for example, to provide necessary clearance during operation, or for provision for equipment assembly and maintenance.

## S2.10.2.2 INSPECTION OF CORRODED RIVETS

A riveted seam or joint is very redundant by design. Therefore, the following guidelines apply when generalized corrosion is present and consistent on a group of adjacent rivets (typically four or more), and not to individual rivets. The Inspector must consider the frequency and consistency of corroded rivet heads, and condition, location, and type of riveted joint (and how it may fail) in determining allowable corrosion.

a) Visually identify all connections containing rivets which show signs of significant corrosion.

b) Categorize each connection as the type which loads the rivets in one of three possible modes (pure shear, pure tension, or combined shear and tension). Refer to Figure S2.10.2.2.

c) A leak around a rivet head may be indicative of a rivet which is loose, broken, or otherwise failing to provide adequate clamping force and shall require further inspection.

   1) A rivet shall be deemed loose if it can be felt to move after being struck on the side of the head in a direction approximately perpendicular to its shank with a 40 oz. engineer's hammer.

   2) NBIC Part 3, S2.13.13 defines procedures to address a leak around a rivet head.

d) Allowable corrosion:

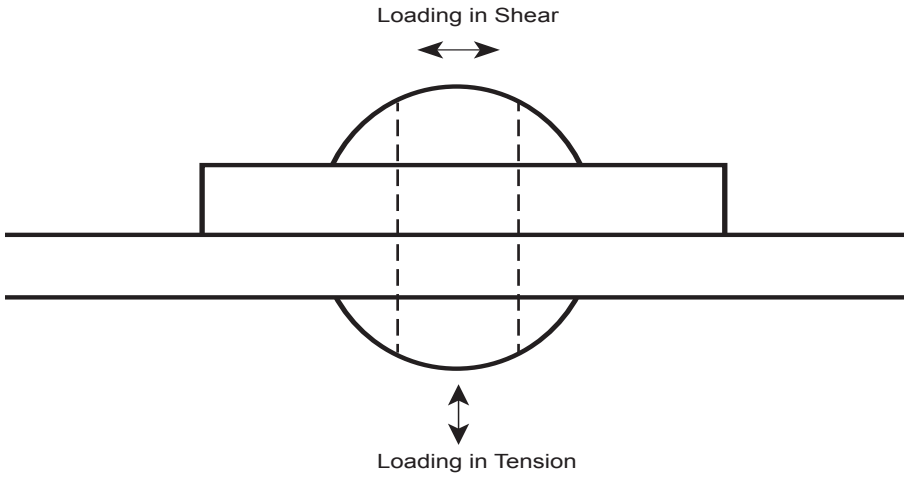
   1) For rivets in pure shear load, the amount of measured head deterioration shall not exceed 80% of their total head volume. Where rivets have countersunk heads, the head diameter must be equal to or greater than 65% of the original head diameter. Severe head corrosion shall require further evaluation of the condition and thickness of the plate at the joint.

   2) For rivets in pure tension, the amount of measured head deterioration shall not exceed 35% of their total head volume. Where rivets have countersunk heads, the head diameter must be equal or greater than 85% of original head diameter. Application of this value shall take into consideration the consistency and frequency of adjacent rivets showing excessive corrosion.

   3) For connections subjected to combined shear and tension loads, the amount of measured head deterioration shall not exceed 60% of their total head volume. Where rivets have countersunk heads, the head diameter must be equal or greater than 75% of original head diameter. Application of this value shall take into consideration the consistency and frequency of adjacent rivets showing excessive corrosion.

      **Note:** The condition of the plate surrounding the rivets including general wastage, pitting, and the condition of the caulking edge, must be considered.

**FIGURE S2.10.2.2**



### S2.10.2.3 INSPECTION OF RIVETED SEAMS (23)

A riveted joint in a vessel subjected to pressure may fail in a number of different ways, depending on the type and relative proportions of the joint. Some methods of failure may be classified as follows:

a) Rivets may shear off;

b) The plate may tear along the centerline of the row of rivets;

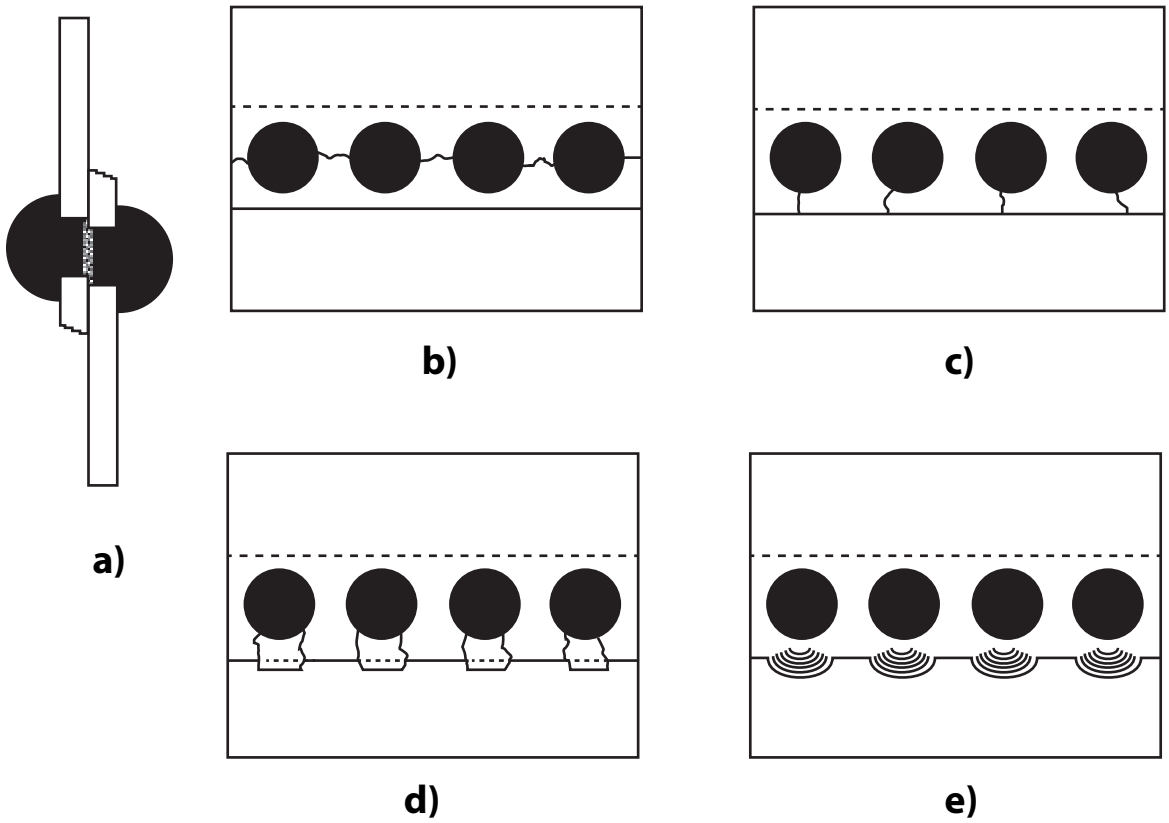
c) The plate may shear in front of the rivets;

d) The plate may tear from the outer edge of the rivet hole to the caulking edge; or

e) The plate may crush in front of the rivets.

Figure S2.10.2.3 illustrates visual indicators of a), b), c), d), and e). The Inspector shall visually inspect for cracked or stressed plate material along a riveted joint. Indications of failure shall be monitored or repaired, at the discretion of the Inspector, and jurisdiction when applicable.

**FIGURE S2.10.2.3** (23)




### S2.10.3 CYLINDRICAL COMPONENTS

The MAWP of cylindrical components under internal pressure shall be determined by the strength of weakest course computed from the minimum thickness of the plate, the tensile strength of the plate, the efficiency of the longitudinal joint, the inside diameter of weakest course, and the design margin allowed by these rules using the following formula or NBIC Part 2, Tables S2.10.3.2 through S2.10.3.7:

$$\text{MAWP} = \frac{\text{TS} \times \text{t} \times \text{E}}{(\text{R} \times \text{FS})}$$

See definitions of nomenclature in NBIC Part 2, S2.10.6.

(23) **S2.10.3.1 CYLINDRICAL COMPONENTS UNDER EXTERNAL PRESSURE**

The MAWP of unstayed plain circular cylindrical components not exceeding 42 inches in diameter and under external pressure shall be determined by the strength of the weakest course computed from the minimum thickness of the plate, the tensile strength of the plate, the type of longitudinal joint, outside diameter of the weakest course, and the length of the firetube, using the following formulas:

$$P_1 = \frac{C_1 \times t^2 \times TS}{\left(\frac{f}{12} + 1\right) \times d_0} \qquad P_2 = \frac{t \times TS}{C_2 \times d_0} \qquad P = min\ (P_1, P_2)$$

**TABLE S2.10.3.1**
CONSTANTS FOR CALCULATED MAWP FOR CYLINDRICAL COMPONENTS UNDER EXTERNAL PRESSURE

| Constant Values | | |
|---|---|---|
| $C_1$ | Longitudinal Joint | |
| | 1-row lap seam | 1.85 |
| | 2-row lap seam | 1.95 |
| | 1-row butt strap, single butt strap | 2.1 |
| | 1-row butt strap, double butt strap | 2.2 |
| | 2-row butt strap, single butt strap | 2.2 |
| | 2-row butt strap, double butt strap | 2.3 |
| $C_2$ | | 5.0 |

**Example 1:** A vertical boiler containing a 1-row lap seam unstayed steel firebox with an outside diameter of 34 inches, height of 24 inches, and a thickness of 0.4 inches is calculated as follows:

$$P_1 = \frac{1.85 \times 0.4^2 \times 55000}{\left(\frac{24}{12} + 1\right) \times 34} = 160\ PSI \qquad P_2 = \frac{0.4 \times 55000}{5.0 \times 34} = 129\ PSI$$

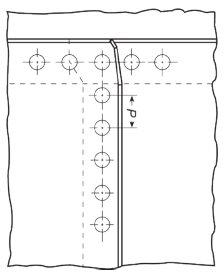
$$P = min\ (160, 129) = 129\ PSI$$

# TABLE S2.10.3.2

## MAXIMUM ALLOWABLE WORKING PRESSURE FOR CYLINDRICAL COMPONENTS (BARREL)

**For Single-Riveted Lap Joint**

| Shell ID | Minimum Thickness of Shell Plate | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0.19 | 0.2 | 0.21 | 0.22 | 0.23 | 0.24 | 0.25 | 0.26 | 0.27 | 0.28 | 0.29 | 0.3 | 0.31 | 0.32 | 0.33 | 0.34 | 0.35 | 0.36 | 0.37 | 0.38 | 0.39 | 0.4 | 0.41 | 0.42 | 0.43 | 0.44 | 0.45 | 0.46 | 0.47 | 0.48 | 0.49 | 0.5 |
| 12 | 168 | 177 | 186 | 195 | 204 | 213 | 222 | 230 | 239 | 248 | 257 | 266 | 275 | 284 | 292 | 301 | 310 | 319 | 328 | 337 | 346 | 354 | 363 | 372 | 381 | 390 | 399 | 408 | 416 | 425 | 434 | 443 |
| 13 | 155 | 164 | 172 | 180 | 188 | 196 | 204 | 213 | 221 | 229 | 237 | 245 | 254 | 262 | 270 | 278 | 286 | 294 | 303 | 311 | 319 | 327 | 335 | 344 | 352 | 360 | 368 | 376 | 384 | 393 | 401 | 409 |
| 14 | 144 | 152 | 160 | 167 | 175 | 182 | 190 | 197 | 205 | 213 | 220 | 228 | 235 | 243 | 251 | 258 | 266 | 273 | 281 | 286 | 296 | 304 | 311 | 319 | 327 | 334 | 342 | 349 | 357 | 365 | 372 | 380 |
| 15 | 135 | 142 | 149 | 156 | 163 | 170 | 177 | 184 | 191 | 198 | 206 | 213 | 220 | 227 | 234 | 241 | 248 | 255 | 262 | 269 | 276 | 284 | 291 | 298 | 305 | 312 | 319 | 326 | 333 | 340 | 347 | 354 |
| 16 | 126 | 133 | 140 | 146 | 153 | 160 | 166 | 173 | 179 | 186 | 193 | 199 | 206 | 213 | 219 | 226 | 233 | 239 | 246 | 253 | 259 | 266 | 272 | 279 | 286 | 292 | 299 | 306 | 312 | 319 | 326 | 332 |
| 17 | 119 | 125 | 131 | 138 | 144 | 150 | 156 | 163 | 169 | 175 | 181 | 188 | 194 | 200 | 206 | 213 | 219 | 225 | 231 | 238 | 244 | 250 | 256 | 263 | 269 | 275 | 281 | 288 | 294 | 300 | 306 | 313 |
| 18 | 112 | 118 | 124 | 130 | 136 | 142 | 148 | 154 | 160 | 165 | 171 | 177 | 183 | 189 | 195 | 201 | 207 | 213 | 219 | 224 | 230 | 236 | 242 | 248 | 254 | 260 | 266 | 272 | 278 | 284 | 289 | 295 |
| 19 | 106 | 112 | 118 | 123 | 129 | 134 | 140 | 146 | 151 | 157 | 162 | 168 | 173 | 179 | 185 | 190 | 196 | 201 | 207 | 213 | 218 | 224 | 229 | 235 | 241 | 246 | 252 | 257 | 263 | 269 | 274 | 280 |
| 20 | 101 | 106 | 112 | 117 | 122 | 128 | 133 | 138 | 144 | 149 | 154 | 160 | 165 | 170 | 175 | 181 | 186 | 191 | 197 | 202 | 207 | 213 | 218 | 223 | 229 | 234 | 239 | 245 | 250 | 255 | 261 | 266 |
| 21 | 96 | 101 | 106 | 111 | 116 | 122 | 127 | 132 | 137 | 142 | 147 | 152 | 157 | 162 | 167 | 172 | 177 | 182 | 187 | 192 | 197 | 203 | 208 | 213 | 218 | 223 | 228 | 233 | 238 | 243 | 248 | 253 |
| 22 | 92 | 97 | 102 | 106 | 111 | 116 | 121 | 126 | 131 | 135 | 140 | 145 | 150 | 155 | 160 | 164 | 169 | 174 | 179 | 184 | 189 | 193 | 198 | 203 | 208 | 213 | 218 | 222 | 227 | 232 | 237 | 242 |
| 23 | 88 | 92 | 97 | 102 | 106 | 111 | 116 | 120 | 125 | 129 | 134 | 139 | 143 | 148 | 153 | 157 | 162 | 166 | 171 | 176 | 180 | 185 | 190 | 194 | 199 | 203 | 208 | 213 | 217 | 222 | 227 | 231 |
| 24 | 84 | 89 | 93 | 97 | 102 | 106 | 111 | 115 | 120 | 124 | 128 | 133 | 137 | 142 | 146 | 151 | 155 | 160 | 164 | 168 | 173 | 177 | 182 | 186 | 191 | 195 | 199 | 204 | 208 | 213 | 217 | 222 |
| 25 | 81 | 85 | 89 | 94 | 98 | 102 | 106 | 111 | 115 | 119 | 123 | 128 | 132 | 136 | 140 | 145 | 149 | 153 | 157 | 162 | 166 | 170 | 174 | 179 | 183 | 187 | 191 | 196 | 200 | 204 | 208 | 213 |
| 26 | 78 | 82 | 86 | 90 | 94 | 98 | 102 | 106 | 110 | 115 | 119 | 123 | 127 | 131 | 135 | 139 | 143 | 147 | 151 | 155 | 160 | 164 | 168 | 172 | 176 | 180 | 184 | 188 | 192 | 196 | 200 | 204 |
| 27 | 75 | 79 | 83 | 87 | 91 | 95 | 98 | 102 | 106 | 110 | 114 | 118 | 122 | 126 | 130 | 134 | 138 | 142 | 146 | 150 | 154 | 158 | 161 | 165 | 169 | 173 | 177 | 181 | 185 | 189 | 193 | 197 |
| 28 | 72 | 76 | 80 | 84 | 87 | 91 | 95 | 99 | 103 | 106 | 110 | 114 | 118 | 122 | 125 | 129 | 133 | 137 | 141 | 144 | 148 | 152 | 156 | 160 | 163 | 167 | 171 | 175 | 178 | 182 | 186 | 190 |
| 29 | 70 | 73 | 77 | 81 | 84 | 88 | 92 | 95 | 99 | 103 | 106 | 110 | 114 | 117 | 121 | 125 | 128 | 132 | 136 | 139 | 143 | 147 | 150 | 154 | 158 | 161 | 165 | 169 | 172 | 176 | 180 | 183 |
| 30 | 67 | 71 | 74 | 78 | 82 | 85 | 89 | 92 | 96 | 99 | 103 | 106 | 110 | 113 | 117 | 121 | 124 | 128 | 131 | 135 | 138 | 142 | 145 | 149 | 152 | 156 | 160 | 163 | 167 | 170 | 174 | 177 |
| 31 | 65 | 69 | 72 | 75 | 79 | 82 | 86 | 89 | 93 | 96 | 99 | 103 | 106 | 110 | 113 | 117 | 120 | 123 | 127 | 130 | 134 | 137 | 141 | 144 | 147 | 151 | 154 | 158 | 161 | 165 | 168 | 172 |
| 32 | 63 | 66 | 70 | 73 | 76 | 80 | 83 | 86 | 90 | 93 | 96 | 100 | 103 | 106 | 110 | 113 | 116 | 120 | 123 | 126 | 130 | 133 | 136 | 140 | 143 | 146 | 150 | 153 | 156 | 160 | 163 | 166 |
| 33 | 61 | 64 | 68 | 71 | 74 | 77 | 81 | 84 | 87 | 90 | 93 | 97 | 100 | 103 | 106 | 110 | 113 | 116 | 119 | 122 | 126 | 129 | 132 | 135 | 139 | 142 | 145 | 148 | 151 | 155 | 158 | 161 |
| 34 | 59 | 63 | 66 | 69 | 72 | 75 | 78 | 81 | 84 | 88 | 91 | 94 | 97 | 100 | 103 | 106 | 109 | 113 | 116 | 119 | 122 | 125 | 128 | 131 | 134 | 138 | 141 | 144 | 147 | 150 | 153 | 156 |
| 35 | 58 | 61 | 64 | 67 | 70 | 73 | 76 | 79 | 82 | 85 | 88 | 91 | 94 | 97 | 100 | 103 | 106 | 109 | 112 | 115 | 118 | 122 | 125 | 128 | 131 | 134 | 137 | 140 | 143 | 146 | 149 | 152 |
| 36 | 56 | 59 | 62 | 65 | 68 | 71 | 74 | 77 | 80 | 83 | 86 | 89 | 92 | 95 | 97 | 100 | 103 | 106 | 109 | 112 | 115 | 118 | 121 | 124 | 127 | 130 | 133 | 136 | 139 | 142 | 145 | 148 |
| 37 | 55 | 57 | 60 | 63 | 66 | 69 | 72 | 75 | 78 | 80 | 83 | 86 | 89 | 92 | 95 | 98 | 101 | 103 | 106 | 109 | 112 | 115 | 118 | 121 | 124 | 126 | 129 | 132 | 135 | 138 | 141 | 144 |
| 38 | 53 | 56 | 59 | 62 | 64 | 67 | 70 | 73 | 76 | 78 | 81 | 84 | 87 | 90 | 92 | 95 | 98 | 101 | 104 | 106 | 109 | 112 | 115 | 118 | 120 | 123 | 126 | 129 | 132 | 134 | 137 | 140 |
| 39 | 52 | 55 | 57 | 60 | 63 | 65 | 68 | 71 | 74 | 76 | 79 | 82 | 85 | 87 | 90 | 93 | 95 | 98 | 101 | 104 | 106 | 109 | 112 | 115 | 117 | 120 | 123 | 125 | 128 | 131 | 134 | 136 |
| 40 | 51 | 53 | 56 | 58 | 61 | 64 | 66 | 69 | 72 | 74 | 77 | 80 | 82 | 85 | 88 | 90 | 93 | 96 | 98 | 101 | 104 | 106 | 109 | 112 | 114 | 117 | 120 | 122 | 125 | 128 | 130 | 133 |
| 41 | 49 | 52 | 54 | 57 | 60 | 62 | 65 | 67 | 70 | 73 | 75 | 78 | 80 | 83 | 86 | 88 | 91 | 93 | 96 | 99 | 101 | 104 | 106 | 109 | 112 | 114 | 117 | 119 | 122 | 124 | 127 | 130 |
| 42 | 48 | 51 | 53 | 56 | 58 | 61 | 63 | 66 | 68 | 71 | 73 | 76 | 78 | 81 | 84 | 86 | 89 | 91 | 94 | 96 | 99 | 101 | 104 | 106 | 109 | 111 | 114 | 116 | 119 | 122 | 124 | 127 |
| 43 | 47 | 49 | 52 | 54 | 57 | 59 | 62 | 64 | 67 | 69 | 72 | 74 | 77 | 79 | 82 | 84 | 87 | 89 | 91 | 94 | 96 | 99 | 101 | 104 | 106 | 109 | 111 | 114 | 116 | 119 | 121 | 124 |
| 44 | 46 | 48 | 51 | 53 | 56 | 58 | 60 | 63 | 65 | 68 | 70 | 73 | 75 | 77 | 80 | 82 | 85 | 87 | 89 | 92 | 94 | 97 | 99 | 102 | 104 | 106 | 109 | 111 | 114 | 116 | 118 | 121 |
| 45 | 45 | 47 | 50 | 52 | 54 | 57 | 59 | 61 | 64 | 66 | 69 | 71 | 73 | 76 | 78 | 80 | 83 | 85 | 87 | 90 | 92 | 95 | 97 | 99 | 102 | 104 | 106 | 109 | 111 | 113 | 116 | 118 |




**TS = Tensile Strength (55,000)**

**t = Thickness of Cylindrical Component**

**TS x t x E/R x FS**

**R = Radius of Shell (inside diameter/2)**

**E = Joint Efficiency (58%)**

**FS = Factor of Safety (6)**

| Shell ID (mm) | Minimum Thickness of Shell Plate (mm) | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 4.75 | 5 | 5.25 | 5.5 | 5.75 | 6 | 6.25 | 6.5 | 6.75 | 7 | 7.25 | 7.5 | 7.75 | 8 | 8.25 | 8.5 |
| 300 | 1163. | 1224 | 1286 | 1347 | 1408 | 1469 | 1531 | 1592 | 1653 | 1714 | 1775 | 1837 | 1898 | 1959 | 2020 | 2082 |
| 325 | 1074 | 1130 | 1187 | 1243 | 1300 | 1356 | 1413 | 1469 | 1526 | 1582 | 1639 | 1695 | 1752 | 1808 | 1865 | 1921 |
| 350 | 997 | 1050 | 1102 | 1154 | 1207 | 1259 | 1312. | 1364 | 1417 | 1469 | 1522 | 1574 | 1627 | 1679 | 1732 | 1784 |
| 375 | 931 | 980 | 1029 | 1078 | 1126 | 1175 | 1224 | 1273 | 1322 | 1371 | 1420 | 1469 | 1518 | 1567 | 1616 | 1665 |
| 400 | 872 | 918 | 964 | 1010 | 1056 | 1102 | 1148 | 1194 | 1240 | 1286 | 1332 | 1378 | 1423 | 1469 | 1515 | 1561 |
| 425 | 821 | 864 | 908 | 951 | 994 | 1037 | 1080 | 1124 | 1167 | 1210 | 1253 | 1296 | 1340 | 1383 | 1426 | 1469 |
| 450 | 775 | 816 | 857 | 898 | 939 | 980 | 1020 | 1061 | 1102 | 1143 | 1184 | 1224 | 1265 | 1306 | 1347 | 1388 |
| 475 | 735 | 773 | 812 | 851 | 889 | 928 | 967 | 1005 | 1044 | 1083 | 1121 | 1160 | 1199 | 1237 | 1276 | 1315 |
| 500 | 698 | 735 | 771 | 808 | 845 | 882 | 918 | 955 | 992 | 1029 | 1065 | 1102 | 1139 | 1175 | 1212 | 1249 |
| 525 | 665 | 700 | 735 | 770 | 805 | 840 | 875 | 910 | 945 | 980 | 1015 | 1050 | 1085 | 1119 | 1154 | 1189 |
| 550 | 634 | 668 | 701 | 735 | 768 | 801 | 835 | 868 | 902 | 935 | 968 | 1002 | 1035 | 1069 | 1102 | 1135 |
| 575 | 607 | 639 | 671 | 703 | 735 | 767 | 799 | 830 | 862 | 894 | 926 | 958 | 990 | 1022 | 1054 | 1086 |
| 600 | 582 | 612 | 643 | 673 | 704 | 735 | 765 | 796 | 827 | 857 | 888 | 918 | 949 | 980 | 1010 | 1041 |
| 625 | 558. | 588 | 617 | 647 | 676 | 705 | 735 | 764 | 793 | 823 | 852 | 882 | 911 | 940 | 970 | 999 |
| 650 | 537 | 565 | 593 | 622 | 650 | 678 | 706 | 735 | 763 | 791 | 819 | 848 | 876 | 904 | 932 | 961 |
| 675 | 517 | 544 | 571 | 599 | 626 | 653 | 680 | 707 | 735 | 762 | 789 | 816 | 844 | 871 | 898 | 925 |
| 700 | 499. | 525 | 551 | 577 | 603 | 630 | 656 | 682 | 708 | 735 | 761 | 787 | 813 | 840 | 866 | 892 |
| 725 | 481 | 507 | 532 | 557 | 583 | 608 | 633 | 659 | 684 | 709 | 735 | 760 | 785 | 811 | 836 | 861 |
| 750 | 465 | 490 | 514 | 539 | 563 | 588 | 612 | 637 | 661 | 686 | 710 | 735 | 759 | 784 | 808 | 833 |
| 775 | 450 | 474 | 498 | 521 | 545 | 569 | 592 | 616 | 640 | 664 | 687 | 711 | 735 | 758 | 782 | 806 |
| 800 | 436 | 459 | 482 | 505 | 528 | 551 | 574 | 597 | 620 | 643 | 666 | 689 | 712 | 735 | 758 | 781 |
| 825 | 423 | 445 | 468 | 490 | 512 | 534 | 557 | 579 | 601 | 623 | 646 | 668 | 690 | 712 | 735 | 757 |
| 850 | 411 | 432 | 454 | 475 | 497 | 519 | 540 | 562 | 583 | 605 | 627 | 648 | 670 | 691 | 713 | 735 |
| 875 | 399 | 420 | 441 | 462 | 483 | 504 | 525 | 546 | 567 | 588 | 609 | 630 | 651 | 672 | 693 | 714 |
| 900 | 388 | 408 | 429 | 449 | 469 | 490 | 510 | 531 | 551 | 571 | 592 | 612 | 633 | 653 | 673 | 694 |
| 925 | 377 | 397 | 417 | 437 | 457 | 477 | 496 | 516 | 536 | 556 | 576 | 596 | 616 | 635 | 655 | 675 |
| 950 | 367 | 387 | 406 | 425 | 445 | 464 | 483 | 503 | 522 | 541 | 561 | 580 | 599 | 619 | 638 | 657 |
| 975 | 358 | 377 | 396. | 414 | 433 | 452 | 471 | 490 | 509 | 527 | 546 | 556 | 584 | 603 | 622 | 640 |
| 1000 | 349 | 367 | 386 | 404 | 422 | 441 | 459 | 478 | 496 | 514 | 533 | 551 | 569 | 588 | 606 | 624 |
| 1025 | 340 | 358 | 376 | 394 | 412 | 430 | 448 | 466 | 484 | 502 | 520 | 538 | 555 | 573 | 591 | 609 |
| 1050 | 332 | 350 | 367 | 385 | 402 | 420 | 437 | 455 | 472 | 490 | 507 | 525 | 542 | 560 | 577 | 595 |
| 1075 | 325. | 342 | 359 | 376 | 393 | 410 | 427 | 444 | 461 | 478 | 495 | 513 | 530 | 547 | 564 | 581 |
| 1100 | 317 | 334 | 351 | 367 | 384 | 401 | 417 | 434 | 451 | 468 | 484 | 501 | 518 | 534 | 551 | 568 |
| 1125 | 310 | 327 | 343 | 359 | 375 | 392 | 408 | 424 | 441 | 457 | 473 | 490 | 506 | 522 | 539 | 555 |
| 1150 | 303 | 319 | 335 | 351 | 367 | 383 | 399 | 415 | 431 | 447 | 463 | 479 | 495 | 511 | 527 | 543 |

$$P = \frac{TS \cdot t \cdot E}{R \cdot FS}$$

TS = Tensile Strength 380,000 kPa
t = Thickness of Cylindrical Component, mm
E = Joint Efficiency 58 %

R = Radius of Shell (inside Diameter/2), mm
FS = Factor of Safety 6
P = MAWP, kPa

Table S2.10.3.1 Metric (Page 1 of 2)
Maximum Allowable Working Pressure for Cylindrical Components (Barrel)
For Single-Riveted Lap Joint

| Shell ID (mm) | Minimum Thickness of Shell Plate (mm) | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 8.75 | 9 | 9.25 | 9.5 | 9.75 | 10 | 10.25 | 10.5 | 10.75 | 11 | 11.25 | 11.5 | 11.75 | 12 | 12.25 | 12.5 |
| 300 | 2143 | 2204 | 2265 | 2326 | 2395 | 2449 | 2510 | 2571 | 2633 | 2694 | 2755 | 2816 | 2877 | 2939 | 3000 | 3061 |
| 325 | 1978 | 2034 | 2091 | 2147 | 2211 | 2261 | 2317 | 2374 | 2430 | 2487 | 2543 | 2600 | 2656 | 2713 | 2769 | 2826 |
| 350 | 1837 | 1889 | 1942 | 1994 | 2053 | 2099 | 2152 | 2204 | 2256 | 2309 | 2361 | 2414 | 2466 | 2519 | 2571 | 2624 |
| 375 | 1714 | 1763 | 1812 | 1861 | 1916 | 1959 | 2008 | 2057 | 2106 | 2155 | 2204 | 2253 | 2302 | 2351 | 2400 | 2449 |
| 400 | 1607 | 1653 | 1699 | 1745 | 1796 | 1837 | 1883 | 1929 | 1974 | 2020 | 2066 | 2112 | 2158 | 2204 | 2250 | 2296 |
| 425 | 1513 | 1556 | 1599 | 1642 | 1691 | 1729 | 1772 | 1815 | 1858 | 1901 | 1945 | 1988 | 2031 | 2074 | 2118 | 2161 |
| 450 | 1429 | 1469 | 1510 | 1551 | 1597 | 1633 | 1673 | 1714 | 1755 | 1796 | 1837 | 1877 | 1918 | 1959 | 2000 | 2041 |
| 475 | 1353 | 1392 | 1431 | 1469 | 1513 | 1547 | 1585 | 1624 | 1663 | 1701 | 1740 | 1779 | 1817 | 1856 | 1895 | 1933 |
| 500 | 1286 | 1322 | 1359 | 1396 | 1437 | 1469 | 1506 | 1543 | 1580 | 1616 | 1653 | 1690 | 1726 | 1763 | 1800 | 1837 |
| 525 | 1224 | 1259 | 1294 | 1329 | 1369 | 1399 | 1434 | 1469 | 1504 | 1539 | 1574 | 1609 | 1644 | 1679 | 1714 | 1749 |
| 550 | 1169 | 1202 | 1236 | 1269 | 1306 | 1336 | 1369 | 1403 | 1436 | 1469 | 1503 | 1536 | 1570 | 1603 | 1636 | 1670 |
| 575 | 1118 | 1150 | 1182 | 1214 | 1250 | 1278 | 1310 | 1342 | 1374 | 1405 | 1437 | 1469 | 1501 | 1533 | 1565 | 1597 |
| 600 | 1071 | 1102 | 1133 | 1163 | 1198 | 1224 | 1255 | 1286 | 1316 | 1347 | 1378 | 1408 | 1439 | 1469 | 1500 | 1531 |
| 625 | 1029 | 1058 | 1087 | 1117 | 1150 | 1175 | 1205 | 1234 | 1264 | 1293 | 1322 | 1352 | 1381 | 1411 | 1440 | 1469 |
| 650 | 989 | 1017 | 1045 | 1074 | 1105 | 1130 | 1159 | 1187 | 1215 | 1243 | 1272 | 1300 | 1328 | 1356 | 1385 | 1413 |
| 675 | 952 | 980 | 1007 | 1034 | 1064 | 1088 | 1116 | 1143 | 1170 | 1197 | 1224 | 1252 | 1279 | 1306 | 1333 | 1360 |
| 700 | 918 | 945 | 971 | 997 | 1026 | 1050 | 1076 | 1102 | 1128 | 1154 | 1181 | 1207 | 1233 | 1259 | 1286 | 1312 |
| 725 | 887 | 912 | 937 | 963 | 991 | 1013 | 1039 | 1064 | 1089 | 1115 | 1140 | 1165 | 1191 | 1216 | 1241 | 1267 |
| 750 | 857 | 882 | 906 | 931 | 958 | 980 | 1004 | 1029 | 1053 | 1078 | 1102 | 1126 | 1151 | 1175 | 1200 | 1224 |
| 775 | 829 | 853 | 877 | 901 | 927 | 948 | 972 | 995 | 1019 | 1043 | 1066 | 1090 | 1114 | 1138 | 1161 | 1185 |
| 800 | 804 | 827 | 849 | 872 | 898 | 918 | 941 | 964 | 987 | 1010 | 1033 | 1056 | 1079 | 1102 | 1125 | 1148 |
| 825 | 779 | 801 | 824 | 846 | 871 | 891 | 913 | 935 | 957 | 980 | 1002 | 1024 | 1046 | 1069 | 1091 | 1113 |
| 850 | 756 | 778 | 799 | 821 | 845 | 864 | 886 | 908 | 929 | 951 | 972 | 994 | 1016 | 1037 | 1059 | 1080 |
| 875 | 735 | 756 | 777 | 798 | 821 | 840 | 861 | 882 | 903 | 924 | 945 | 966 | 987 | 1008 | 1029 | 1050 |
| 900 | 714 | 735 | 755 | 775 | 798 | 816 | 837 | 857 | 878 | 898 | 918 | 939 | 959 | 980 | 1000 | 1020 |
| 925 | 695 | 715 | 735 | 755 | 777 | 794 | 814 | 834 | 854 | 874 | 894 | 913 | 933 | 953 | 973 | 993 |
| 950 | 677 | 696 | 715 | 735 | 756 | 773 | 793 | 812 | 831 | 851 | 870 | 889 | 909 | 928 | 947 | 967 |
| 975 | 659 | 678 | 697 | 716 | 737 | 754 | 772 | 791 | 810 | 829 | 848 | 867 | 885 | 904 | 923 | 942 |
| 1000 | 643 | 661 | 680 | 698 | 719 | 735 | 753 | 771 | 790 | 808 | 827 | 845 | 863 | 882 | 900 | 918 |
| 1025 | 627 | 645 | 663 | 681 | 701 | 717 | 735 | 753 | 771 | 788 | 806 | 824 | 842 | 860 | 878 | 896 |
| 1050 | 612 | 630 | 647 | 665 | 684 | 700 | 717 | 735 | 752 | 770 | 787 | 805 | 822 | 840 | 857 | 875 |
| 1075 | 598 | 615 | 632 | 649 | 668 | 683 | 700 | 718 | 735 | 752 | 769 | 786 | 803 | 820 | 837 | 854 |
| 1100 | 584 | 601 | 618 | 634 | 653 | 668 | 685 | 701 | 718 | 735 | 751 | 768 | 785 | 801 | 818 | 835 |
| 1125 | 571 | 588 | 604 | 620 | 639 | 653 | 669 | 686 | 702 | 718 | 735 | 751 | 767 | 784 | 800 | 816 |
| 1150 | 559 | 575 | 591 | 607 | 625 | 639 | 655 | 671 | 687 | 703 | 719 | 735 | 751 | 767 | 783 | 799 |

$$P = \frac{TS \cdot t \cdot E}{R \cdot FS}$$

TS = Tensile Strength 380,000 kPa
t = Thickness of Cylindrical Component, mm
E = Joint Efficiency 58 %

R = Radius of Shell (inside Diameter/2), mm
FS = Factor of Safety 6
P = MAWP, kPa

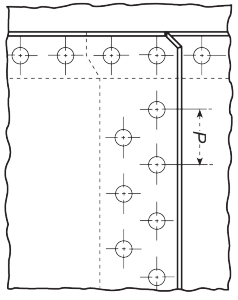
Table S2.10.3.1 Metric (Page 2 of 2)
Maximum Allowable Working Pressure for Cylindrical Components (Barrel)
For Single-Riveted Lap Joint

# TABLE S2.10.3.3

## MAXIMUM ALLOWABLE WORKING PRESSURE FOR CYLINDRICAL COMPONENTS (BARREL)

### For Double-Riveted Lap Joint

| Shell ID | Minimum Thickness of Shell Plate | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0.19 | 0.2 | 0.21 | 0.22 | 0.23 | 0.24 | 0.25 | 0.26 | 0.27 | 0.28 | 0.29 | 0.3 | 0.31 | 0.32 | 0.33 | 0.34 | 0.35 | 0.36 | 0.37 | 0.38 | 0.39 | 0.4 | 0.41 | 0.42 | 0.43 | 0.44 | 0.45 | 0.46 | 0.47 | 0.48 | 0.49 | 0.5 |
| 12 | 215 | 226 | 237 | 249 | 260 | 271 | 283 | 294 | 305 | 317 | 328 | 339 | 350 | 362 | 373 | 384 | 396 | 407 | 418 | 430 | 441 | 452 | 464 | 475 | 486 | 497 | 509 | 520 | 531 | 543 | 554 | 565 |
| 13 | 198 | 209 | 219 | 230 | 240 | 250 | 261 | 271 | 282 | 292 | 303 | 313 | 324 | 334 | 344 | 355 | 365 | 376 | 386 | 397 | 407 | 417 | 428 | 438 | 449 | 459 | 470 | 480 | 490 | 501 | 511 | 522 |
| 14 | 184 | 194 | 204 | 213 | 223 | 233 | 242 | 252 | 262 | 271 | 281 | 291 | 300 | 310 | 320 | 329 | 339 | 349 | 359 | 368 | 378 | 388 | 397 | 407 | 417 | 426 | 436 | 446 | 455 | 465 | 475 | 485 |
| 15 | 172 | 181 | 190 | 199 | 208 | 217 | 226 | 235 | 244 | 253 | 262 | 271 | 280 | 289 | 298 | 308 | 317 | 326 | 335 | 344 | 353 | 362 | 371 | 380 | 389 | 398 | 407 | 416 | 425 | 434 | 443 | 452 |
| 16 | 161 | 170 | 178 | 187 | 195 | 204 | 212 | 220 | 229 | 237 | 246 | 254 | 263 | 271 | 280 | 288 | 297 | 305 | 314 | 322 | 331 | 339 | 348 | 356 | 365 | 373 | 382 | 390 | 399 | 407 | 415 | 424 |
| 17 | 152 | 160 | 168 | 176 | 184 | 192 | 200 | 207 | 215 | 223 | 231 | 239 | 247 | 255 | 263 | 271 | 279 | 287 | 295 | 303 | 311 | 319 | 327 | 335 | 343 | 351 | 359 | 367 | 375 | 383 | 391 | 399 |
| 18 | 143 | 151 | 158 | 166 | 173 | 181 | 188 | 196 | 204 | 211 | 219 | 226 | 234 | 241 | 249 | 256 | 264 | 271 | 279 | 286 | 294 | 301 | 309 | 317 | 324 | 332 | 339 | 347 | 354 | 362 | 369 | 377 |
| 19 | 136 | 143 | 150 | 157 | 164 | 171 | 179 | 186 | 193 | 200 | 207 | 214 | 221 | 228 | 236 | 243 | 250 | 257 | 264 | 271 | 278 | 286 | 293 | 300 | 307 | 314 | 321 | 328 | 336 | 343 | 350 | 357 |
| 20 | 129 | 136 | 142 | 149 | 156 | 163 | 170 | 176 | 183 | 190 | 197 | 204 | 210 | 217 | 224 | 231 | 237 | 244 | 251 | 258 | 265 | 271 | 278 | 285 | 292 | 298 | 305 | 312 | 319 | 326 | 332 | 339 |
| 21 | 123 | 129 | 136 | 142 | 149 | 155 | 162 | 168 | 174 | 181 | 187 | 194 | 200 | 207 | 213 | 220 | 226 | 233 | 239 | 245 | 252 | 258 | 265 | 271 | 278 | 284 | 291 | 297 | 304 | 310 | 317 | 323 |
| 22 | 117 | 123 | 130 | 136 | 142 | 148 | 154 | 160 | 167 | 173 | 179 | 185 | 191 | 197 | 204 | 210 | 216 | 222 | 228 | 234 | 241 | 247 | 253 | 259 | 265 | 271 | 278 | 284 | 209 | 296 | 302 | 308 |
| 23 | 112 | 118 | 124 | 130 | 136 | 142 | 147 | 153 | 159 | 165 | 171 | 177 | 183 | 189 | 195 | 201 | 206 | 212 | 218 | 224 | 230 | 236 | 242 | 248 | 254 | 260 | 265 | 271 | 277 | 283 | 289 | 295 |
| 24 | 107 | 113 | 119 | 124 | 130 | 136 | 141 | 147 | 153 | 158 | 164 | 170 | 175 | 181 | 187 | 192 | 198 | 204 | 209 | 215 | 220 | 226 | 232 | 237 | 243 | 249 | 254 | 260 | 266 | 271 | 277 | 283 |
| 25 | 103 | 109 | 114 | 119 | 125 | 130 | 136 | 141 | 147 | 152 | 157 | 163 | 168 | 174 | 179 | 185 | 190 | 195 | 201 | 206 | 212 | 217 | 222 | 228 | 233 | 239 | 244 | 250 | 255 | 260 | 266 | 271 |
| 26 | 99 | 104 | 110 | 115 | 120 | 125 | 130 | 136 | 141 | 146 | 151 | 157 | 162 | 167 | 172 | 177 | 183 | 188 | 193 | 198 | 204 | 209 | 214 | 219 | 224 | 230 | 235 | 240 | 245 | 250 | 256 | 261 |
| 27 | 95 | 100 | 106 | 111 | 116 | 121 | 126 | 131 | 136 | 141 | 146 | 151 | 156 | 161 | 166 | 171 | 176 | 181 | 186 | 191 | 196 | 201 | 206 | 211 | 216 | 221 | 226 | 231 | 236 | 241 | 246 | 251 |
| 28 | 92 | 97 | 102 | 107 | 111 | 116 | 121 | 126 | 131 | 136 | 141 | 145 | 150 | 155 | 160 | 165 | 170 | 174 | 179 | 184 | 189 | 194 | 199 | 204 | 208 | 213 | 218 | 223 | 228 | 233 | 237 | 242 |
| 29 | 89 | 94 | 98 | 103 | 108 | 112 | 117 | 122 | 126 | 131 | 136 | 140 | 145 | 150 | 154 | 159 | 164 | 168 | 173 | 178 | 182 | 187 | 192 | 196 | 201 | 206 | 211 | 215 | 220 | 225 | 229 | 234 |
| 30 | 86 | 90 | 95 | 99 | 104 | 109 | 113 | 118 | 122 | 127 | 131 | 136 | 140 | 145 | 149 | 154 | 158 | 163 | 167 | 172 | 176 | 181 | 185 | 190 | 194 | 199 | 204 | 208 | 213 | 217 | 222 | 226 |
| 31 | 83 | 88 | 92 | 96 | 101 | 105 | 109 | 114 | 118 | 123 | 127 | 131 | 136 | 140 | 144 | 149 | 153 | 158 | 162 | 166 | 171 | 175 | 179 | 184 | 188 | 193 | 197 | 201 | 206 | 210 | 214 | 219 |
| 32 | 81 | 85 | 89 | 93 | 98 | 102 | 106 | 110 | 114 | 119 | 123 | 127 | 131 | 136 | 140 | 144 | 148 | 153 | 157 | 161 | 165 | 170 | 174 | 178 | 182 | 187 | 191 | 195 | 199 | 204 | 208 | 212 |
| 33 | 78 | 82 | 86 | 90 | 95 | 99 | 103 | 107 | 111 | 115 | 119 | 123 | 127 | 132 | 136 | 140 | 144 | 148 | 152 | 156 | 160 | 164 | 169 | 173 | 177 | 181 | 185 | 189 | 193 | 197 | 201 | 206 |
| 34 | 76 | 80 | 84 | 88 | 92 | 96 | 100 | 104 | 108 | 112 | 116 | 120 | 124 | 128 | 132 | 136 | 140 | 144 | 148 | 152 | 156 | 160 | 164 | 168 | 172 | 176 | 180 | 184 | 188 | 192 | 196 | 200 |
| 35 | 74 | 78 | 81 | 85 | 89 | 93 | 97 | 101 | 105 | 109 | 112 | 116 | 120 | 124 | 128 | 132 | 136 | 140 | 143 | 147 | 151 | 155 | 159 | 163 | 167 | 171 | 174 | 178 | 182 | 186 | 190 | 194 |
| 36 | 72 | 75 | 79 | 83 | 87 | 90 | 94 | 98 | 102 | 106 | 109 | 113 | 117 | 121 | 124 | 128 | 132 | 136 | 139 | 143 | 147 | 151 | 155 | 158 | 162 | 166 | 170 | 173 | 177 | 181 | 185 | 188 |
| 37 | 70 | 73 | 77 | 81 | 84 | 88 | 92 | 95 | 99 | 103 | 106 | 110 | 114 | 117 | 121 | 125 | 128 | 132 | 136 | 139 | 143 | 147 | 150 | 154 | 158 | 161 | 165 | 169 | 172 | 176 | 180 | 183 |
| 38 | 68 | 71 | 75 | 79 | 82 | 86 | 89 | 93 | 96 | 100 | 104 | 107 | 111 | 114 | 118 | 121 | 125 | 129 | 132 | 136 | 139 | 143 | 146 | 150 | 154 | 157 | 161 | 164 | 168 | 171 | 175 | 179 |
| 39 | 66 | 70 | 73 | 77 | 80 | 83 | 87 | 90 | 94 | 97 | 101 | 104 | 108 | 111 | 115 | 118 | 122 | 125 | 129 | 132 | 136 | 139 | 143 | 146 | 150 | 153 | 157 | 160 | 163 | 167 | 170 | 174 |
| 40 | 64 | 68 | 71 | 75 | 78 | 81 | 85 | 88 | 92 | 95 | 98 | 102 | 105 | 109 | 112 | 115 | 119 | 122 | 125 | 129 | 132 | 136 | 139 | 142 | 146 | 149 | 153 | 156 | 159 | 163 | 166 | 170 |
| 41 | 63 | 66 | 69 | 73 | 76 | 79 | 83 | 86 | 89 | 93 | 96 | 99 | 103 | 106 | 109 | 113 | 116 | 119 | 122 | 126 | 129 | 132 | 136 | 139 | 142 | 146 | 149 | 152 | 156 | 159 | 162 | 165 |
| 42 | 61 | 65 | 68 | 71 | 74 | 78 | 81 | 84 | 87 | 90 | 94 | 97 | 100 | 103 | 107 | 110 | 113 | 116 | 120 | 123 | 126 | 129 | 132 | 136 | 139 | 142 | 145 | 149 | 152 | 155 | 158 | 162 |
| 43 | 60 | 63 | 66 | 69 | 73 | 76 | 79 | 82 | 85 | 88 | 91 | 95 | 98 | 101 | 104 | 107 | 110 | 114 | 117 | 120 | 123 | 126 | 129 | 133 | 136 | 139 | 142 | 145 | 148 | 151 | 155 | 158 |
| 44 | 59 | 62 | 65 | 68 | 71 | 74 | 77 | 80 | 83 | 86 | 89 | 93 | 96 | 99 | 102 | 105 | 108 | 111 | 114 | 117 | 120 | 123 | 126 | 130 | 133 | 136 | 139 | 142 | 145 | 148 | 151 | 154 |
| 45 | 57 | 60 | 63 | 66 | 69 | 72 | 75 | 78 | 81 | 84 | 87 | 90 | 93 | 96 | 99 | 103 | 106 | 109 | 112 | 115 | 118 | 121 | 124 | 127 | 130 | 133 | 136 | 139 | 142 | 145 | 148 | 151 |




**TS = Tensile Strength (55,000)**

**t = Thickness of Cylindrical Component**

**TS x t x E/R x FS**

**R = Radius of Shell (inside diameter/2)**

**E = Joint Efficiency (74%)**

**FS = Factor of Safety (6)**

| Shell ID (mm) | Minimum Thickness of Shell Plate (mm) | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 4.75 | 5 | 5.25 | 5.5 | 5.75 | 6 | 6.25 | 6.5 | 6.75 | 7 | 7.25 | 7.5 | 7.75 | 8 | 8.25 | **8.5** |
| 300 | **1484** | **1562** | **1640** | **1718** | **1797** | **1875** | **1953** | **2031** | **2109** | **2187** | **2265** | **2343** | **2421** | **2500** | **2578** | **2656** |
| 325 | **1370** | **1442** | **1514** | **1586** | **1658** | **1730** | **1803** | **1875** | **1947** | **2019** | **2091** | **2163** | **2235** | **2307** | **2379** | **2451** |
| 350 | **1272** | **1339** | **1406** | **1473** | **1540** | **1607** | **1674** | **1741** | **1808** | **1875** | **1942** | **2009** | **2076** | **2142** | **2209** | **2276** |
| 375 | **1187** | **1250** | **1312** | **1375** | **1437** | **1500** | **1562** | **1625** | **1687** | **1750** | **1812** | **1875** | **1937** | **2000** | **2062** | **2125** |
| 400 | **1113** | **1172** | **1230** | **1289** | **1347** | **1406** | **1465** | **1523** | **1582** | **1640** | **1699** | **1758** | **1816** | **1875** | **1933** | **1992** |
| 425 | **1048** | **1103** | **1158** | **1213** | **1268** | **1323** | **1378** | **1434** | **1489** | **1544** | **1599** | **1654** | **1709** | **1764** | **1820** | **1875** |
| 450 | **989** | **1041** | **1094** | **1146** | **1198** | **1250** | **1302** | **1354** | **1406** | **1458** | **1510** | **1562** | **1614** | **1666** | **1718** | **1771** |
| 475 | **937** | **987** | **1036** | **1085** | **1135** | **1184** | **1233** | **1283** | **1332** | **1381** | **1431** | **1480** | **1529** | **1579** | **1628** | **1677** |
| 500 | **890** | **937** | **984** | **1031** | **1078** | **1125** | **1172** | **1219** | **1265** | **1312** | **1359** | **1406** | **1453** | **1500** | **1547** | **1593** |
| 525 | **848** | **893** | **937** | **982** | **1027** | **1071** | **1116** | **1161** | **1205** | **1250** | **1294** | **1339** | **1384** | **1428** | **1473** | **1518** |
| 550 | **810** | **852** | **895** | **937** | **980** | **1023** | **1065** | **1108** | **1150** | **1193** | **1236** | **1278** | **1321** | **1363** | **1406** | **1449** |
| 575 | **774** | **815** | **856** | **897** | **937** | **978** | **1019** | **1060** | **1100** | **1141** | **1182** | **1223** | **1263** | **1304** | **1345** | **1386** |
| 600 | **742** | **781** | **820** | **859** | **898** | **937** | **976** | **1015** | **1055** | **1094** | **1133** | **1172** | **1211** | **1250** | **1289** | **1328** |
| 625 | **712** | **750** | **787** | **825** | **862** | **900** | **937** | **975** | **1012** | **1050** | **1087** | **1125** | **1162** | **1200** | **1237** | **1275** |
| 650 | **685** | **721** | **757** | **793** | **829** | **865** | **901** | **937** | **973** | **1009** | **1045** | **1082** | **1118** | **1154** | **1190** | **1226** |
| 675 | **660** | **694** | **729** | **764** | **798** | **833** | **868** | **903** | **937** | **972** | **1007** | **1041** | **1076** | **1111** | **1146** | **1180** |
| 700 | **636** | **670** | **703** | **736** | **770** | **803** | **837** | **870** | **904** | **937** | **971** | **1004** | **1038** | **1071** | **1105** | **1138** |
| 725 | **614** | **646** | **679** | **711** | **743** | **776** | **808** | **840** | **873** | **905** | **937** | **970** | **1002** | **1034** | **1067** | **1099** |
| 750 | **594** | **625** | **656** | **687** | **719** | **750** | **781** | **812** | **844** | **875** | **906** | **937** | **969** | **1000** | **1031** | **1062** |
| 775 | **574** | **605** | **635** | **665** | **695** | **726** | **756** | **786** | **816** | **847** | **877** | **907** | **937** | **968** | **998** | **1028** |
| 800 | **557** | **586** | **615** | **644** | **674** | **703** | **732** | **762** | **791** | **820** | **849** | **879** | **908** | **937** | **967** | **996** |
| 825 | **540** | **568** | **596** | **625** | **653** | **682** | **710** | **739** | **767** | **795** | **824** | **852** | **881** | **909** | **937** | **966** |
| 850 | **524** | **551** | **579** | **607** | **634** | **662** | **689** | **717** | **744** | **772** | **799** | **827** | **855** | **882** | **910** | **937** |
| 875 | **509** | **536** | **562** | **589** | **616** | **643** | **670** | **696** | **723** | **750** | **777** | **803** | **830** | **857** | **884** | **911** |
| 900 | **495** | **521** | **547** | **573** | **599** | **625** | **651** | **677** | **703** | **729** | **755** | **781** | **807** | **833** | **859** | **885** |
| 925 | **481** | **507** | **532** | **557** | **583** | **608** | **633** | **659** | **684** | **709** | **735** | **760** | **785** | **811** | **836** | **861** |
| 950 | **469** | **493** | **518** | **543** | **567** | **592** | **617** | **641** | **666** | **691** | **715** | **740** | **765** | **789** | **814** | **839** |
| 975 | **457** | **481** | **505** | **529** | **553** | **577** | **601** | **625** | **649** | **673** | **697** | **721** | **745** | **769** | **793** | **817** |
| 1000 | **445** | **469** | **492** | **516** | **539** | **562** | **586** | **609** | **633** | **656** | **680** | **703** | **726** | **750** | **773** | **797** |
| 1025 | **434** | **457** | **480** | **503** | **526** | **549** | **572** | **594** | **617** | **640** | **663** | **686** | **709** | **732** | **754** | **777** |
| 1050 | **424** | **446** | **469** | **491** | **513** | **536** | **558** | **580** | **603** | **625** | **647** | **670** | **692** | **714** | **736** | **759** |
| 1075 | **414** | **436** | **458** | **480** | **501** | **523** | **545** | **567** | **589** | **610** | **632** | **654** | **676** | **698** | **719** | **741** |
| 1100 | **405** | **426** | **447** | **469** | **490** | **511** | **533** | **554** | **575** | **596** | **618** | **639** | **660** | **682** | **703** | **724** |
| 1125 | **396** | **417** | **437** | **458** | **479** | **500** | **521** | **542** | **562** | **583** | **604** | **625** | **646** | **667** | **687** | **708** |
| 1150 | **387** | **408** | **428** | **448** | **469** | **489** | **509** | **530** | **550** | **571** | **591** | **611** | **632** | **652** | **672** | **693** |

$$P = \frac{TS \cdot t \cdot E}{R \cdot FS}$$

R = Radius of Shell (inside Diameter/2), mm
FS = Factor of Safety 6
P = MAWP, kPa

TS = Tensile Strength 380,000 kPa
t = Thickness of Cylindrical Component, mm
E = Joint Efficiency 74 %

Table S2.10.3.2 Metric (Page 1 of 2)
Maximum Allowable Working Pressure for Cylindrical Components (Barrel)
For Double-Riveted Lap Joint

| Shell ID (mm) | Minimum Thickness of Shell Plate (mm) | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 8.75 | 9 | 9.25 | 9.5 | 9.75 | 10 | 10.25 | 10.5 | 10.75 | 11 | 11.25 | 11.5 | 11.75 | 12 | 12.25 | 12.5 |
| 300 | 2734 | 2812 | 2890 | 2968 | 3056 | 3124 | 3203 | 3281 | 3359 | 3437 | 3515 | 3593 | 3671 | 3749 | 3827 | 3906 |
| 325 | 2524 | 2596 | 2668 | 2740 | 2821 | 2884 | 2956 | 3028 | 3100 | 3173 | 3245 | 3317 | 3389 | 3461 | 3533 | 3605 |
| 350 | 2343 | 2410 | 2477 | 2544 | 2619 | 2678 | 2745 | 2812 | 2879 | 2946 | 3013 | 3080 | 3147 | 3214 | 3281 | 3348 |
| 375 | 2187 | 2250 | 2312 | 2375 | 2445 | 2500 | 2562 | 2625 | 2687 | 2750 | 2812 | 2874 | 2937 | 2999 | 3062 | 3124 |
| 400 | 2050 | 2109 | 2168 | 2226 | 2292 | 2343 | 2402 | 2461 | 2519 | 2578 | 2636 | 2695 | 2753 | 2812 | 2871 | 2929 |
| 425 | 1930 | 1985 | 2040 | 2095 | 2157 | 2205 | 2261 | 2316 | 2371 | 2426 | 2481 | 2536 | 2591 | 2647 | 2702 | 2757 |
| 450 | 1823 | 1875 | 1927 | 1979 | 2037 | 2083 | 2135 | 2187 | 2239 | 2291 | 2343 | 2395 | 2447 | 2500 | 2552 | 2604 |
| 475 | 1727 | 1776 | 1825 | 1875 | 1930 | 1973 | 2023 | 2072 | 2121 | 2171 | 2220 | 2269 | 2319 | 2368 | 2417 | 2467 |
| 500 | 1640 | 1687 | 1734 | 1781 | 1833 | 1875 | 1922 | 1968 | 2015 | 2062 | 2109 | 2156 | 2203 | 2250 | 2296 | 2343 |
| 525 | 1562 | 1607 | 1651 | 1696 | 1746 | 1785 | 1830 | 1875 | 1919 | 1964 | 2009 | 2053 | 2098 | 2142 | 2187 | 2232 |
| 550 | 1491 | 1534 | 1576 | 1619 | 1667 | 1704 | 1747 | 1789 | 1832 | 1875 | 1917 | 1960 | 2002 | 2045 | 2088 | 2130 |
| 575 | 1426 | 1467 | 1508 | 1549 | 1594 | 1630 | 1671 | 1712 | 1752 | 1793 | 1834 | 1875 | 1915 | 1956 | 1997 | 2038 |
| 600 | 1367 | 1406 | 1445 | 1484 | 1528 | 1562 | 1601 | 1640 | 1679 | 1718 | 1758 | 1797 | 1836 | 1875 | 1914 | 1953 |
| 625 | 1312 | 1350 | 1387 | 1425 | 1467 | 1500 | 1537 | 1575 | 1612 | 1650 | 1687 | 1725 | 1762 | 1800 | 1837 | 1875 |
| 650 | 1262 | 1298 | 1334 | 1370 | 1410 | 1442 | 1478 | 1514 | 1550 | 1586 | 1622 | 1658 | 1694 | 1730 | 1767 | 1803 |
| 675 | 1215 | 1250 | 1284 | 1319 | 1358 | 1389 | 1423 | 1458 | 1493 | 1528 | 1562 | 1597 | 1632 | 1666 | 1701 | 1736 |
| 700 | 1172 | 1205 | 1239 | 1272 | 1310 | 1339 | 1373 | 1406 | 1439 | 1473 | 1506 | 1540 | 1573 | 1607 | 1640 | 1674 |
| 725 | 1131 | 1164 | 1196 | 1228 | 1264 | 1293 | 1325 | 1358 | 1390 | 1422 | 1454 | 1487 | 1519 | 1551 | 1584 | 1616 |
| 750 | 1094 | 1125 | 1156 | 1187 | 1222 | 1250 | 1281 | 1312 | 1344 | 1375 | 1406 | 1437 | 1468 | 1500 | 1531 | 1562 |
| 775 | 1058 | 1089 | 1119 | 1149 | 1183 | 1209 | 1240 | 1270 | 1300 | 1330 | 1361 | 1391 | 1421 | 1451 | 1482 | 1512 |
| 800 | 1025 | 1055 | 1084 | 1113 | 1146 | 1172 | 1201 | 1230 | 1260 | 1289 | 1318 | 1347 | 1377 | 1406 | 1435 | 1465 |
| 825 | 994 | 1023 | 1051 | 1079 | 1111 | 1136 | 1165 | 1193 | 1221 | 1250 | 1278 | 1307 | 1335 | 1363 | 1392 | 1420 |
| 850 | 965 | 992 | 1020 | 1048 | 1078 | 1103 | 1130 | 1158 | 1185 | 1213 | 1241 | 1268 | 1296 | 1323 | 1351 | 1378 |
| 875 | 937 | 964 | 991 | 1018 | 1048 | 1071 | 1098 | 1125 | 1152 | 1178 | 1205 | 1232 | 1259 | 1285 | 1312 | 1339 |
| 900 | 911 | 937 | 963 | 989 | 1019 | 1041 | 1068 | 1094 | 1120 | 1146 | 1172 | 1198 | 1224 | 1250 | 1276 | 1302 |
| 925 | 887 | 912 | 937 | 963 | 991 | 1013 | 1039 | 1064 | 1089 | 1115 | 1140 | 1165 | 1191 | 1216 | 1241 | 1267 |
| 950 | 863 | 888 | 913 | 937 | 965 | 987 | 1011 | 1036 | 1061 | 1085 | 1110 | 1135 | 1159 | 1184 | 1209 | 1233 |
| 975 | 841 | 865 | 889 | 913 | 940 | 961 | 985 | 1009 | 1033 | 1058 | 1082 | 1106 | 1130 | 1154 | 1178 | 1202 |
| 1000 | 820 | 844 | 867 | 890 | 917 | 937 | 961 | 984 | 1008 | 1031 | 1055 | 1078 | 1101 | 1125 | 1148 | 1172 |
| 1025 | 800 | 823 | 846 | 869 | 894 | 914 | 937 | 960 | 983 | 1006 | 1029 | 1052 | 1075 | 1097 | 1120 | 1143 |
| 1050 | 781 | 803 | 826 | 848 | 873 | 893 | 915 | 937 | 960 | 982 | 1004 | 1027 | 1049 | 1071 | 1094 | 1116 |
| 1075 | 763 | 785 | 807 | 828 | 853 | 872 | 894 | 916 | 937 | 959 | 981 | 1003 | 1025 | 1046 | 1068 | 1090 |
| 1100 | 746 | 767 | 788 | 810 | 833 | 852 | 873 | 895 | 916 | 937 | 959 | 980 | 1001 | 1023 | 1044 | 1065 |
| 1125 | 729 | 750 | 771 | 792 | 815 | 833 | 854 | 875 | 896 | 917 | 937 | 958 | 979 | 1000 | 1021 | 1041 |
| 1150 | 713 | 734 | 754 | 774 | 797 | 815 | 835 | 856 | 876 | 897 | 917 | 937 | 958 | 978 | 998 | 1019 |

$$P = \frac{TS \cdot t \cdot E}{R \cdot FS}$$

TS = Tensile Strength 380,000 kPa
t = Thickness of Cylindrical Component, mm
E = Joint Efficiency 74 %

R = Radius of Shell (inside Diameter/2), mm
FS = Factor of Safety 6
P = MAWP, kPa

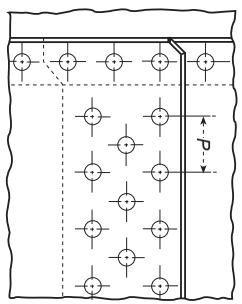
Table S2.10.3.2 Metric (Page 2 of 2)
Maximum Allowable Working Pressure for Cylindrical Components (Barrel)
For Double-Riveted Lap Joint

# TABLE S2.10.3.4

## MAXIMUM ALLOWABLE WORKING PRESSURE FOR CYLINDRICAL COMPONENTS (BARREL)

**For Triple-Riveted Lap Joint**

| Shell ID | Minimum Thickness of Shell Plate | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0.19 | 0.2 | 0.21 | 0.22 | 0.23 | 0.24 | 0.25 | 0.26 | 0.27 | 0.28 | 0.29 | 0.3 | 0.31 | 0.32 | 0.33 | 0.34 | 0.35 | 0.36 | 0.37 | 0.38 | 0.39 | 0.4 | 0.41 | 0.42 | 0.43 | 0.44 | 0.45 | 0.46 | 0.47 | 0.48 | 0.49 | 0.5 |
| 12 | 226 | 238 | 250 | 262 | 274 | 286 | 298 | 310 | 322 | 334 | 346 | 358 | 369 | 381 | 393 | 405 | 417 | 429 | 441 | 453 | 465 | 477 | 489 | 501 | 512 | 524 | 536 | 548 | 560 | 572 | 584 | 596 |
| 13 | 209 | 220 | 231 | 242 | 253 | 264 | 275 | 286 | 297 | 308 | 319 | 330 | 341 | 352 | 363 | 374 | 385 | 396 | 407 | 418 | 429 | 440 | 451 | 462 | 473 | 484 | 495 | 506 | 517 | 528 | 539 | 550 |
| 14 | 194 | 204 | 215 | 225 | 235 | 245 | 255 | 266 | 276 | 286 | 296 | 306 | 317 | 327 | 337 | 347 | 358 | 368 | 378 | 388 | 398 | 409 | 419 | 429 | 439 | 449 | 460 | 470 | 480 | 490 | 501 | 511 |
| 15 | 181 | 191 | 200 | 210 | 219 | 229 | 238 | 248 | 257 | 267 | 276 | 286 | 296 | 305 | 315 | 324 | 334 | 343 | 353 | 362 | 372 | 381 | 391 | 400 | 410 | 419 | 429 | 439 | 448 | 458 | 467 | 477 |
| 16 | 170 | 179 | 188 | 197 | 206 | 215 | 223 | 232 | 241 | 250 | 259 | 268 | 277 | 286 | 295 | 304 | 313 | 322 | 331 | 340 | 349 | 358 | 366 | 375 | 384 | 393 | 402 | 411 | 420 | 429 | 438 | 447 |
| 17 | 160 | 168 | 177 | 185 | 193 | 202 | 210 | 219 | 227 | 236 | 244 | 252 | 261 | 269 | 278 | 286 | 294 | 303 | 311 | 320 | 328 | 336 | 345 | 353 | 362 | 370 | 379 | 387 | 395 | 404 | 412 | 421 |
| 18 | 151 | 159 | 167 | 175 | 183 | 191 | 199 | 207 | 215 | 222 | 230 | 238 | 246 | 254 | 262 | 270 | 278 | 286 | 294 | 302 | 310 | 318 | 326 | 334 | 342 | 350 | 358 | 365 | 373 | 381 | 389 | 397 |
| 19 | 143 | 151 | 158 | 166 | 173 | 181 | 188 | 196 | 203 | 211 | 218 | 226 | 233 | 241 | 248 | 256 | 263 | 271 | 278 | 286 | 294 | 301 | 309 | 316 | 324 | 331 | 339 | 346 | 354 | 361 | 369 | 376 |
| 20 | 136 | 143 | 150 | 157 | 164 | 172 | 179 | 186 | 193 | 200 | 207 | 215 | 222 | 229 | 236 | 243 | 250 | 257 | 265 | 272 | 279 | 286 | 293 | 300 | 307 | 315 | 322 | 329 | 336 | 343 | 350 | 358 |
| 21 | 129 | 136 | 143 | 150 | 157 | 163 | 170 | 177 | 184 | 191 | 197 | 204 | 211 | 218 | 225 | 232 | 238 | 245 | 252 | 259 | 266 | 272 | 279 | 286 | 293 | 300 | 306 | 313 | 320 | 327 | 334 | 340 |
| 22 | 124 | 130 | 137 | 143 | 150 | 156 | 163 | 169 | 176 | 182 | 189 | 195 | 202 | 208 | 215 | 221 | 228 | 234 | 241 | 247 | 254 | 260 | 267 | 273 | 280 | 286 | 293 | 299 | 306 | 312 | 319 | 325 |
| 23 | 118 | 124 | 131 | 137 | 143 | 149 | 155 | 162 | 168 | 174 | 180 | 187 | 193 | 199 | 205 | 211 | 218 | 224 | 230 | 236 | 242 | 249 | 255 | 261 | 267 | 274 | 280 | 286 | 292 | 298 | 305 | 311 |
| 24 | 113 | 119 | 125 | 131 | 137 | 143 | 149 | 155 | 161 | 167 | 173 | 179 | 185 | 191 | 197 | 203 | 209 | 215 | 220 | 226 | 232 | 238 | 244 | 250 | 256 | 262 | 268 | 274 | 280 | 286 | 292 | 298 |
| 25 | 109 | 114 | 120 | 126 | 132 | 137 | 143 | 149 | 154 | 160 | 166 | 172 | 177 | 183 | 189 | 194 | 200 | 206 | 212 | 217 | 223 | 229 | 235 | 240 | 246 | 252 | 257 | 263 | 269 | 275 | 280 | 286 |
| 26 | 105 | 110 | 116 | 121 | 127 | 132 | 138 | 143 | 149 | 154 | 160 | 165 | 171 | 176 | 182 | 187 | 193 | 198 | 204 | 209 | 215 | 220 | 226 | 231 | 237 | 242 | 248 | 253 | 259 | 264 | 270 | 275 |
| 27 | 101 | 106 | 111 | 117 | 122 | 127 | 132 | 138 | 143 | 148 | 154 | 159 | 164 | 169 | 175 | 180 | 185 | 191 | 196 | 201 | 207 | 212 | 217 | 222 | 228 | 233 | 238 | 244 | 249 | 254 | 260 | 265 |
| 28 | 97 | 102 | 107 | 112 | 117 | 123 | 128 | 133 | 138 | 143 | 148 | 153 | 158 | 163 | 169 | 174 | 179 | 184 | 189 | 194 | 199 | 204 | 209 | 215 | 220 | 225 | 230 | 235 | 240 | 245 | 250 | 255 |
| 29 | 94 | 99 | 104 | 108 | 113 | 118 | 123 | 128 | 133 | 138 | 143 | 148 | 153 | 158 | 163 | 168 | 173 | 178 | 182 | 187 | 192 | 197 | 202 | 207 | 212 | 217 | 222 | 227 | 232 | 237 | 242 | 247 |
| 30 | 91 | 95 | 100 | 105 | 110 | 114 | 119 | 124 | 129 | 133 | 138 | 143 | 148 | 153 | 157 | 162 | 167 | 172 | 176 | 181 | 186 | 191 | 195 | 200 | 205 | 210 | 215 | 219 | 224 | 229 | 234 | 238 |
| 31 | 88 | 92 | 97 | 101 | 106 | 111 | 115 | 120 | 125 | 129 | 134 | 138 | 143 | 148 | 152 | 157 | 161 | 166 | 171 | 175 | 180 | 185 | 189 | 194 | 198 | 203 | 208 | 212 | 217 | 221 | 226 | 231 |
| 32 | 85 | 89 | 94 | 98 | 103 | 107 | 112 | 116 | 121 | 125 | 130 | 134 | 139 | 143 | 147 | 152 | 156 | 161 | 165 | 170 | 174 | 179 | 183 | 188 | 192 | 197 | 201 | 206 | 210 | 215 | 219 | 223 |
| 33 | 82 | 87 | 91 | 95 | 100 | 104 | 108 | 113 | 117 | 121 | 126 | 130 | 134 | 139 | 143 | 147 | 152 | 156 | 160 | 165 | 169 | 173 | 178 | 182 | 186 | 191 | 195 | 199 | 204 | 208 | 212 | 217 |
| 34 | 80 | 84 | 88 | 93 | 97 | 101 | 105 | 109 | 114 | 118 | 122 | 126 | 130 | 135 | 139 | 143 | 147 | 151 | 156 | 160 | 164 | 168 | 172 | 177 | 181 | 185 | 189 | 193 | 198 | 202 | 206 | 210 |
| 35 | 78 | 82 | 86 | 90 | 94 | 98 | 102 | 106 | 110 | 114 | 118 | 123 | 127 | 131 | 135 | 139 | 143 | 147 | 151 | 155 | 159 | 163 | 168 | 172 | 176 | 180 | 184 | 188 | 192 | 196 | 200 | 204 |
| 36 | 75 | 79 | 83 | 87 | 91 | 95 | 99 | 103 | 107 | 111 | 115 | 119 | 123 | 127 | 131 | 135 | 139 | 143 | 147 | 151 | 155 | 159 | 163 | 167 | 171 | 175 | 179 | 183 | 187 | 191 | 195 | 199 |
| 37 | 73 | 77 | 81 | 85 | 89 | 93 | 97 | 100 | 104 | 108 | 112 | 116 | 120 | 124 | 128 | 131 | 135 | 139 | 143 | 147 | 151 | 155 | 158 | 162 | 166 | 170 | 174 | 178 | 182 | 186 | 189 | 193 |
| 38 | 72 | 75 | 79 | 83 | 87 | 90 | 94 | 98 | 102 | 105 | 109 | 113 | 117 | 120 | 124 | 128 | 132 | 135 | 139 | 143 | 147 | 151 | 154 | 158 | 162 | 166 | 169 | 173 | 177 | 181 | 184 | 188 |
| 39 | 70 | 73 | 77 | 81 | 84 | 88 | 92 | 95 | 99 | 103 | 106 | 110 | 114 | 117 | 121 | 125 | 128 | 132 | 136 | 139 | 143 | 147 | 150 | 154 | 158 | 161 | 165 | 169 | 172 | 176 | 180 | 183 |
| 40 | 68 | 72 | 75 | 79 | 82 | 86 | 89 | 93 | 97 | 100 | 104 | 107 | 111 | 114 | 118 | 122 | 125 | 129 | 132 | 136 | 139 | 143 | 147 | 150 | 154 | 157 | 161 | 164 | 168 | 172 | 175 | 179 |
| 41 | 66 | 70 | 73 | 77 | 80 | 84 | 87 | 91 | 94 | 98 | 101 | 105 | 108 | 112 | 115 | 119 | 122 | 126 | 129 | 133 | 136 | 140 | 143 | 146 | 150 | 153 | 157 | 160 | 164 | 167 | 171 | 174 |
| 42 | 65 | 68 | 72 | 75 | 78 | 82 | 85 | 89 | 92 | 95 | 99 | 102 | 106 | 109 | 112 | 116 | 119 | 123 | 126 | 129 | 133 | 136 | 140 | 143 | 146 | 150 | 153 | 157 | 160 | 163 | 167 | 170 |
| 43 | 63 | 67 | 70 | 73 | 76 | 80 | 83 | 86 | 90 | 93 | 96 | 100 | 103 | 106 | 110 | 113 | 116 | 120 | 123 | 126 | 130 | 133 | 136 | 140 | 143 | 146 | 150 | 153 | 156 | 160 | 163 | 166 |
| 44 | 62 | 65 | 68 | 72 | 75 | 78 | 81 | 85 | 88 | 91 | 94 | 98 | 101 | 104 | 107 | 111 | 114 | 117 | 120 | 124 | 127 | 130 | 133 | 137 | 140 | 143 | 146 | 150 | 153 | 156 | 159 | 163 |
| 45 | 60 | 64 | 67 | 70 | 73 | 76 | 79 | 83 | 86 | 89 | 92 | 95 | 99 | 102 | 105 | 108 | 111 | 114 | 118 | 121 | 124 | 127 | 130 | 133 | 137 | 140 | 143 | 146 | 149 | 153 | 156 | 159 |




**TS = Tensile Strength (55,000)**

**t = Thickness of Cylindrical Component**

**TS x t x E/R x FS**

**R = Radius of Shell (inside diameter/2)**

**E = Joint Efficiency (78%)**

**FS = Factor of Safety (6)**

| Shell ID (mm) | Minimum Thickness of Shell Plate (mm) | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 4.75 | 5 | 5.25 | 5.5 | 5.75 | 6 | 6.25 | 6.5 | 6.75 | 7 | 7.25 | 7.5 | 7.75 | 8 | 8.25 | 8.5 |
| 300 | 1564 | 1647 | 1729 | 1811 | 1894 | 1976 | 2058 | 2141 | 2223 | 2305 | 2388 | 2470 | 2552 | 2635 | 2717 | 2799 |
| 325 | 1444 | 1520 | 1596 | 1672 | 1748 | 1824 | 1900 | 1976 | 2052 | 2128 | 2204 | 2280 | 2356 | 2432 | 2508 | 2584 |
| 350 | 1341 | 1411 | 1482 | 1553 | 1623 | 1694 | 1764 | 1835 | 1905 | 1976 | 2047 | 2117 | 2188 | 2258 | 2329 | 2399 |
| 375 | 1251 | 1317 | 1383 | 1449 | 1515 | 1581 | 1647 | 1713 | 1778 | 1844 | 1910 | 1976 | 2042 | 2108 | 2174 | 2239 |
| 400 | 1173 | 1235 | 1297 | 1359 | 1420 | 1482 | 1544 | 1606 | 1667 | 1729 | 1791 | 1853 | 1914 | 1976 | 2038 | 2100 |
| 425 | 1104 | 1162 | 1220 | 1279 | 1337 | 1395 | 1453 | 1511 | 1569 | 1627 | 1685 | 1744 | 1802 | 1860 | 1918 | 1976 |
| 450 | 1043 | 1098 | 1153 | 1208 | 1262 | 1317 | 1372 | 1427 | 1482 | 1537 | 1592 | 1647 | 1702 | 1756 | 1811 | 1866 |
| 475 | 988 | 1040 | 1092 | 1144 | 1196 | 1248 | 1300 | 1352 | 1404 | 1456 | 1508 | 1560 | 1612 | 1664 | 1716 | 1768 |
| 500 | 939 | 988 | 1037 | 1087 | 1136 | 1186 | 1235 | 1284 | 1334 | 1383 | 1433 | 1482 | 1531 | 1581 | 1630 | 1680 |
| 525 | 894 | 941 | 988 | 1035 | 1082 | 1129 | 1176 | 1223 | 1270 | 1317 | 1364 | 1411 | 1458 | 1506 | 1553 | 1600 |
| 550 | 853 | 898 | 943 | 988 | 1033 | 1078 | 1123 | 1168 | 1213 | 1257 | 1302 | 1347 | 1392 | 1437 | 1482 | 1527 |
| 575 | 816 | 859 | 902 | 945 | 988 | 1031 | 1074 | 1117 | 1160 | 1203 | 1246 | 1289 | 1332 | 1375 | 1418 | 1461 |
| 600 | 782 | 823 | 865 | 906 | 947 | 988 | 1029 | 1070 | 1112 | 1153 | 1194 | 1235 | 1276 | 1317 | 1359 | 1400 |
| 625 | 751 | 790 | 830 | 869 | 909 | 948 | 988 | 1028 | 1067 | 1107 | 1146 | 1186 | 1225 | 1265 | 1304 | 1344 |
| 650 | 722 | 760 | 798 | 836 | 874 | 912 | 950 | 988 | 1026 | 1064 | 1102 | 1140 | 1178 | 1216 | 1254 | 1292 |
| 675 | 695 | 732 | 768 | 805 | 842 | 878 | 915 | 951 | 988 | 1025 | 1061 | 1098 | 1134 | 1171 | 1208 | 1244 |
| 700 | 670 | 706 | 741 | 776 | 812 | 847 | 882 | 917 | 953 | 988 | 1023 | 1059 | 1094 | 1129 | 1164 | 1200 |
| 725 | 647 | 681 | 715 | 750 | 784 | 818 | 852 | 886 | 920 | 954 | 988 | 1022 | 1056 | 1090 | 1124 | 1158 |
| 750 | 626 | 659 | 692 | 725 | 757 | 790 | 823 | 856 | 889 | 922 | 955 | 988 | 1021 | 1054 | 1087 | 1120 |
| 775 | 606 | 637 | 669 | 701 | 733 | 765 | 797 | 829 | 861 | 892 | 924 | 956 | 988 | 1020 | 1052 | 1084 |
| 800 | 587 | 618 | 648 | 679 | 710 | 741 | 772 | 803 | 834 | 865 | 895 | 926 | 957 | 988 | 1019 | 1050 |
| 825 | 569 | 599 | 629 | 659 | 689 | 719 | 748 | 778 | 808 | 838 | 868 | 898 | 928 | 958 | 988 | 1018 |
| 850 | 552 | 581 | 610 | 639 | 668 | 697 | 726 | 756 | 785 | 814 | 843 | 872 | 901 | 930 | 959 | 988 |
| 875 | 536 | 565 | 593 | 621 | 649 | 677 | 706 | 734 | 762 | 790 | 819 | 847 | 875 | 903 | 932 | 960 |
| 900 | 521 | 549 | 576 | 604 | 631 | 659 | 686 | 714 | 741 | 768 | 796 | 823 | 851 | 878 | 906 | 933 |
| 925 | 507 | 534 | 561 | 587 | 614 | 641 | 668 | 694 | 721 | 748 | 774 | 801 | 828 | 854 | 881 | 908 |
| 950 | 494 | 520 | 546 | 572 | 598 | 624 | 650 | 676 | 702 | 728 | 754 | 780 | 806 | 832 | 858 | 884 |
| 975 | 481 | 507 | 532 | 557 | 583 | 608 | 633 | 659 | 684 | 709 | 735 | 760 | 785 | 811 | 836 | 861 |
| 1000 | 469 | 494 | 519 | 543 | 568 | 593 | 618 | 642 | 667 | 692 | 716 | 741 | 766 | 790 | 815 | 840 |
| 1025 | 458 | 482 | 506 | 530 | 554 | 578 | 602 | 627 | 651 | 675 | 699 | 723 | 747 | 771 | 795 | 819 |
| 1050 | 447 | 470 | 494 | 518 | 541 | 565 | 588 | 612 | 635 | 659 | 682 | 706 | 729 | 753 | 776 | 800 |
| 1075 | 437 | 460 | 483 | 505 | 528 | 551 | 574 | 597 | 620 | 643 | 666 | 689 | 712 | 735 | 758 | 781 |
| 1100 | 427 | 449 | 472 | 494 | 516 | 539 | 561 | 584 | 606 | 629 | 651 | 674 | 696 | 719 | 741 | 763 |
| 1125 | 417 | 439 | 461 | 483 | 505 | 527 | 549 | 571 | 593 | 615 | 637 | 659 | 681 | 703 | 725 | 746 |
| 1150 | 408 | 430 | 451 | 473 | 494 | 515 | 537 | 558 | 580 | 601 | 623 | 644 | 666 | 687 | 709 | 730 |

$$P = \frac{TS \cdot t \cdot E}{R \cdot FS}$$

TS = Tensile Strength 380,000 kPa
t = Thickness of Cylindrical Component, mm
E = Joint Efficiency 78%

R = Radius of Shell (inside Diameter/2), mm
FS = Factor of Safety 6
P = MAWP, kPa

Table S2.10.3.3 Metric (Page 1 of 2)
Maximum Allowable Working Pressure for Cylindrical Components (Barrel)
For Triple-Riveted Lap Joint

| Shell ID (mm) | Minimum Thickness of Shell Plate (mm) | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 8.75 | 9 | 9.25 | 9.5 | 9.75 | 10 | 10.25 | 10.5 | 10.75 | 11 | 11.25 | 11.5 | 11.75 | 12 | 12.25 | 12.5 |
| 300 | 2882 | 2964 | 3046 | 3129 | 3221 | 3293 | 3376 | 3458 | 3540 | 3623 | 3705 | 3787 | 3870 | 3952 | 4034 | 4117 |
| 325 | 2660 | 2736 | 2812 | 2888 | 2973 | 3040 | 3116 | 3192 | 3268 | 3344 | 3420 | 3496 | 3572 | 3648 | 3724 | 3800 |
| 350 | 2470 | 2541 | 2611 | 2682 | 2761 | 2823 | 2893 | 2964 | 3035 | 3105 | 3176 | 3246 | 3317 | 3387 | 3458 | 3529 |
| 375 | 2305 | 2371 | 2437 | 2503 | 2577 | 2635 | 2701 | 2766 | 2832 | 2898 | 2964 | 3030 | 3096 | 3162 | 3227 | 3293 |
| 400 | 2161 | 2223 | 2285 | 2347 | 2416 | 2470 | 2532 | 2594 | 2655 | 2717 | 2779 | 2841 | 2902 | 2964 | 3026 | 3088 |
| 425 | 2034 | 2092 | 2150 | 2208 | 2274 | 2325 | 2383 | 2441 | 2499 | 2557 | 2615 | 2673 | 2732 | 2790 | 2848 | 2906 |
| 450 | 1921 | 1976 | 2031 | 2086 | 2147 | 2196 | 2250 | 2305 | 2360 | 2415 | 2470 | 2525 | 2580 | 2635 | 2690 | 2744 |
| 475 | 1820 | 1872 | 1924 | 1976 | 2034 | 2080 | 2132 | 2184 | 2236 | 2288 | 2340 | 2392 | 2444 | 2496 | 2548 | 2600 |
| 500 | 1729 | 1778 | 1828 | 1877 | 1933 | 1976 | 2025 | 2075 | 2124 | 2174 | 2223 | 2272 | 2322 | 2371 | 2421 | 2470 |
| 525 | 1647 | 1694 | 1741 | 1788 | 1841 | 1882 | 1929 | 1976 | 2023 | 2070 | 2117 | 2164 | 2211 | 2258 | 2305 | 2352 |
| 550 | 1572 | 1617 | 1662 | 1707 | 1757 | 1796 | 1841 | 1886 | 1931 | 1976 | 2021 | 2066 | 2111 | 2156 | 2201 | 2245 |
| 575 | 1503 | 1546 | 1589 | 1632 | 1680 | 1718 | 1761 | 1804 | 1847 | 1890 | 1933 | 1976 | 2019 | 2062 | 2105 | 2148 |
| 600 | 1441 | 1482 | 1523 | 1564 | 1610 | 1647 | 1688 | 1729 | 1770 | 1811 | 1853 | 1894 | 1935 | 1976 | 2017 | 2058 |
| 625 | 1383 | 1423 | 1462 | 1502 | 1546 | 1581 | 1620 | 1660 | 1699 | 1739 | 1778 | 1818 | 1857 | 1897 | 1936 | 2976 |
| 650 | 1330 | 1368 | 1406 | 1444 | 1487 | 1520 | 1558 | 1596 | 1634 | 1672 | 1710 | 1748 | 1786 | 1824 | 1862 | 1900 |
| 675 | 1281 | 1317 | 1354 | 1391 | 1432 | 1464 | 1500 | 1537 | 1573 | 1610 | 1647 | 1683 | 1720 | 1756 | 1793 | 1830 |
| 700 | 1235 | 1270 | 1306 | 1341 | 1380 | 1411 | 1447 | 1482 | 1517 | 1553 | 1588 | 1623 | 1658 | 1694 | 1729 | 1764 |
| 725 | 1192 | 1226 | 1261 | 1295 | 1333 | 1363 | 1397 | 1431 | 1465 | 1499 | 1533 | 1567 | 1601 | 1635 | 1669 | 1703 |
| 750 | 1153 | 1186 | 1219 | 1251 | 1288 | 1317 | 1350 | 1383 | 1416 | 1449 | 1482 | 1515 | 1548 | 1581 | 1614 | 1647 |
| 775 | 1115 | 1147 | 1179 | 1211 | 1247 | 1275 | 1307 | 1339 | 1370 | 1402 | 1434 | 1466 | 1498 | 1530 | 1562 | 1594 |
| 800 | 1081 | 1112 | 1142 | 1173 | 1208 | 1235 | 1266 | 1297 | 1328 | 1359 | 1389 | 1420 | 1451 | 1482 | 1513 | 1544 |
| 825 | 1048 | 1078 | 1108 | 1138 | 1171 | 1198 | 1228 | 1257 | 1287 | 1317 | 1347 | 1377 | 1407 | 1437 | 1467 | 1497 |
| 850 | 1017 | 1046 | 1075 | 1104 | 1137 | 1162 | 1191 | 1220 | 1250 | 1279 | 1308 | 1337 | 1366 | 1395 | 1424 | 1453 |
| 875 | 988 | 1016 | 1044 | 1073 | 1104 | 1129 | 1157 | 1186 | 1214 | 1242 | 1270 | 1299 | 1327 | 1355 | 1383 | 1411 |
| 900 | 961 | 988 | 1015 | 1043 | 1074 | 1098 | 1125 | 1153 | 1180 | 1208 | 1235 | 1262 | 1290 | 1317 | 1345 | 1372 |
| 925 | 935 | 961 | 988 | 1015 | 1045 | 1068 | 1095 | 1122 | 1148 | 1175 | 1202 | 1228 | 1255 | 1282 | 1308 | 1335 |
| 950 | 910 | 936 | 962 | 988 | 1017 | 1040 | 1066 | 1092 | 1118 | 1144 | 1170 | 1196 | 1222 | 1248 | 1274 | 1300 |
| 975 | 887 | 912 | 937 | 963 | 991 | 1013 | 1039 | 1064 | 1089 | 1115 | 1140 | 1165 | 1191 | 1216 | 1241 | 1267 |
| 1000 | 865 | 889 | 914 | 939 | 966 | 988 | 1013 | 1037 | 1062 | 1087 | 1112 | 1136 | 1161 | 1186 | 1210 | 1235 |
| 1025 | 843 | 868 | 892 | 916 | 943 | 964 | 988 | 1012 | 1036 | 1060 | 1084 | 1108 | 1133 | 1157 | 1181 | 1205 |
| 1050 | 823 | 847 | 870 | 894 | 920 | 941 | 964 | 988 | 1012 | 1035 | 1059 | 1082 | 1106 | 1129 | 1153 | 1176 |
| 1075 | 804 | 827 | 850 | 873 | 899 | 919 | 942 | 965 | 988 | 1011 | 1034 | 1057 | 1080 | 1103 | 1126 | 1149 |
| 1100 | 786 | 808 | 831 | 853 | 878 | 898 | 921 | 943 | 966 | 988 | 1010 | 1033 | 1055 | 1078 | 1100 | 1123 |
| 1125 | 768 | 790 | 812 | 834 | 859 | 878 | 900 | 922 | 944 | 966 | 988 | 1010 | 1032 | 1054 | 1076 | 1098 |
| 1150 | 752 | 773 | 795 | 816 | 840 | 859 | 881 | 902 | 924 | 945 | 967 | 988 | 1009 | 1031 | 1052 | 1074 |

$$P = \frac{TS \cdot t \cdot E}{R \cdot FS}$$

TS = Tensile Strength 380,000 kPa
t = Thickness of Cylindrical Component, mm
E = Joint Efficiency 78%
R = Radius of Shell (inside Diameter/2), mm
FS = Factor of Safety 6
P = MAWP, kPa

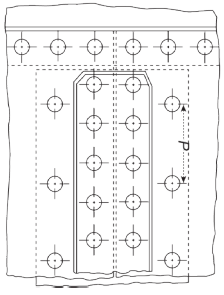
Table S2.10.3.3 Metric (Page 2 of 2)
Maximum Allowable Working Pressure for Cylindrical Components (Barrel)
For Triple-Riveted Lap Joint

## TABLE S2.10.3.5

MAXIMUM ALLOWABLE WORKING PRESSURE FOR CYLINDRICAL COMPONENTS (BARREL)

**For Buttstrap Double-Riveted Joint**

| Shell ID | Minimum Thickness of Shell Plate | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0.19 | 0.2 | 0.21 | 0.22 | 0.23 | 0.24 | 0.25 | 0.26 | 0.27 | 0.28 | 0.29 | 0.3 | 0.31 | 0.32 | 0.33 | 0.34 | 0.35 | 0.36 | 0.37 | 0.38 | 0.39 | 0.4 | 0.41 | 0.42 | 0.43 | 0.44 | 0.45 | 0.46 | 0.47 | 0.48 | 0.49 | 0.5 |
| 12 | 286 | 301 | 316 | 331 | 346 | 361 | 376 | 391 | 406 | 421 | 436 | 451 | 466 | 481 | 496 | 511 | 526 | 541 | 556 | 571 | 586 | 601 | 616 | 631 | 646 | 661 | 677 | 692 | 707 | 722 | 737 | 752 |
| 13 | 264 | 278 | 291 | 305 | 319 | 333 | 347 | 361 | 375 | 389 | 402 | 416 | 430 | 444 | 458 | 472 | 486 | 500 | 513 | 527 | 541 | 555 | 569 | 583 | 597 | 611 | 624 | 638 | 652 | 666 | 680 | 694 |
| 14 | 245 | 258 | 271 | 283 | 296 | 309 | 322 | 335 | 348 | 361 | 374 | 387 | 399 | 412 | 425 | 438 | 451 | 464 | 477 | 490 | 503 | 515 | 528 | 541 | 554 | 567 | 580 | 593 | 606 | 619 | 631 | 644 |
| 15 | 229 | 241 | 253 | 265 | 277 | 289 | 301 | 313 | 325 | 337 | 349 | 361 | 373 | 385 | 397 | 409 | 421 | 433 | 445 | 457 | 469 | 481 | 493 | 505 | 517 | 529 | 541 | 553 | 565 | 577 | 589 | 601 |
| 16 | 214 | 226 | 237 | 248 | 259 | 271 | 282 | 293 | 304 | 316 | 327 | 338 | 350 | 361 | 372 | 383 | 395 | 406 | 417 | 428 | 440 | 451 | 462 | 474 | 485 | 496 | 507 | 519 | 530 | 541 | 552 | 564 |
| 17 | 202 | 212 | 223 | 233 | 244 | 255 | 265 | 276 | 287 | 297 | 308 | 318 | 329 | 340 | 350 | 361 | 371 | 382 | 393 | 403 | 414 | 424 | 435 | 446 | 456 | 467 | 478 | 488 | 499 | 509 | 520 | 531 |
| 18 | 190 | 200 | 210 | 220 | 231 | 241 | 251 | 261 | 271 | 281 | 291 | 301 | 311 | 321 | 331 | 341 | 351 | 361 | 371 | 381 | 391 | 401 | 411 | 421 | 431 | 441 | 451 | 461 | 471 | 481 | 491 | 501 |
| 19 | 180 | 190 | 199 | 209 | 218 | 228 | 237 | 247 | 256 | 266 | 275 | 285 | 294 | 304 | 313 | 323 | 332 | 342 | 351 | 361 | 370 | 380 | 389 | 399 | 408 | 418 | 427 | 437 | 446 | 456 | 465 | 475 |
| 20 | 171 | 180 | 189 | 198 | 207 | 216 | 226 | 235 | 244 | 253 | 262 | 271 | 280 | 289 | 298 | 307 | 316 | 325 | 334 | 343 | 352 | 361 | 370 | 379 | 388 | 397 | 406 | 415 | 424 | 433 | 442 | 451 |
| 21 | 163 | 172 | 180 | 189 | 198 | 206 | 215 | 223 | 232 | 241 | 249 | 258 | 266 | 275 | 283 | 292 | 301 | 309 | 318 | 326 | 335 | 344 | 352 | 361 | 369 | 378 | 387 | 395 | 404 | 412 | 421 | 430 |
| 22 | 156 | 164 | 172 | 180 | 189 | 197 | 205 | 213 | 221 | 230 | 238 | 246 | 254 | 262 | 271 | 279 | 287 | 295 | 303 | 312 | 320 | 328 | 336 | 344 | 353 | 361 | 369 | 377 | 385 | 394 | 402 | 410 |
| 23 | 149 | 157 | 165 | 173 | 180 | 188 | 196 | 204 | 212 | 220 | 227 | 235 | 243 | 251 | 259 | 267 | 275 | 282 | 290 | 298 | 306 | 314 | 322 | 329 | 337 | 345 | 353 | 361 | 369 | 376 | 384 | 392 |
| 24 | 143 | 150 | 158 | 165 | 173 | 180 | 188 | 195 | 203 | 210 | 218 | 226 | 233 | 241 | 248 | 256 | 263 | 271 | 278 | 286 | 293 | 301 | 308 | 316 | 323 | 331 | 338 | 346 | 353 | 361 | 368 | 376 |
| 25 | 137 | 144 | 152 | 159 | 166 | 173 | 180 | 188 | 195 | 202 | 209 | 216 | 224 | 231 | 238 | 245 | 253 | 260 | 267 | 274 | 281 | 289 | 296 | 303 | 310 | 318 | 325 | 332 | 339 | 346 | 354 | 361 |
| 26 | 132 | 139 | 146 | 153 | 160 | 167 | 173 | 180 | 187 | 194 | 201 | 208 | 215 | 222 | 229 | 236 | 243 | 250 | 257 | 264 | 271 | 278 | 284 | 291 | 298 | 305 | 312 | 319 | 326 | 333 | 340 | 347 |
| 27 | 127 | 134 | 140 | 147 | 154 | 160 | 167 | 174 | 180 | 187 | 194 | 200 | 207 | 214 | 220 | 227 | 234 | 241 | 247 | 254 | 261 | 267 | 274 | 281 | 287 | 294 | 301 | 307 | 314 | 321 | 327 | 334 |
| 28 | 122 | 129 | 135 | 142 | 148 | 155 | 161 | 168 | 174 | 180 | 187 | 193 | 200 | 206 | 213 | 219 | 226 | 232 | 238 | 245 | 251 | 258 | 264 | 271 | 277 | 283 | 290 | 296 | 303 | 309 | 316 | 322 |
| 29 | 118 | 124 | 131 | 137 | 143 | 149 | 156 | 162 | 168 | 174 | 180 | 187 | 193 | 199 | 205 | 212 | 218 | 224 | 230 | 236 | 243 | 249 | 255 | 261 | 267 | 274 | 280 | 286 | 292 | 299 | 305 | 311 |
| 30 | 114 | 120 | 126 | 132 | 138 | 144 | 150 | 156 | 162 | 168 | 174 | 180 | 186 | 192 | 198 | 204 | 210 | 216 | 222 | 229 | 235 | 241 | 247 | 253 | 259 | 265 | 271 | 277 | 283 | 289 | 295 | 301 |
| 31 | 111 | 116 | 122 | 128 | 134 | 140 | 145 | 151 | 157 | 163 | 169 | 175 | 180 | 186 | 192 | 198 | 204 | 209 | 215 | 221 | 227 | 233 | 239 | 244 | 250 | 256 | 262 | 268 | 274 | 279 | 285 | 291 |
| 32 | 107 | 113 | 118 | 124 | 130 | 135 | 141 | 147 | 152 | 158 | 163 | 169 | 175 | 180 | 186 | 192 | 197 | 203 | 209 | 214 | 220 | 226 | 231 | 237 | 242 | 248 | 254 | 259 | 265 | 271 | 276 | 282 |
| 33 | 104 | 109 | 115 | 120 | 126 | 131 | 137 | 142 | 148 | 153 | 159 | 164 | 169 | 175 | 180 | 186 | 191 | 197 | 202 | 208 | 213 | 219 | 224 | 230 | 235 | 241 | 246 | 251 | 257 | 262 | 268 | 273 |
| 34 | 101 | 106 | 111 | 117 | 122 | 127 | 133 | 138 | 143 | 149 | 154 | 159 | 164 | 170 | 175 | 180 | 186 | 191 | 196 | 202 | 207 | 212 | 218 | 223 | 228 | 233 | 239 | 244 | 249 | 255 | 260 | 265 |
| 35 | 98 | 103 | 108 | 113 | 119 | 124 | 129 | 134 | 139 | 144 | 149 | 155 | 160 | 165 | 170 | 175 | 180 | 186 | 191 | 196 | 201 | 206 | 211 | 216 | 222 | 227 | 232 | 237 | 242 | 247 | 253 | 258 |
| 36 | 95 | 100 | 105 | 110 | 115 | 120 | 125 | 130 | 135 | 140 | 145 | 150 | 155 | 160 | 165 | 170 | 175 | 180 | 185 | 190 | 195 | 200 | 205 | 210 | 215 | 220 | 226 | 231 | 236 | 241 | 246 | 251 |
| 37 | 93 | 98 | 102 | 107 | 112 | 117 | 122 | 127 | 132 | 137 | 141 | 146 | 151 | 156 | 161 | 166 | 171 | 176 | 180 | 185 | 190 | 195 | 200 | 205 | 210 | 215 | 219 | 224 | 229 | 234 | 239 | 244 |
| 38 | 90 | 95 | 100 | 104 | 109 | 114 | 119 | 123 | 128 | 133 | 138 | 142 | 147 | 152 | 157 | 161 | 166 | 171 | 176 | 180 | 185 | 190 | 195 | 199 | 204 | 209 | 214 | 218 | 223 | 228 | 233 | 237 |
| 39 | 88 | 93 | 97 | 102 | 106 | 111 | 116 | 120 | 125 | 130 | 134 | 139 | 143 | 148 | 153 | 157 | 162 | 167 | 171 | 176 | 180 | 185 | 190 | 194 | 199 | 204 | 208 | 213 | 217 | 222 | 227 | 231 |
| 40 | 86 | 90 | 95 | 99 | 104 | 108 | 113 | 117 | 122 | 126 | 131 | 135 | 140 | 144 | 149 | 153 | 158 | 162 | 167 | 171 | 176 | 180 | 185 | 189 | 194 | 198 | 203 | 207 | 212 | 216 | 221 | 226 |
| 41 | 84 | 88 | 92 | 97 | 101 | 106 | 110 | 114 | 119 | 123 | 128 | 132 | 136 | 141 | 145 | 150 | 154 | 158 | 163 | 167 | 172 | 176 | 180 | 185 | 189 | 194 | 198 | 202 | 207 | 211 | 216 | 220 |
| 42 | 82 | 86 | 90 | 94 | 99 | 103 | 107 | 112 | 116 | 120 | 125 | 129 | 133 | 137 | 142 | 146 | 150 | 155 | 159 | 163 | 168 | 172 | 176 | 180 | 185 | 189 | 193 | 198 | 202 | 206 | 210 | 215 |
| 43 | 80 | 84 | 88 | 92 | 96 | 101 | 105 | 109 | 113 | 117 | 122 | 126 | 130 | 134 | 138 | 143 | 147 | 151 | 155 | 159 | 164 | 168 | 172 | 176 | 180 | 185 | 189 | 193 | 197 | 201 | 206 | 210 |
| 44 | 78 | 82 | 86 | 90 | 94 | 98 | 103 | 107 | 111 | 115 | 119 | 123 | 127 | 131 | 135 | 139 | 144 | 148 | 152 | 156 | 160 | 164 | 168 | 172 | 176 | 180 | 185 | 189 | 193 | 197 | 201 | 205 |
| 45 | 76 | 80 | 84 | 88 | 92 | 96 | 100 | 104 | 108 | 112 | 116 | 120 | 124 | 128 | 132 | 136 | 140 | 144 | 148 | 152 | 156 | 160 | 164 | 168 | 172 | 176 | 180 | 184 | 188 | 192 | 196 | 200 |




**TS = Tensile Strength (55,000)**

**t = Thickness of Cylindrical Component**

**TS x t x E/R x FS**

**R = Radius of Shell (inside diameter/2)**

**E = Joint Efficiency (82%)**

**FS = Factor of Safety (5)**

| Shell ID (mm) | Minimum Thickness of Shell Plate (mm) | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 4.75 | 5 | 5.25 | 5.5 | 5.75 | 6 | 6.25 | 6.5 | 6.75 | 7 | 7.25 | 7.5 | 7.75 | 8 | 8.25 | **8.5** |
| 300 | **1973** | **2077** | **2181** | **2285** | **2389** | **2493** | **2597** | **2701** | **2804** | **2908** | **3012** | **3116** | **3220** | **3324** | **3428** | 3531 |
| 325 | **1822** | **1918** | **2013** | **2109** | **2205** | **2301** | **2397** | **2493** | **2589** | **2685** | **2780** | **2876** | **2972** | **3068** | **3164** | 3260 |
| 350 | **1692** | **1781** | **1870** | **1959** | **2048** | **2137** | **2226** | **2315** | **2404** | **2493** | **2582** | **2671** | **2760** | **2849** | **2938** | 3027 |
| 375 | **1579** | **1662** | **1745** | **1828** | **1911** | **1994** | **2077** | **2160** | **2244** | **2327** | **2410** | **2493** | **2576** | **2659** | **2742** | 2825 |
| 400 | **1480** | **1558** | **1636** | **1714** | **1792** | **1870** | **1948** | **2025** | **2103** | **2181** | **2259** | **2337** | **2415** | **2493** | **2571** | 2649 |
| 425 | **1393** | **1466** | **1540** | **1613** | **1686** | **1760** | **1833** | **1906** | **1980** | **2053** | **2126** | **2200** | **2273** | **2346** | **2419** | 2493 |
| 450 | **1316** | **1385** | **1454** | **1523** | **1593** | **1662** | **1731** | **1800** | **1870** | **1939** | **2008** | **2077** | **2147** | **2216** | **2285** | 2354 |
| 475 | **1246** | **1312** | **1378** | **1443** | **1509** | **1574** | **1640** | **1706** | **1771** | **1837** | **1902** | **1968** | **2034** | **2099** | **2165** | 2230 |
| 500 | **1184** | **1246** | **1309** | **1371** | **1433** | **1496** | **1558** | **1620** | **1683** | **1745** | **1807** | **1870** | **1932** | **1994** | **2057** | 2119 |
| 525 | **1128** | **1187** | **1246** | **1306** | **1365** | **1424** | **1484** | **1543** | **1603** | **1662** | **1721** | **1781** | **1840** | **1899** | **1959** | 2018 |
| 550 | **1076** | **1133** | **1190** | **1246** | **1303** | **1360** | **1416** | **1473** | **1530** | **1586** | **1643** | **1700** | **1756** | **1813** | **1870** | 1926 |
| 575 | **1030** | **1084** | **1138** | **1192** | **1246** | **1301** | **1355** | **1409** | **1463** | **1517** | **1572** | **1626** | **1680** | **1734** | **1788** | 1843 |
| 600 | **987** | **1039** | **1091** | **1143** | **1194** | **1246** | **1298** | **1350** | **1402** | **1454** | **1506** | **1558** | **1610** | **1662** | **1714** | 1766 |
| 625 | **947** | **997** | **1047** | **1097** | **1147** | **1197** | **1246** | **1296** | **1346** | **1396** | **1446** | **1496** | **1546** | **1595** | **1645** | 1695 |
| 650 | **911** | **959** | **1007** | **1055** | **1103** | **1151** | **1198** | **1246** | **1294** | **1342** | **1390** | **1438** | **1486** | **1534** | **1582** | 1630 |
| 675 | **877** | **923** | **969** | **1016** | **1062** | **1108** | **1154** | **1200** | **1246** | **1293** | **1339** | **1385** | **1431** | **1477** | **1523** | 1570 |
| 700 | **846** | **890** | **935** | **979** | **1024** | **1068** | **1113** | **1157** | **1202** | **1246** | **1291** | **1335** | **1380** | **1424** | **1469** | 1513 |
| 725 | **817** | **860** | **903** | **946** | **989** | **1032** | **1074** | **1117** | **1160** | **1203** | **1246** | **1289** | **1332** | **1375** | **1418** | 1461 |
| 750 | **789** | **831** | **872** | **914** | **956** | **997** | **1039** | **1080** | **1122** | **1163** | **1205** | **1246** | **1288** | **1329** | **1371** | 1413 |
| 775 | **764** | **804** | **844** | **885** | **925** | **965** | **1005** | **1045** | **1086** | **1126** | **1166** | **1206** | **1246** | **1287** | **1327** | 1367 |
| 800 | **740** | **779** | **818** | **857** | **896** | **935** | **974** | **1013** | **1052** | **1091** | **1130** | **1169** | **1207** | **1246** | **1285** | 1324 |
| 825 | **718** | **755** | **793** | **831** | **869** | **906** | **944** | **982** | **1020** | **1058** | **1095** | **1133** | **1171** | **1209** | **1246** | 1284 |
| 850 | **697** | **733** | **770** | **806** | **843** | **880** | **916** | **953** | **990** | **1026** | **1063** | **1100** | **1136** | **1173** | **1210** | 1246 |
| 875 | **677** | **712** | **748** | **783** | **819** | **855** | **890** | **926** | **962** | **997** | **1033** | **1068** | **1104** | **1140** | **1175** | 1211 |
| 900 | **658** | **692** | **727** | **762** | **796** | **831** | **866** | **900** | **935** | **969** | **1004** | **1039** | **1073** | **1108** | **1143** | 1177 |
| 925 | **640** | **674** | **707** | **741** | **775** | **808** | **842** | **876** | **910** | **943** | **977** | **1011** | **1044** | **1078** | **1112** | 1145 |
| 950 | **623** | **656** | **689** | **722** | **754** | **787** | **820** | **853** | **886** | **918** | **951** | **984** | **1017** | **1050** | **1082** | 1115 |
| 975 | **607** | **639** | **671** | **703** | **735** | **767** | **799** | **831** | **863** | **895** | **927** | **959** | **991** | **1023** | **1055** | 1087 |
| 1000 | **592** | **623** | **654** | **686** | **717** | **748** | **779** | **810** | **841** | **872** | **904** | **935** | **966** | **997** | **1028** | 1059 |
| 1025 | **578** | **608** | **638** | **669** | **699** | **730** | **760** | **790** | **821** | **851** | **882** | **912** | **942** | **973** | **1003** | 1034 |
| 1050 | **564** | **594** | **623** | **653** | **683** | **712** | **742** | **772** | **801** | **831** | **861** | **890** | **920** | **950** | **979** | 1009 |
| 1075 | **551** | **580** | **609** | **638** | **667** | **696** | **725** | **754** | **783** | **812** | **841** | **870** | **899** | **928** | **957** | 986 |
| 1100 | **538** | **567** | **595** | **623** | **652** | **680** | **708** | **737** | **765** | **793** | **821** | **850** | **878** | **906** | **935** | 963 |
| 1125 | **526** | **554** | **582** | **609** | **637** | **665** | **692** | **720** | **748** | **776** | **803** | **831** | **859** | **886** | **914** | 942 |
| 1150 | **515** | **542** | **569** | **596** | **623** | **650** | **677** | **704** | **732** | **759** | **786** | **813** | **840** | **867** | **894** | 921 |

$$P = \frac{TS \cdot t \cdot E}{R \cdot FS}$$

TS = Tensile Strength 380,000 kPa
t = Thickness of Cylindrical Component, mm
E = Joint Efficiency 82%

R = Radius of Shell (inside Diameter/2), mm
FS = Factor of Safety 5
P = MAWP, kPa

Table S2.10.3.4 Metric (Page 1 of 2)
Maximum Allowable Working Pressure for Cylindrical Components (Barrel)
For Buttstrap Double-Riveted Joint

| Shell ID (mm) | Minimum Thickness of Shell Plate (mm) | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 8.75 | 9 | 9.25 | 9.5 | 9.75 | 10 | 10.25 | 10.5 | 10.75 | 11 | 11.25 | 11.5 | 11.75 | 12 | 12.25 | 12.5 |
| 300 | 3635 | 3739 | 3843 | 3947 | 4051 | 4155 | 4259 | 4362 | 4466 | 4570 | 4674 | 4778 | 4882 | 4986 | 5089 | 5193 |
| 325 | 3356 | 3452 | 3547 | 3643 | 3739 | 3835 | 3931 | 4027 | 4123 | 4219 | 4314 | 4410 | 4506 | 4602 | 4698 | 4794 |
| 350 | 3116 | 3205 | 3294 | 3383 | 3472 | 3561 | 3650 | 3739 | 3828 | 3917 | 4006 | 4095 | 4184 | 4273 | 4362 | 4451 |
| 375 | 2908 | 2991 | 3074 | 3158 | 3241 | 3324 | 3407 | 3490 | 3573 | 3656 | 3739 | 3822 | 3905 | 3988 | 4072 | 4155 |
| 400 | 2727 | 2804 | 2882 | 2960 | 3038 | 3116 | 3194 | 3272 | 3350 | 3428 | 3506 | 3583 | 3661 | 3739 | 3817 | 3895 |
| 425 | 2566 | 2639 | 2713 | 2786 | 2859 | 2933 | 3006 | 3079 | 3153 | 3226 | 3299 | 3373 | 3446 | 3519 | 3593 | 3666 |
| 450 | 2424 | 2493 | 2562 | 2631 | 2701 | 2770 | 2839 | 2908 | 2978 | 3047 | 3116 | 3185 | 3254 | 3324 | 3393 | 3462 |
| 475 | 2296 | 2362 | 2427 | 2493 | 2558 | 2624 | 2690 | 2755 | 2821 | 2886 | 2952 | 3018 | 3083 | 3149 | 3214 | 3280 |
| 500 | 2181 | 2244 | 2306 | 2368 | 2430 | 2493 | 2555 | 2617 | 2680 | 2742 | 2804 | 2867 | 2929 | 2991 | 3054 | 3116 |
| 525 | 2077 | 2137 | 2196 | 2255 | 2315 | 2374 | 2433 | 2493 | 2552 | 2612 | 2671 | 2730 | 2790 | 2849 | 2908 | 2968 |
| 550 | 1983 | 2040 | 2096 | 2153 | 2210 | 2266 | 2323 | 2379 | 2436 | 2493 | 2549 | 2606 | 2663 | 2719 | 2776 | 2833 |
| 575 | 1897 | 1951 | 2005 | 2059 | 2113 | 2168 | 2222 | 2276 | 2330 | 2384 | 2439 | 2493 | 2547 | 2601 | 2655 | 2710 |
| 600 | 1818 | 1870 | 1922 | 1973 | 2025 | 2077 | 2129 | 2181 | 2233 | 2285 | 2337 | 2389 | 2441 | 2493 | 2545 | 2597 |
| 625 | 1745 | 1795 | 1845 | 1895 | 1944 | 1994 | 2044 | 2094 | 2144 | 2194 | 2244 | 2293 | 2343 | 2393 | 2443 | 2493 |
| 650 | 1678 | 1726 | 1774 | 1822 | 1870 | 1918 | 1965 | 2013 | 2061 | 2109 | 2157 | 2205 | 2253 | 2301 | 2349 | 2397 |
| 675 | 1616 | 1662 | 1708 | 1754 | 1800 | 1847 | 1893 | 1939 | 1985 | 2031 | 2077 | 2123 | 2170 | 2216 | 2262 | 2308 |
| 700 | 1558 | 1603 | 1647 | 1692 | 1736 | 1781 | 1825 | 1870 | 1914 | 1959 | 2003 | 2048 | 2092 | 2137 | 2181 | 2226 |
| 725 | 1504 | 1547 | 1590 | 1633 | 1676 | 1719 | 1762 | 1805 | 1848 | 1891 | 1934 | 1977 | 2020 | 2063 | 2106 | 2149 |
| 750 | 1454 | 1496 | 1537 | 1579 | 1620 | 1662 | 1703 | 1745 | 1787 | 1828 | 1870 | 1911 | 1953 | 1994 | 2036 | 2077 |
| 775 | 1407 | 1447 | 1488 | 1528 | 1568 | 1608 | 1648 | 1689 | 1729 | 1769 | 1809 | 1849 | 1890 | 1930 | 1970 | 2010 |
| 800 | 1363 | 1402 | 1441 | 1480 | 1519 | 1558 | 1597 | 1636 | 1675 | 1714 | 1753 | 1792 | 1831 | 1870 | 1909 | 1948 |
| 825 | 1322 | 1360 | 1397 | 1435 | 1473 | 1511 | 1549 | 1586 | 1624 | 1662 | 1700 | 1737 | 1775 | 1813 | 1851 | 1888 |
| 850 | 1283 | 1320 | 1356 | 1393 | 1430 | 1466 | 1503 | 1540 | 1576 | 1613 | 1650 | 1686 | 1723 | 1760 | 1796 | 1833 |
| 875 | 1246 | 1282 | 1318 | 1353 | 1389 | 1424 | 1460 | 1496 | 1531 | 1567 | 1603 | 1638 | 1674 | 1709 | 1745 | 1781 |
| 900 | 1212 | 1246 | 1281 | 1316 | 1350 | 1385 | 1420 | 1454 | 1489 | 1523 | 1558 | 1593 | 1627 | 1662 | 1696 | 1731 |
| 925 | 1179 | 1213 | 1246 | 1280 | 1314 | 1347 | 1381 | 1415 | 1449 | 1482 | 1516 | 1550 | 1583 | 1617 | 1651 | 1684 |
| 950 | 1148 | 1181 | 1214 | 1246 | 1279 | 1312 | 1345 | 1378 | 1410 | 1443 | 1476 | 1509 | 1542 | 1574 | 1607 | 1640 |
| 975 | 1119 | 1151 | 1182 | 1214 | 1246 | 1278 | 1310 | 1342 | 1374 | 1406 | 1438 | 1470 | 1502 | 1534 | 1566 | 1598 |
| 1000 | 1091 | 1122 | 1153 | 1184 | 1215 | 1246 | 1278 | 1309 | 1340 | 1371 | 1402 | 1433 | 1465 | 1496 | 1527 | 1558 |
| 1025 | 1064 | 1094 | 1125 | 1155 | 1186 | 1216 | 1246 | 1277 | 1307 | 1338 | 1368 | 1398 | 1429 | 1459 | 1490 | 1520 |
| 1050 | 1039 | 1068 | 1098 | 1128 | 1157 | 1187 | 1217 | 1246 | 1276 | 1306 | 1335 | 1365 | 1395 | 1424 | 1454 | 1484 |
| 1075 | 1015 | 1043 | 1072 | 1101 | 1130 | 1159 | 1188 | 1217 | 1246 | 1275 | 1304 | 1333 | 1362 | 1391 | 1420 | 1449 |
| 1100 | 991 | 1020 | 1048 | 1076 | 1105 | 1133 | 1161 | 1190 | 1218 | 1246 | 1275 | 1303 | 1331 | 1360 | 1388 | 1416 |
| 1125 | 969 | 997 | 1025 | 1053 | 1080 | 1108 | 1136 | 1163 | 1191 | 1219 | 1246 | 1274 | 1302 | 1329 | 1357 | 1385 |
| 1150 | 948 | 975 | 1003 | 1030 | 1057 | 1084 | 1111 | 1138 | 1165 | 1192 | 1219 | 1246 | 1273 | 1301 | 1328 | 1355 |

$$P = \frac{TS \cdot t \cdot E}{R \cdot FS}$$

TS = Tensile Strength 380,000 kPa
t = Thickness of Cylindrical Component, mm
E = Joint Efficiency 82%

R = Radius of Shell (inside Diameter/2), mm
FS = Factor of Safety 5
P = MAWP, kPa

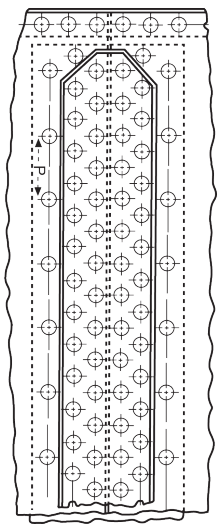
Table S2.10.3.4 Metric (Page 2 of 2)
Maximum Allowable Working Pressure for Cylindrical Components (Barrel)
For Buttstrap Double-Riveted Joint

# TABLE S2.10.3.6

## MAXIMUM ALLOWABLE WORKING PRESSURE FOR CYLINDRICAL COMPONENTS (BARREL)

**For Buttstrap Triple-Riveted Joint**

| Shell ID | Minimum Thickness of Shell Plate | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0.19 | 0.2 | 0.21 | 0.22 | 0.23 | 0.24 | 0.25 | 0.26 | 0.27 | 0.28 | 0.29 | 0.3 | 0.31 | 0.32 | 0.33 | 0.34 | 0.35 | 0.36 | 0.37 | 0.38 | 0.39 | 0.4 | 0.41 | 0.42 | 0.43 | 0.44 | 0.45 | 0.46 | 0.47 | 0.48 | 0.49 | 0.5 |
| 12 | 307 | 323 | 339 | 355 | 371 | 387 | 403 | 419 | 436 | 452 | 468 | 484 | 500 | 516 | 532 | 549 | 565 | 581 | 597 | 613 | 629 | 645 | 661 | 678 | 694 | 710 | 726 | 742 | 758 | 774 | 791 | 807 |
| 13 | 283 | 298 | 313 | 328 | 343 | 357 | 372 | 387 | 402 | 417 | 432 | 447 | 462 | 477 | 491 | 506 | 521 | 536 | 551 | 566 | 581 | 596 | 611 | 625 | 640 | 655 | 670 | 685 | 700 | 715 | 730 | 745 |
| 14 | 263 | 277 | 290 | 304 | 318 | 332 | 346 | 360 | 373 | 387 | 401 | 415 | 429 | 443 | 456 | 470 | 484 | 498 | 512 | 525 | 539 | 553 | 567 | 581 | 595 | 608 | 622 | 636 | 650 | 664 | 678 | 691 |
| 15 | 245 | 258 | 271 | 284 | 297 | 310 | 323 | 336 | 348 | 361 | 374 | 387 | 400 | 413 | 426 | 439 | 452 | 465 | 478 | 490 | 503 | 516 | 529 | 542 | 555 | 568 | 581 | 594 | 607 | 620 | 632 | 645 |
| 16 | 230 | 242 | 254 | 266 | 278 | 290 | 303 | 315 | 327 | 339 | 351 | 363 | 375 | 387 | 399 | 411 | 424 | 436 | 448 | 460 | 472 | 484 | 496 | 508 | 520 | 532 | 545 | 557 | 569 | 581 | 593 | 605 |
| 17 | 216 | 228 | 239 | 251 | 262 | 273 | 285 | 296 | 307 | 319 | 330 | 342 | 353 | 364 | 376 | 387 | 399 | 410 | 421 | 433 | 444 | 456 | 467 | 478 | 490 | 501 | 512 | 524 | 535 | 547 | 558 | 569 |
| 18 | 204 | 215 | 226 | 237 | 247 | 258 | 269 | 280 | 290 | 301 | 312 | 323 | 333 | 344 | 355 | 366 | 376 | 387 | 398 | 409 | 419 | 430 | 441 | 452 | 462 | 473 | 484 | 495 | 506 | 516 | 527 | 538 |
| 19 | 194 | 204 | 214 | 224 | 234 | 245 | 255 | 265 | 275 | 285 | 295 | 306 | 316 | 326 | 336 | 346 | 357 | 367 | 377 | 387 | 397 | 408 | 418 | 428 | 438 | 448 | 459 | 469 | 479 | 489 | 499 | 509 |
| 20 | 184 | 194 | 203 | 213 | 223 | 232 | 242 | 252 | 261 | 271 | 281 | 290 | 300 | 310 | 319 | 329 | 339 | 348 | 358 | 368 | 378 | 387 | 397 | 407 | 416 | 426 | 436 | 445 | 455 | 465 | 474 | 484 |
| 21 | 175 | 184 | 194 | 203 | 212 | 221 | 230 | 240 | 249 | 258 | 267 | 277 | 286 | 295 | 304 | 313 | 323 | 332 | 341 | 350 | 360 | 369 | 378 | 387 | 396 | 406 | 415 | 424 | 433 | 443 | 452 | 461 |
| 22 | 167 | 176 | 185 | 194 | 202 | 211 | 220 | 229 | 238 | 246 | 255 | 264 | 273 | 282 | 290 | 299 | 308 | 317 | 326 | 334 | 343 | 352 | 361 | 370 | 378 | 387 | 396 | 405 | 414 | 422 | 431 | 440 |
| 23 | 160 | 168 | 177 | 185 | 194 | 202 | 210 | 219 | 227 | 236 | 244 | 253 | 261 | 269 | 278 | 286 | 295 | 303 | 311 | 320 | 328 | 337 | 345 | 354 | 362 | 370 | 379 | 387 | 396 | 404 | 412 | 421 |
| 24 | 153 | 161 | 169 | 177 | 186 | 194 | 202 | 210 | 218 | 226 | 234 | 242 | 250 | 258 | 266 | 274 | 282 | 290 | 298 | 307 | 315 | 323 | 331 | 339 | 347 | 355 | 363 | 371 | 379 | 387 | 395 | 403 |
| 25 | 147 | 155 | 163 | 170 | 178 | 186 | 194 | 201 | 209 | 217 | 225 | 232 | 240 | 248 | 256 | 263 | 271 | 279 | 287 | 294 | 302 | 310 | 318 | 325 | 333 | 341 | 348 | 356 | 364 | 372 | 379 | 387 |
| 26 | 141 | 149 | 156 | 164 | 171 | 179 | 186 | 194 | 201 | 208 | 216 | 223 | 231 | 238 | 246 | 253 | 261 | 268 | 276 | 283 | 290 | 298 | 305 | 313 | 320 | 328 | 335 | 343 | 350 | 357 | 365 | 372 |
| 27 | 136 | 143 | 151 | 158 | 165 | 172 | 179 | 186 | 194 | 201 | 208 | 215 | 222 | 229 | 237 | 244 | 251 | 258 | 265 | 272 | 280 | 287 | 294 | 301 | 308 | 315 | 323 | 330 | 337 | 344 | 351 | 359 |
| 28 | 131 | 138 | 145 | 152 | 159 | 166 | 173 | 180 | 187 | 194 | 201 | 207 | 214 | 221 | 228 | 235 | 242 | 249 | 256 | 263 | 270 | 277 | 283 | 290 | 297 | 304 | 311 | 318 | 325 | 332 | 339 | 346 |
| 29 | 127 | 134 | 140 | 147 | 154 | 160 | 167 | 174 | 180 | 187 | 194 | 200 | 207 | 214 | 220 | 227 | 234 | 240 | 247 | 254 | 260 | 267 | 274 | 280 | 287 | 294 | 300 | 307 | 314 | 320 | 327 | 334 |
| 30 | 123 | 129 | 136 | 142 | 148 | 155 | 161 | 168 | 174 | 181 | 187 | 194 | 200 | 207 | 213 | 219 | 226 | 232 | 239 | 245 | 252 | 258 | 265 | 271 | 277 | 284 | 290 | 297 | 303 | 310 | 316 | 323 |
| 31 | 119 | 125 | 131 | 137 | 144 | 150 | 156 | 162 | 169 | 175 | 181 | 187 | 194 | 200 | 206 | 212 | 219 | 225 | 231 | 237 | 244 | 250 | 256 | 262 | 269 | 275 | 281 | 287 | 294 | 300 | 306 | 312 |
| 32 | 115 | 121 | 127 | 133 | 139 | 145 | 151 | 157 | 163 | 169 | 175 | 182 | 188 | 194 | 200 | 206 | 212 | 218 | 224 | 230 | 236 | 242 | 248 | 254 | 260 | 266 | 272 | 278 | 284 | 290 | 296 | 303 |
| 33 | 111 | 117 | 123 | 129 | 135 | 141 | 147 | 153 | 158 | 164 | 170 | 176 | 182 | 188 | 194 | 199 | 205 | 211 | 217 | 223 | 229 | 235 | 241 | 246 | 252 | 258 | 264 | 270 | 276 | 282 | 287 | 293 |
| 34 | 108 | 114 | 120 | 125 | 131 | 137 | 142 | 148 | 154 | 159 | 165 | 171 | 177 | 182 | 188 | 194 | 199 | 205 | 211 | 216 | 222 | 228 | 233 | 239 | 245 | 251 | 256 | 262 | 268 | 273 | 279 | 285 |
| 35 | 105 | 111 | 116 | 122 | 127 | 133 | 138 | 144 | 149 | 155 | 160 | 166 | 171 | 177 | 183 | 188 | 194 | 199 | 205 | 210 | 216 | 221 | 227 | 232 | 238 | 243 | 249 | 254 | 260 | 266 | 271 | 277 |
| 36 | 102 | 108 | 113 | 118 | 124 | 129 | 134 | 140 | 145 | 151 | 156 | 161 | 167 | 172 | 177 | 183 | 188 | 194 | 199 | 204 | 210 | 215 | 220 | 226 | 231 | 237 | 242 | 247 | 253 | 258 | 264 | 269 |
| 37 | 99 | 105 | 110 | 115 | 120 | 126 | 131 | 136 | 141 | 147 | 152 | 157 | 162 | 167 | 173 | 178 | 183 | 188 | 194 | 199 | 204 | 209 | 215 | 220 | 225 | 230 | 235 | 241 | 246 | 251 | 256 | 262 |
| 38 | 97 | 102 | 107 | 112 | 117 | 122 | 127 | 132 | 138 | 143 | 148 | 153 | 158 | 163 | 168 | 173 | 178 | 183 | 189 | 194 | 199 | 204 | 209 | 214 | 219 | 224 | 229 | 234 | 239 | 245 | 250 | 255 |
| 39 | 94 | 99 | 104 | 109 | 114 | 119 | 124 | 129 | 134 | 139 | 144 | 149 | 154 | 159 | 164 | 169 | 174 | 179 | 184 | 189 | 194 | 199 | 204 | 208 | 213 | 218 | 223 | 228 | 233 | 238 | 243 | 248 |
| 40 | 92 | 97 | 102 | 106 | 111 | 116 | 121 | 126 | 131 | 136 | 140 | 145 | 150 | 155 | 160 | 165 | 169 | 174 | 179 | 184 | 189 | 194 | 198 | 203 | 208 | 213 | 218 | 223 | 227 | 232 | 237 | 242 |
| 41 | 90 | 94 | 99 | 104 | 109 | 113 | 118 | 123 | 127 | 132 | 137 | 142 | 146 | 151 | 156 | 161 | 165 | 170 | 175 | 179 | 184 | 189 | 194 | 198 | 203 | 208 | 212 | 217 | 222 | 227 | 231 | 236 |
| 42 | 88 | 92 | 97 | 101 | 106 | 111 | 115 | 120 | 124 | 129 | 134 | 138 | 143 | 148 | 152 | 157 | 161 | 166 | 171 | 175 | 180 | 184 | 189 | 194 | 198 | 203 | 207 | 212 | 217 | 221 | 226 | 230 |
| 43 | 86 | 90 | 95 | 99 | 104 | 108 | 113 | 117 | 122 | 126 | 131 | 135 | 140 | 144 | 149 | 153 | 158 | 162 | 167 | 171 | 176 | 180 | 185 | 189 | 194 | 198 | 203 | 207 | 212 | 216 | 221 | 225 |
| 44 | 84 | 88 | 92 | 97 | 101 | 106 | 110 | 114 | 119 | 123 | 128 | 132 | 136 | 141 | 145 | 150 | 154 | 158 | 163 | 167 | 172 | 176 | 180 | 185 | 189 | 194 | 198 | 202 | 207 | 211 | 216 | 220 |
| 45 | 82 | 86 | 90 | 95 | 99 | 103 | 108 | 112 | 116 | 120 | 125 | 129 | 133 | 138 | 142 | 146 | 151 | 155 | 159 | 163 | 168 | 172 | 176 | 181 | 185 | 189 | 194 | 198 | 202 | 207 | 211 | 215 |




**TS = Tensile Strength (55,000)**

**t = Thickness of Cylindrical Component**

**E = Joint Efficiency (88%)**

**TS x t x E/R x FS**

**R = Radius of Shell (inside diameter/2)**

**FS = Factor of Safety (5)**

| Shell ID (mm) | Minimum Thickness of Shell Plate (mm) | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 4.75 | 5 | 5.25 | 5.5 | 5.75 | 6 | 6.25 | 6.5 | 6.75 | 7 | 7.25 | 7.5 | 7.75 | 8 | 8.25 | 8.5 |
| 300 | 2118 | 2229 | 2341 | 2452 | 2564 | 2675 | 2787 | 2898 | 3010 | 3121 | 3233 | 3344 | 3455 | 3567 | 3678 | 3790 |
| 325 | 1955 | 2058 | 2161 | 2264 | 2367 | 2469 | 2572 | 2675 | 2778 | 2881 | 2984 | 3087 | 3190 | 3293 | 3395 | 3498 |
| 350 | 1815 | 1911 | 2006 | 2102 | 2197 | 2293 | 2389 | 2484 | 2580 | 2675 | 2771 | 2866 | 2962 | 3057 | 3153 | 3248 |
| 375 | 1694 | 1783 | 1873 | 1962 | 2051 | 2140 | 2229 | 2319 | 2408 | 2497 | 2586 | 2675 | 2764 | 2854 | 2943 | 3032 |
| 400 | 1588 | 1672 | 1756 | 1839 | 1923 | 2006 | 2090 | 2174 | 2257 | 2341 | 2424 | 2508 | 2592 | 2675 | 2759 | 2842 |
| 425 | 1495 | 1574 | 1652 | 1731 | 1810 | 1888 | 1967 | 2046 | 2124 | 2203 | 2282 | 2360 | 2439 | 2518 | 2597 | 2675 |
| 450 | 1412 | 1486 | 1561 | 1635 | 1709 | 1783 | 1858 | 1932 | 2006 | 2081 | 2155 | 2229 | 2304 | 2378 | 2452 | 2527 |
| 475 | 1338 | 1408 | 1478 | 1549 | 1619 | 1690 | 1760 | 1830 | 1901 | 1971 | 2042 | 2112 | 2182 | 2253 | 2323 | 2394 |
| 500 | 1271 | 1338 | 1404 | 1471 | 1538 | 1605 | 1672 | 1739 | 1806 | 1873 | 1940 | 2006 | 2073 | 2140 | 2207 | 2274 |
| 525 | 1210 | 1274 | 1338 | 1401 | 1465 | 1529 | 1592 | 1656 | 1720 | 1783 | 1847 | 1911 | 1975 | 2038 | 2102 | 2166 |
| 550 | 1155 | 1216 | 1277 | 1338 | 1398 | 1459 | 1520 | 1581 | 1642 | 1702 | 1763 | 1824 | 1885 | 1946 | 2006 | 2067 |
| 575 | 1105 | 1163 | 1221 | 1279 | 1338 | 1396 | 1454 | 1512 | 1570 | 1628 | 1687 | 1745 | 1803 | 1861 | 1919 | 1977 |
| 600 | 1059 | 1115 | 1170 | 1226 | 1282 | 1338 | 1393 | 1449 | 1505 | 1561 | 1616 | 1672 | 1728 | 1783 | 1839 | 1895 |
| 625 | 1017 | 1070 | 1124 | 1177 | 1231 | 1284 | 1338 | 1391 | 1445 | 1498 | 1552 | 1605 | 1659 | 1712 | 1766 | 1819 |
| 650 | 977 | 1029 | 1080 | 1132 | 1183 | 1235 | 1286 | 1338 | 1389 | 1440 | 1492 | 1543 | 1595 | 1646 | 1698 | 1749 |
| 675 | 941 | 991 | 1040 | 1090 | 1139 | 1189 | 1239 | 1288 | 1338 | 1387 | 1437 | 1486 | 1536 | 1585 | 1635 | 1684 |
| 700 | 908 | 955 | 1003 | 1051 | 1099 | 1147 | 1194 | 1242 | 1290 | 1338 | 1385 | 1433 | 1481 | 1529 | 1576 | 1624 |
| 725 | 876 | 922 | 969 | 1015 | 1061 | 1107 | 1153 | 1199 | 1245 | 1291 | 1338 | 1384 | 1430 | 1476 | 1522 | 1568 |
| 750 | 847 | 892 | 936 | 981 | 1025 | 1070 | 1115 | 1159 | 1204 | 1248 | 1293 | 1338 | 1382 | 1427 | 1471 | 1516 |
| 775 | 820 | 863 | 906 | 949 | 992 | 1036 | 1079 | 1122 | 1165 | 1208 | 1251 | 1294 | 1338 | 1381 | 1424 | 1467 |
| 800 | 794 | 836 | 878 | 920 | 961 | 1003 | 1045 | 1087 | 1129 | 1170 | 1212 | 1254 | 1296 | 1338 | 1379 | 1421 |
| 825 | 770 | 811 | 851 | 892 | 932 | 973 | 1013 | 1054 | 1094 | 1135 | 1175 | 1216 | 1257 | 1297 | 1338 | 1378 |
| 850 | 747 | 787 | 826 | 866 | 905 | 944 | 984 | 1023 | 1062 | 1102 | 1141 | 1180 | 1220 | 1259 | 1298 | 1338 |
| 875 | 726 | 764 | 803 | 841 | 879 | 917 | 955 | 994 | 1032 | 1070 | 1108 | 1147 | 1185 | 1223 | 1261 | 1299 |
| 900 | 706 | 743 | 780 | 817 | 855 | 892 | 929 | 966 | 1003 | 1040 | 1078 | 1115 | 1152 | 1189 | 1226 | 1263 |
| 925 | 687 | 723 | 759 | 795 | 831 | 868 | 904 | 940 | 976 | 1012 | 1048 | 1085 | 1121 | 1157 | 1193 | 1229 |
| 950 | 669 | 704 | 739 | 774 | 810 | 845 | 880 | 915 | 950 | 986 | 1021 | 1056 | 1091 | 1126 | 1162 | 1197 |
| 975 | 652 | 686 | 720 | 755 | 789 | 823 | 857 | 892 | 926 | 960 | 995 | 1029 | 1063 | 1098 | 1132 | 1166 |
| 1000 | 635 | 669 | 702 | 736 | 769 | 803 | 836 | 869 | 903 | 936 | 970 | 1003 | 1037 | 1070 | 1104 | 1137 |
| 1025 | 620 | 652 | 685 | 718 | 750 | 783 | 816 | 848 | 881 | 913 | 946 | 979 | 1011 | 1044 | 1077 | 1109 |
| 1050 | 605 | 637 | 669 | 701 | 732 | 764 | 796 | 828 | 860 | 892 | 924 | 955 | 987 | 1019 | 1051 | 1083 |
| 1075 | 591 | 622 | 653 | 684 | 715 | 747 | 778 | 809 | 840 | 871 | 902 | 933 | 964 | 995 | 1027 | 1058 |
| 1100 | 578 | 608 | 638 | 669 | 699 | 730 | 760 | 790 | 821 | 851 | 882 | 912 | 942 | 973 | 1003 | 1034 |
| 1125 | 565 | 594 | 624 | 654 | 684 | 713 | 743 | 773 | 803 | 832 | 862 | 892 | 921 | 951 | 981 | 1011 |
| 1150 | 552 | 582 | 611 | 640 | 669 | 698 | 727 | 756 | 785 | 814 | 843 | 872 | 901 | 931 | 960 | 989 |

$$P = \frac{TS \cdot t \cdot E}{R \cdot FS}$$

TS = Tensile Strength 380,000 kPa
t = Thickness of Cylindrical Component, mm
E = Joint Efficiency 88%

R = Radius of Shell (inside Diameter/2), mm
FS = Factor of Safety 5
P = MAWP, kPa

Table S2.10.3.5 Metric (Page 1 of 2)
Maximum Allowable Working Pressure for Cylindrical Components (Barrel)
For Buttstrap Triple-Riveted Joint

| Shell ID (mm) | Minimum Thickness of Shell Plate (mm) | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 8.75 | 9 | 9.25 | 9.5 | 9.75 | 10 | 10.25 | 10.5 | 10.75 | 11 | 11.25 | 11.5 | 11.75 | 12 | 12.25 | 12.5 |
| 300 | 3901 | 4013 | 4124 | 4236 | 4347 | 4459 | 4570 | 4682 | 4793 | 4905 | 5016 | 5127 | 5239 | 5350 | 5462 | 5573 |
| 325 | 3601 | 3704 | 3807 | 3910 | 4013 | 4116 | 4219 | 4321 | 4424 | 4527 | 4630 | 4733 | 4836 | 4939 | 5042 | 5145 |
| 350 | 3344 | 3440 | 3535 | 3631 | 3726 | 3822 | 3917 | 4013 | 4108 | 4204 | 4299 | 4395 | 4491 | 4586 | 4682 | 4777 |
| 375 | 3121 | 3210 | 3299 | 3389 | 3478 | 3567 | 3656 | 3745 | 3834 | 3924 | 4013 | 4102 | 4191 | 4280 | 4369 | 4459 |
| 400 | 2926 | 3010 | 3093 | 3177 | 3260 | 3344 | 3428 | 3511 | 3595 | 3678 | 3762 | 3846 | 3929 | 4013 | 4096 | 4180 |
| 425 | 2754 | 2833 | 2911 | 2990 | 3069 | 3147 | 3226 | 3305 | 3383 | 3462 | 3541 | 3619 | 3698 | 3777 | 3855 | 3934 |
| 450 | 2601 | 2675 | 2750 | 2824 | 2898 | 2972 | 3047 | 3121 | 3195 | 3270 | 3344 | 3418 | 3493 | 3567 | 3641 | 3716 |
| 475 | 2464 | 2534 | 2605 | 2675 | 2746 | 2816 | 2886 | 2957 | 3027 | 3098 | 3168 | 3238 | 3309 | 3379 | 3450 | 3520 |
| 500 | 2341 | 2408 | 2475 | 2541 | 2608 | 2675 | 2742 | 2809 | 2876 | 2943 | 3010 | 3076 | 3143 | 3210 | 3277 | 3344 |
| 525 | 2229 | 2293 | 2357 | 2420 | 2484 | 2548 | 2612 | 2675 | 2739 | 2803 | 2866 | 2930 | 2994 | 3057 | 3121 | 3185 |
| 550 | 2128 | 2189 | 2250 | 2310 | 2371 | 2432 | 2493 | 2554 | 2614 | 2675 | 2736 | 2797 | 2858 | 2918 | 2979 | 3040 |
| 575 | 2035 | 2094 | 2152 | 2210 | 2268 | 2326 | 2384 | 2443 | 2501 | 2559 | 2617 | 2675 | 2733 | 2792 | 2850 | 2908 |
| 600 | 1951 | 2006 | 2062 | 2118 | 2174 | 2229 | 2285 | 2341 | 2397 | 2452 | 2508 | 2564 | 2619 | 2675 | 2731 | 2787 |
| 625 | 1873 | 1926 | 1980 | 2033 | 2087 | 2140 | 2194 | 2247 | 2301 | 2354 | 2408 | 2461 | 2515 | 2568 | 2622 | 2675 |
| 650 | 1801 | 1852 | 1904 | 1955 | 2006 | 2058 | 2109 | 2161 | 2212 | 2264 | 2315 | 2367 | 2418 | 2469 | 2521 | 2572 |
| 675 | 1734 | 1783 | 1833 | 1883 | 1932 | 1982 | 2031 | 2081 | 2130 | 2180 | 2229 | 2279 | 2328 | 2378 | 2427 | 2477 |
| 700 | 1672 | 1720 | 1768 | 1815 | 1863 | 1911 | 1959 | 2006 | 2054 | 2102 | 2150 | 2197 | 2245 | 2293 | 2341 | 2389 |
| 725 | 1614 | 1660 | 1707 | 1753 | 1799 | 1845 | 1891 | 1937 | 1983 | 2029 | 2076 | 2122 | 2168 | 2214 | 2260 | 2306 |
| 750 | 1561 | 1605 | 1650 | 1694 | 1739 | 1783 | 1828 | 1873 | 1917 | 1962 | 2006 | 2051 | 2096 | 2140 | 2185 | 2229 |
| 775 | 1510 | 1553 | 1596 | 1640 | 1683 | 1726 | 1769 | 1812 | 1855 | 1899 | 1942 | 1985 | 2028 | 2071 | 2114 | 2157 |
| 800 | 1463 | 1505 | 1547 | 1588 | 1630 | 1672 | 1714 | 1756 | 1797 | 1839 | 1881 | 1923 | 1965 | 2006 | 2048 | 2090 |
| 825 | 1419 | 1459 | 1500 | 1540 | 1581 | 1621 | 1662 | 1702 | 1743 | 1783 | 1824 | 1865 | 1905 | 1946 | 1986 | 2027 |
| 850 | 1377 | 1416 | 1456 | 1495 | 1534 | 1574 | 1613 | 1652 | 1692 | 1731 | 1770 | 1810 | 1849 | 1888 | 1928 | 1967 |
| 875 | 1338 | 1376 | 1414 | 1452 | 1490 | 1529 | 1567 | 1605 | 1643 | 1682 | 1720 | 1758 | 1796 | 1834 | 1873 | 1911 |
| 900 | 1300 | 1338 | 1375 | 1412 | 1449 | 1486 | 1523 | 1561 | 1598 | 1635 | 1672 | 1709 | 1746 | 1783 | 1821 | 1858 |
| 925 | 1265 | 1301 | 1338 | 1374 | 1410 | 1446 | 1482 | 1518 | 1555 | 1591 | 1627 | 1663 | 1699 | 1735 | 1771 | 1808 |
| 950 | 1232 | 1267 | 1302 | 1338 | 1373 | 1408 | 1443 | 1478 | 1514 | 1549 | 1584 | 1619 | 1654 | 1690 | 1725 | 1760 |
| 975 | 1200 | 1235 | 1269 | 1303 | 1338 | 1372 | 1406 | 1440 | 1475 | 1509 | 1543 | 1578 | 1612 | 1646 | 1681 | 1715 |
| 1000 | 1170 | 1204 | 1237 | 1271 | 1304 | 1338 | 1371 | 1404 | 1438 | 1471 | 1505 | 1538 | 1572 | 1605 | 1639 | 1672 |
| 1025 | 1142 | 1174 | 1207 | 1240 | 1272 | 1305 | 1338 | 1370 | 1403 | 1435 | 1468 | 1501 | 1533 | 1566 | 1599 | 1631 |
| 1050 | 1115 | 1147 | 1178 | 1210 | 1242 | 1274 | 1306 | 1338 | 1369 | 1401 | 1433 | 1465 | 1497 | 1529 | 1561 | 1592 |
| 1075 | 1089 | 1120 | 1151 | 1182 | 1213 | 1244 | 1275 | 1306 | 1338 | 1369 | 1400 | 1431 | 1462 | 1493 | 1524 | 1555 |
| 1100 | 1064 | 1094 | 1125 | 1155 | 1186 | 1216 | 1246 | 1277 | 1307 | 1338 | 1368 | 1398 | 1429 | 1459 | 1490 | 1520 |
| 1125 | 1040 | 1070 | 1100 | 1130 | 1159 | 1189 | 1219 | 1248 | 1278 | 1308 | 1338 | 1367 | 1397 | 1427 | 1456 | 1486 |
| 1150 | 1018 | 1047 | 1076 | 1105 | 1134 | 1163 | 1192 | 1221 | 1250 | 1279 | 1309 | 1338 | 1367 | 1396 | 1425 | 1454 |

$$P = \frac{TS \cdot t \cdot E}{R \cdot FS}$$

TS = Tensile Strength 380,000 kPa
t = Thickness of Cylindrical Component, mm
E = Joint Efficiency 88%

R = Radius of Shell (inside Diameter/2), mm
FS = Factor of Safety 5
P = MAWP, kPa

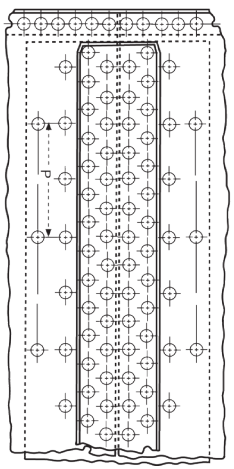
Table S2.10.3.5 Metric (Page 2 of 2)
Maximum Allowable Working Pressure for Cylindrical Components (Barrel)
For Buttstrap Triple-Riveted Joint

# TABLE S2.10.3.7

## MAXIMUM ALLOWABLE WORKING PRESSURE FOR CYLINDRICAL COMPONENTS (BARREL)

**For Buttstrap Quadruple-Riveted Joint**

| Shell ID | Minimum Thickness of Shell Plate | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0.19 | 0.2 | 0.21 | 0.22 | 0.23 | 0.24 | 0.25 | 0.26 | 0.27 | 0.28 | 0.29 | 0.3 | 0.31 | 0.32 | 0.33 | 0.34 | 0.35 | 0.36 | 0.37 | 0.38 | 0.39 | 0.4 | 0.41 | 0.42 | 0.43 | 0.44 | 0.45 | 0.46 | 0.47 | 0.48 | 0.49 | 0.5 |
| 12 | 327 | 345 | 362 | 379 | 396 | 414 | 431 | 448 | 465 | 483 | 500 | 517 | 534 | 551 | 569 | 586 | 603 | 620 | 638 | 655 | 672 | 689 | 707 | 724 | 741 | 758 | 776 | 793 | 810 | 827 | 844 | 862 |
| 13 | 302 | 318 | 334 | 350 | 366 | 382 | 398 | 414 | 430 | 445 | 461 | 477 | 493 | 509 | 525 | 541 | 557 | 573 | 589 | 604 | 620 | 636 | 652 | 668 | 684 | 700 | 716 | 732 | 748 | 764 | 779 | 795 |
| 14 | 281 | 295 | 310 | 325 | 340 | 355 | 369 | 384 | 399 | 414 | 428 | 443 | 458 | 473 | 487 | 502 | 517 | 532 | 547 | 561 | 576 | 591 | 606 | 620 | 635 | 650 | 665 | 679 | 694 | 709 | 724 | 739 |
| 15 | 262 | 276 | 290 | 303 | 317 | 331 | 345 | 358 | 372 | 386 | 400 | 414 | 427 | 441 | 455 | 469 | 483 | 496 | 510 | 524 | 538 | 551 | 565 | 579 | 593 | 607 | 620 | 634 | 648 | 662 | 676 | 689 |
| 16 | 246 | 259 | 271 | 284 | 297 | 310 | 323 | 336 | 349 | 362 | 375 | 388 | 401 | 414 | 427 | 439 | 452 | 465 | 478 | 491 | 504 | 517 | 530 | 543 | 556 | 569 | 582 | 595 | 607 | 620 | 633 | 646 |
| 17 | 231 | 243 | 255 | 268 | 280 | 292 | 304 | 316 | 328 | 341 | 353 | 365 | 377 | 389 | 401 | 414 | 426 | 438 | 450 | 462 | 474 | 487 | 499 | 511 | 523 | 535 | 547 | 560 | 572 | 584 | 596 | 608 |
| 18 | 218 | 230 | 241 | 253 | 264 | 276 | 287 | 299 | 310 | 322 | 333 | 345 | 356 | 368 | 379 | 391 | 402 | 414 | 425 | 437 | 448 | 460 | 471 | 483 | 494 | 506 | 517 | 528 | 540 | 551 | 563 | 574 |
| 19 | 207 | 218 | 229 | 239 | 250 | 261 | 272 | 283 | 294 | 305 | 316 | 327 | 337 | 348 | 359 | 370 | 381 | 392 | 403 | 414 | 424 | 435 | 446 | 457 | 468 | 479 | 490 | 501 | 512 | 522 | 533 | 544 |
| 20 | 196 | 207 | 217 | 227 | 238 | 248 | 259 | 269 | 279 | 290 | 300 | 310 | 321 | 331 | 341 | 352 | 362 | 372 | 383 | 393 | 403 | 414 | 424 | 434 | 445 | 455 | 465 | 476 | 486 | 496 | 507 | 517 |
| 21 | 187 | 197 | 207 | 217 | 226 | 236 | 246 | 256 | 266 | 276 | 286 | 295 | 305 | 315 | 325 | 335 | 345 | 355 | 364 | 374 | 384 | 394 | 404 | 414 | 423 | 433 | 443 | 453 | 463 | 473 | 483 | 492 |
| 22 | 179 | 188 | 197 | 207 | 216 | 226 | 235 | 244 | 254 | 263 | 273 | 282 | 291 | 301 | 310 | 320 | 329 | 338 | 348 | 357 | 367 | 376 | 385 | 395 | 404 | 414 | 423 | 432 | 442 | 451 | 461 | 470 |
| 23 | 171 | 180 | 189 | 198 | 207 | 216 | 225 | 234 | 243 | 252 | 261 | 270 | 279 | 288 | 297 | 306 | 315 | 324 | 333 | 342 | 351 | 360 | 369 | 378 | 387 | 396 | 405 | 414 | 423 | 432 | 441 | 450 |
| 24 | 164 | 172 | 181 | 190 | 198 | 207 | 215 | 224 | 233 | 241 | 250 | 259 | 267 | 276 | 284 | 293 | 302 | 310 | 319 | 327 | 336 | 345 | 353 | 362 | 371 | 379 | 388 | 396 | 405 | 414 | 422 | 431 |
| 25 | 157 | 165 | 174 | 182 | 190 | 199 | 207 | 215 | 223 | 232 | 240 | 248 | 256 | 265 | 273 | 281 | 290 | 298 | 306 | 314 | 323 | 331 | 339 | 347 | 356 | 364 | 372 | 381 | 389 | 397 | 405 | 414 |
| 26 | 151 | 159 | 167 | 175 | 183 | 191 | 199 | 207 | 215 | 223 | 231 | 239 | 247 | 255 | 262 | 270 | 278 | 286 | 294 | 302 | 310 | 318 | 326 | 334 | 342 | 350 | 358 | 366 | 374 | 382 | 390 | 398 |
| 27 | 146 | 153 | 161 | 169 | 176 | 184 | 191 | 199 | 207 | 214 | 222 | 230 | 237 | 245 | 253 | 260 | 268 | 276 | 283 | 291 | 299 | 306 | 314 | 322 | 329 | 337 | 345 | 352 | 360 | 368 | 375 | 383 |
| 28 | 140 | 148 | 155 | 162 | 170 | 177 | 185 | 192 | 199 | 207 | 214 | 222 | 229 | 236 | 244 | 251 | 259 | 266 | 273 | 281 | 288 | 295 | 303 | 310 | 318 | 325 | 332 | 340 | 347 | 355 | 362 | 369 |
| 29 | 135 | 143 | 150 | 157 | 164 | 171 | 178 | 185 | 193 | 200 | 207 | 214 | 221 | 228 | 235 | 242 | 250 | 257 | 264 | 271 | 278 | 285 | 292 | 300 | 307 | 314 | 321 | 328 | 335 | 342 | 349 | 357 |
| 30 | 131 | 138 | 145 | 152 | 159 | 165 | 172 | 179 | 186 | 193 | 200 | 207 | 214 | 221 | 227 | 234 | 241 | 248 | 255 | 262 | 269 | 276 | 283 | 290 | 296 | 303 | 310 | 317 | 324 | 331 | 338 | 345 |
| 31 | 127 | 133 | 140 | 147 | 153 | 160 | 167 | 173 | 180 | 187 | 193 | 200 | 207 | 213 | 220 | 227 | 233 | 240 | 247 | 253 | 260 | 267 | 274 | 280 | 287 | 294 | 300 | 307 | 314 | 320 | 327 | 334 |
| 32 | 123 | 129 | 136 | 142 | 149 | 155 | 162 | 168 | 174 | 181 | 187 | 194 | 200 | 207 | 213 | 220 | 226 | 233 | 239 | 246 | 252 | 259 | 265 | 271 | 278 | 284 | 291 | 297 | 304 | 310 | 317 | 323 |
| 33 | 119 | 125 | 132 | 138 | 144 | 150 | 157 | 163 | 169 | 175 | 182 | 188 | 194 | 201 | 207 | 213 | 219 | 226 | 232 | 238 | 244 | 251 | 257 | 263 | 269 | 276 | 282 | 288 | 295 | 301 | 307 | 313 |
| 34 | 116 | 122 | 128 | 134 | 140 | 146 | 152 | 158 | 164 | 170 | 176 | 182 | 189 | 195 | 201 | 207 | 213 | 219 | 225 | 231 | 237 | 243 | 249 | 255 | 262 | 268 | 274 | 280 | 286 | 292 | 298 | 304 |
| 35 | 112 | 118 | 124 | 130 | 136 | 142 | 148 | 154 | 160 | 165 | 171 | 177 | 183 | 189 | 195 | 201 | 207 | 213 | 219 | 225 | 230 | 236 | 242 | 248 | 254 | 260 | 266 | 272 | 278 | 284 | 290 | 295 |
| 36 | 109 | 115 | 121 | 126 | 132 | 138 | 144 | 149 | 155 | 161 | 167 | 172 | 178 | 184 | 190 | 195 | 201 | 207 | 213 | 218 | 224 | 230 | 236 | 241 | 247 | 253 | 259 | 264 | 270 | 276 | 281 | 287 |
| 37 | 106 | 112 | 117 | 123 | 129 | 134 | 140 | 145 | 151 | 156 | 162 | 168 | 173 | 179 | 184 | 190 | 196 | 201 | 207 | 212 | 218 | 224 | 229 | 235 | 240 | 246 | 252 | 257 | 263 | 268 | 274 | 279 |
| 38 | 103 | 109 | 114 | 120 | 125 | 131 | 136 | 141 | 147 | 152 | 158 | 163 | 169 | 174 | 180 | 185 | 190 | 196 | 201 | 207 | 212 | 218 | 223 | 229 | 234 | 239 | 245 | 250 | 256 | 261 | 267 | 272 |
| 39 | 101 | 106 | 111 | 117 | 122 | 127 | 133 | 138 | 143 | 148 | 154 | 159 | 164 | 170 | 175 | 180 | 186 | 191 | 196 | 201 | 207 | 212 | 217 | 223 | 228 | 233 | 239 | 244 | 249 | 255 | 260 | 265 |
| 40 | 98 | 103 | 109 | 114 | 119 | 124 | 129 | 134 | 140 | 145 | 150 | 155 | 160 | 165 | 171 | 176 | 181 | 186 | 191 | 196 | 202 | 207 | 212 | 217 | 222 | 227 | 233 | 238 | 243 | 248 | 253 | 259 |
| 41 | 96 | 101 | 106 | 111 | 116 | 121 | 126 | 131 | 136 | 141 | 146 | 151 | 156 | 161 | 166 | 171 | 177 | 182 | 187 | 192 | 197 | 202 | 207 | 212 | 217 | 222 | 227 | 232 | 237 | 242 | 247 | 252 |
| 42 | 94 | 98 | 103 | 108 | 113 | 118 | 123 | 128 | 133 | 138 | 143 | 148 | 153 | 158 | 162 | 167 | 172 | 177 | 182 | 187 | 192 | 197 | 202 | 207 | 212 | 217 | 222 | 226 | 231 | 236 | 241 | 246 |
| 43 | 91 | 96 | 101 | 106 | 111 | 115 | 120 | 125 | 130 | 135 | 139 | 144 | 149 | 154 | 159 | 164 | 168 | 173 | 178 | 183 | 188 | 192 | 197 | 202 | 207 | 212 | 216 | 221 | 226 | 231 | 236 | 240 |
| 44 | 89 | 94 | 99 | 103 | 108 | 113 | 118 | 122 | 127 | 132 | 136 | 141 | 146 | 150 | 155 | 160 | 165 | 169 | 174 | 179 | 183 | 188 | 193 | 197 | 202 | 207 | 212 | 216 | 221 | 226 | 230 | 235 |
| 45 | 87 | 92 | 97 | 101 | 106 | 110 | 115 | 119 | 124 | 129 | 133 | 138 | 142 | 147 | 152 | 156 | 161 | 165 | 170 | 175 | 179 | 184 | 188 | 193 | 198 | 202 | 207 | 211 | 216 | 221 | 225 | 230 |




**TS = Tensile Strength (55,000)**

**t = Thickness of Cylindrical Component**

**TS x t x E/R x FS**

**R = Radius of Shell (inside diameter/2)**

**E = Joint Efficiency (94%)**

**FS = Factor of Safety (5)**

| Shell ID (mm) | Minimum Thickness of Shell Plate (mm) | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 4.75 | 5 | 5.25 | 5.5 | 5.75 | 6 | 6.25 | 6.5 | 6.75 | 7 | 7.25 | 7.5 | 7.75 | 8 | 8.25 |
| 300 | 2262 | 2381 | 2500 | 2619 | 2739 | 2858 | 2977 | 3096 | 3215 | 3334 | 3453 | 3572 | 3691 | 3810 | 3929 |
| 325 | 2088 | 2198 | 2308 | 2418 | 2528 | 2638 | 2748 | 2858 | 2968 | 3077 | 3187 | 3297 | 3407 | 3517 | 3627 |
| 350 | 1939 | 2041 | 2143 | 2245 | 2347 | 2449 | 2551 | 2653 | 2756 | 2858 | 2960 | 3062 | 3164 | 3266 | 3368 |
| 375 | 1810 | 1905 | 2000 | 2096 | 2191 | 2286 | 2381 | 2477 | 2572 | 2667 | 2762 | 2858 | 2953 | 3048 | 3143 |
| 400 | 1697 | 1786 | 1875 | 1965 | 2054 | 2143 | 2233 | 2322 | 2411 | 2500 | 2590 | 2679 | 2768 | 2858 | 2947 |
| 425 | 1597 | 1681 | 1765 | 1849 | 1933 | 2017 | 2101 | 2185 | 2269 | 2353 | 2437 | 2521 | 2605 | 2690 | 2774 |
| 450 | 1508 | 1588 | 1667 | 1746 | 1826 | 1905 | 1984 | 2064 | 2143 | 2223 | 2302 | 2381 | 2461 | 2540 | 2619 |
| 475 | 1429 | 1504 | 1579 | 1654 | 1730 | 1805 | 1880 | 1955 | 2030 | 2106 | 2181 | 2256 | 2331 | 2406 | 2482 |
| 500 | 1357 | 1429 | 1500 | 1572 | 1643 | 1715 | 1786 | 1857 | 1929 | 2000 | 2072 | 2143 | 2215 | 2286 | 2358 |
| 525 | 1293 | 1361 | 1429 | 1497 | 1565 | 1633 | 1701 | 1769 | 1837 | 1905 | 1973 | 2041 | 2109 | 2177 | 2245 |
| 550 | 1234 | 1299 | 1364 | 1429 | 1494 | 1559 | 1624 | 1689 | 1754 | 1818 | 1883 | 1948 | 2013 | 2078 | 2143 |
| 575 | 1180 | 1242 | 1305 | 1367 | 1429 | 1491 | 1553 | 1615 | 1677 | 1739 | 1802 | 1864 | 1926 | 1988 | 2050 |
| 600 | 1131 | 1191 | 1250 | 1310 | 1369 | 1429 | 1488 | 1548 | 1607 | 1667 | 1726 | 1786 | 1846 | 1905 | 1965 |
| 625 | 1086 | 1143 | 1200 | 1257 | 1314 | 1372 | 1429 | 1486 | 1543 | 1600 | 1657 | 1715 | 1772 | 1829 | 1886 |
| 650 | 1044 | 1099 | 1154 | 1209 | 1264 | 1319 | 1374 | 1429 | 1484 | 1539 | 1594 | 1649 | 1704 | 1759 | 1813 |
| 675 | 1005 | 1058 | 1111 | 1164 | 1217 | 1270 | 1323 | 1376 | 1429 | 1482 | 1535 | 1588 | 1640 | 1693 | 1746 |
| 700 | 970 | 1021 | 1072 | 1123 | 1174 | 1225 | 1276 | 1327 | 1378 | 1429 | 1480 | 1531 | 1582 | 1633 | 1684 |
| 725 | 936 | 985 | 1035 | 1084 | 1133 | 1182 | 1232 | 1281 | 1330 | 1380 | 1429 | 1478 | 1527 | 1577 | 1626 |
| 750 | 905 | 953 | 1000 | 1048 | 1095 | 1143 | 1191 | 1238 | 1286 | 1334 | 1381 | 1429 | 1476 | 1524 | 1572 |
| 775 | 876 | 922 | 968 | 1014 | 1060 | 1106 | 1152 | 1198 | 1244 | 1291 | 1337 | 1383 | 1429 | 1475 | 1521 |
| 800 | 848 | 893 | 938 | 982 | 1027 | 1072 | 1116 | 1161 | 1206 | 1250 | 1295 | 1340 | 1384 | 1429 | 1473 |
| 825 | 823 | 866 | 909 | 953 | 996 | 1039 | 1082 | 1126 | 1169 | 1212 | 1256 | 1299 | 1342 | 1386 | 1429 |
| 850 | 798 | 840 | 882 | 925 | 967 | 1009 | 1051 | 1093 | 1135 | 1177 | 1219 | 1261 | 1303 | 1345 | 1387 |
| 875 | 776 | 816 | 857 | 898 | 939 | 980 | 1021 | 1061 | 1102 | 1143 | 1184 | 1225 | 1266 | 1306 | 1347 |
| 900 | 754 | 794 | 833 | 873 | 913 | 953 | 992 | 1032 | 1072 | 1111 | 1151 | 1191 | 1230 | 1270 | 1310 |
| 925 | 734 | 772 | 811 | 850 | 888 | 927 | 965 | 1004 | 1043 | 1081 | 1120 | 1158 | 1197 | 1236 | 1274 |
| 950 | 714 | 752 | 790 | 827 | 865 | 902 | 940 | 978 | 1015 | 1053 | 1090 | 1128 | 1166 | 1203 | 1241 |
| 975 | 696 | 733 | 769 | 806 | 843 | 879 | 916 | 953 | 989 | 1026 | 1062 | 1099 | 1136 | 1172 | 1209 |
| 1000 | 679 | 714 | 750 | 786 | 822 | 857 | 893 | 929 | 964 | 1000 | 1036 | 1072 | 1107 | 1143 | 1179 |
| 1025 | 662 | 697 | 732 | 767 | 802 | 836 | 871 | 906 | 941 | 976 | 1011 | 1045 | 1080 | 1115 | 1150 |
| 1050 | 646 | 680 | 714 | 748 | 782 | 816 | 850 | 884 | 919 | 953 | 987 | 1021 | 1055 | 1089 | 1123 |
| 1075 | 631 | 665 | 698 | 731 | 764 | 797 | 831 | 864 | 897 | 930 | 964 | 997 | 1030 | 1063 | 1097 |
| 1100 | 617 | 649 | 682 | 714 | 747 | 779 | 812 | 844 | 877 | 909 | 942 | 974 | 1007 | 1039 | 1072 |
| 1125 | 603 | 635 | 667 | 699 | 730 | 762 | 794 | 826 | 857 | 889 | 921 | 953 | 984 | 1016 | 1048 |
| 1150 | 590 | 621 | 652 | 683 | 714 | 745 | 777 | 808 | 839 | 870 | 901 | 932 | 963 | 994 | 1025 |

$$P = \frac{TS \cdot t \cdot E}{R \cdot FS}$$

TS = Tensile Strength 380,000 kPa
t = Thickness of Cylindrical Component, mm
E = Joint Efficiency 94%

R = Radius of Shell (inside Diameter/2), mm
FS = Factor of Safety 5
P = MAWP, kPa

Table S2.10.3.6 Metric (Page 1 of 2)
Maximum Allowable Working Pressure for Cylindrical Components (Barrel)
For Buttstrap Quadruple-Riveted Joint

| Shell ID (mm) | Minimum Thickness of Shell Plate (mm) | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 8.75 | 9 | 9.25 | 9.5 | 9.75 | 10 | 10.25 | 10.5 | 10.75 | 11 | 11.25 | 11.5 | 11.75 | 12 | 12.25 | 12.5 |
| 300 | 4167 | 4286 | 4405 | 4525 | 4644 | 4763 | 4882 | 5001 | 5120 | 5239 | 5358 | 5477 | 5596 | 5715 | 5834 | 5953 |
| 325 | 3847 | 3957 | 4067 | 4176 | 4286 | 4396 | 4506 | 4616 | 4726 | 4836 | 4946 | 5056 | 5166 | 5276 | 5385 | 5495 |
| 350 | 3572 | 3674 | 3776 | 3878 | 3980 | 4082 | 4184 | 4286 | 4388 | 4491 | 4593 | 4695 | 4797 | 4899 | 5001 | 5103 |
| 375 | 3334 | 3429 | 3524 | 3620 | 3715 | 3810 | 3905 | 4001 | 4096 | 4191 | 4286 | 4382 | 4477 | 4572 | 4667 | 4763 |
| 400 | 3126 | 3215 | 3304 | 3393 | 3483 | 3572 | 3661 | 3751 | 3840 | 3929 | 4019 | 4108 | 4197 | 4286 | 4376 | 4465 |
| 425 | 2942 | 3026 | 3110 | 3194 | 3278 | 3362 | 3446 | 3530 | 3614 | 3698 | 3782 | 3866 | 3950 | 4034 | 4118 | 4202 |
| 450 | 2778 | 2858 | 2937 | 3016 | 3096 | 3175 | 3254 | 3334 | 3413 | 3493 | 3572 | 3651 | 3731 | 3810 | 3890 | 3969 |
| 475 | 2632 | 2707 | 2782 | 2858 | 2933 | 3008 | 3083 | 3158 | 3234 | 3309 | 3384 | 3459 | 3534 | 3610 | 3685 | 3760 |
| 500 | 2500 | 2572 | 2643 | 2715 | 2786 | 2858 | 2929 | 3000 | 3072 | 3143 | 3215 | 3286 | 3358 | 3429 | 3501 | 3572 |
| 525 | 2381 | 2449 | 2517 | 2585 | 2653 | 2722 | 2790 | 2858 | 2926 | 2994 | 3062 | 3130 | 3198 | 3266 | 3334 | 3402 |
| 550 | 2273 | 2338 | 2403 | 2468 | 2533 | 2598 | 2663 | 2728 | 2793 | 2858 | 2923 | 2987 | 3052 | 3117 | 3182 | 3247 |
| 575 | 2174 | 2236 | 2299 | 2361 | 2423 | 2485 | 2547 | 2609 | 2671 | 2733 | 2795 | 2858 | 2920 | 2982 | 3044 | 3106 |
| 600 | 2084 | 2143 | 2203 | 2262 | 2322 | 2381 | 2441 | 2500 | 2560 | 2619 | 2679 | 2739 | 2798 | 2858 | 2917 | 2977 |
| 625 | 2000 | 2057 | 2115 | 2172 | 2229 | 2286 | 2343 | 2400 | 2458 | 2515 | 2572 | 2629 | 2686 | 2743 | 2800 | 2858 |
| 650 | 1923 | 1978 | 2033 | 2088 | 2143 | 2198 | 2253 | 2308 | 2363 | 2418 | 2473 | 2528 | 2583 | 2638 | 2693 | 2748 |
| 675 | 1852 | 1905 | 1958 | 2011 | 2064 | 2117 | 2170 | 2223 | 2275 | 2328 | 2381 | 2434 | 2487 | 2540 | 2593 | 2646 |
| 700 | 1786 | 1837 | 1888 | 1939 | 1990 | 2041 | 2092 | 2143 | 2194 | 2245 | 2296 | 2347 | 2398 | 2449 | 2500 | 2551 |
| 725 | 1724 | 1774 | 1823 | 1872 | 1921 | 1971 | 2020 | 2069 | 2119 | 2168 | 2217 | 2266 | 2316 | 2365 | 2414 | 2463 |
| 750 | 1667 | 1715 | 1762 | 1810 | 1857 | 1905 | 1953 | 2000 | 2048 | 2096 | 2143 | 2191 | 2238 | 2286 | 2334 | 2381 |
| 775 | 1613 | 1659 | 1705 | 1751 | 1798 | 1844 | 1890 | 1936 | 1982 | 2028 | 2074 | 2120 | 2166 | 2212 | 2258 | 2305 |
| 800 | 1563 | 1607 | 1652 | 1697 | 1741 | 1786 | 1831 | 1875 | 1920 | 1965 | 2009 | 2054 | 2099 | 2143 | 2188 | 2233 |
| 825 | 1515 | 1559 | 1602 | 1645 | 1689 | 1732 | 1775 | 1818 | 1862 | 1905 | 1948 | 1992 | 2035 | 2078 | 2122 | 2165 |
| 850 | 1471 | 1513 | 1555 | 1597 | 1639 | 1681 | 1723 | 1765 | 1807 | 1849 | 1891 | 1933 | 1975 | 2017 | 2059 | 2101 |
| 875 | 1429 | 1470 | 1510 | 1551 | 1592 | 1633 | 1674 | 1715 | 1755 | 1796 | 1837 | 1878 | 1919 | 1959 | 2000 | 2041 |
| 900 | 1389 | 1429 | 1468 | 1508 | 1548 | 1588 | 1627 | 1667 | 1707 | 1746 | 1786 | 1826 | 1865 | 1905 | 1945 | 1984 |
| 925 | 1352 | 1390 | 1429 | 1467 | 1506 | 1545 | 1583 | 1622 | 1660 | 1699 | 1738 | 1776 | 1815 | 1854 | 1892 | 1931 |
| 950 | 1316 | 1354 | 1391 | 1429 | 1466 | 1504 | 1542 | 1579 | 1617 | 1654 | 1692 | 1730 | 1767 | 1805 | 1842 | 1880 |
| 975 | 1282 | 1319 | 1356 | 1392 | 1429 | 1465 | 1502 | 1539 | 1575 | 1612 | 1649 | 1685 | 1722 | 1759 | 1795 | 1832 |
| 1000 | 1250 | 1286 | 1322 | 1357 | 1393 | 1429 | 1465 | 1500 | 1536 | 1572 | 1607 | 1643 | 1679 | 1715 | 1750 | 1786 |
| 1025 | 1220 | 1255 | 1289 | 1324 | 1359 | 1394 | 1429 | 1464 | 1498 | 1533 | 1568 | 1603 | 1638 | 1673 | 1708 | 1742 |
| 1050 | 1191 | 1225 | 1259 | 1293 | 1327 | 1361 | 1395 | 1429 | 1463 | 1497 | 1531 | 1565 | 1599 | 1633 | 1667 | 1701 |
| 1075 | 1163 | 1196 | 1229 | 1263 | 1296 | 1329 | 1362 | 1396 | 1429 | 1462 | 1495 | 1528 | 1562 | 1595 | 1628 | 1661 |
| 1100 | 1137 | 1169 | 1201 | 1234 | 1266 | 1299 | 1331 | 1364 | 1396 | 1429 | 1461 | 1494 | 1526 | 1559 | 1591 | 1624 |
| 1125 | 1111 | 1143 | 1175 | 1207 | 1238 | 1270 | 1302 | 1334 | 1365 | 1397 | 1429 | 1461 | 1492 | 1524 | 1556 | 1588 |
| 1150 | 1087 | 1118 | 1149 | 1180 | 1211 | 1242 | 1273 | 1305 | 1336 | 1367 | 1398 | 1429 | 1460 | 1491 | 1522 | 1553 |

$$P = \frac{TS \cdot t \cdot E}{R \cdot FS}$$

TS = Tensile Strength 380,000 kPa
t = Thickness of Cylindrical Component, mm
E = Joint Efficiency 94%

R = Radius of Shell (inside Diameter/2), mm
FS = Factor of Safety 5
P= MAWP , KPa

Table S2.10.3.6 Metric (Page 2 of 2)
Maximum Allowable Working Pressure for Cylindrical Components (Barrel)
For Buttstrap Quadruple–Riveted Joint

### S2.10.4 STAYED SURFACES

The maximum allowable working pressure for stayed flat plates and those parts which, by these rules, require staying as flat plates with stays or staybolts of uniform diameter, uniformly spaced, shall be calculated using the following formula or NBIC Part 2, Table S2.10.4.

When pitches of stays or staybolts of uniform diameter are symmetrical and form a rectangle, the equation may be replaced with the following equation:

$$P = \frac{2 * t^2 * S * C}{l^2 + w^2}$$

See definitions of nomenclature in S2.10.6.

### S2.10.4.1 STAYBOLTS

The maximum allowable working pressure for symmetrically spaced corroded staybolts will be calculated using the formula provided in either of the two following paragraphs or the accompanying tables. Equations calculate MAWP based on measuring the staybolt spacing on the stayed surface and the minimum diameter of the corroded staybolt.

a) Iron Staybolt

Staybolts which are of iron or of unknown material shall be calculated using the following formula or Table S2.10.4.1-a. The table is based on a stress value of 7,500 psi (51.7 MPa) for staybolts. Refer to ASME Section 1, 1971 Edition, Table PG-23.3, for allowable loads for all staybolts.

$$p = \frac{\pi \left[\frac{d}{2}\right]^2 s}{p^2}$$

S = 7,500 psi (51.7 MPa)

b) Steel Staybolts

Staybolts of known, steel material shall be calculated using the following formula or Table S2.10.4.1-b. The table is based on a stress value of 11,300 psi (78.0 MPa) for staybolts. Refer to ASME Section 1, 1971 Addenda for allowable loads for all staybolts.

$$p = \frac{\pi \left[\frac{d}{2}\right]^2 s}{1.1 x p^2}$$

S = 11,300 psi (78.0 MPa)

### S2.10.4.2 BULGING

Stayed surfaces shall be examined and any deformations shall be measured and recorded. Deformations may be caused from freezing, localized overheating, broken staybolts, or extended use (cyclic activity). Deformations may by described as bulging, bagging, or pillow/mattress-effects. The bulged section depth is defined as the protrusion of the sheet beyond its original position.

a) Changes in deformations between inspections shall be noted and shall require additional evaluation to determine fitness for service.

b) The probable cause of the deformation shall be determined and, where possible, resolved. For example, overheating due to scale build-up requires removal of scale.

c) The amount of the bulging shall be measured:

1) If the depth of the bulge does not exceed 50% of plate thickness, then no further activity is required.

2) If the depth of the bulge is between 50% and 100% plate thickness, and thread engagement is not affected, then additional NDE is required.

**Note:** If ultrasonic thickness testing is performed (see S2.6.2 c)), then it is performed on a tight 1 in. (25 mm) grid to determine any thinning throughout the deformation. Any generalized thinning shall be used in the calculation of MAWP (see S2.6.2 b)). If the depth of the bulge exceeds the thickness of the plate, then repair is required.

d) The location of the deformations shall be examined. If the point of tangency of the curve in a bulge is within 't' of the edge of the staybolt head, then determination of thread engagement shall be made ('t' is defined in S2.10.6 and is the minimum thickness of the shell plate). Removal of one or more staybolts may be required to make this determination. Refer to figure NBIC Part 2, Figure S2.10.4.2 a).

Cracks, deformations, and/or missing portions of the threaded staybolt head may indicate a deformation of the plate at the staybolt.

e) The following guidelines apply where repair is required.

1) Plate may only be repaired using a flush patch, in accordance with NBIC Part 3, Supplement 2.

2) Where a deformation is to be repaired, all portions of the deformity shall be repaired. For example, for contiguous bulging where only some bulges exceed allowable deformation, the entire bulged area shall be repaired (See Figure S2.10.4.2-b). Unrelated bulges separated by non-deformed plate shall be independently evaluated.



**FIGURE S2.10.4.2-a**

POINT OF TANGENCY OF THE CURVE IN A BULGE WITHIN 't' OF THE EDGE OF THE STAYBOLT

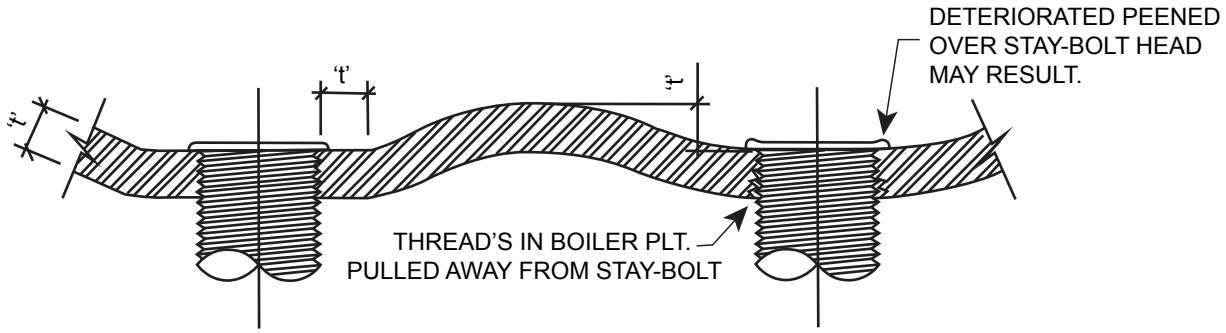


**FIGURE S2.10.4.2-b**

CONTINUOUS BULGING WHERE ONLY SOME BULGES EXCEED ALLOWABLE DEFORMATION



| Thickness of Stayed Surface, in. | Staybolt Spacing (Maximum Pitch, in.) | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 3.5 | 3.625 | 3.75 | 3.875 | 4 | 4.125 | 4.25 | 4.375 | 4.5 | 4.625 | 4.75 | 4.875 | 5 | 5.125 | 5.25 | 5.375 | 5.5 | 5.625 | 5.75 | 5.875 | 6 |
| 0.19 | 85 | 80 | 74 | 70 | 65 | 61 | 58 | 55 | 52 | 49 | 46 | 44 | 42 | 40 | 38 | 36 | 35 | 33 | 32 | 30 | 29 |
| 0.20 | 95 | 88 | 82 | 77 | 72 | 68 | 64 | 61 | 57 | 54 | 51 | 49 | 46+ | 44 | 42 | 40 | 38 | 37 | 35 | 34 | 32 |
| 0.21 | 104 | 97 | 91 | 85 | 80 | 75 | 71 | 67 | 63 | 60 | 57 | 54 | 51 | 49 | 46 | 44 | 42 | 40 | 39 | 37 | 36 |
| 0.22 | 115 | 107 | 100 | 93 | 88 | 82 | 78 | 73 | 69 | 66 | 62 | 59 | 56 | 53 | 51 | 49 | 46 | 44 | 42 | 41 | 39 |
| 0.23 | 125 | 117 | 109 | 102 | 96 | 90 | 85 | 80 | 76 | 72 | 68 | 65 | 61 | 58 | 56 | 53 | 51 | 48 | 46 | 44 | 43 |
| 0.24 | 136 | 127 | 119 | 111 | 104 | 98 | 92 | 87 | 82 | 78 | 74 | 70 | 67 | 64 | 61 | 58 | 55 | 53 | 50 | 48 | 46 |
| 0.25 | 148 | 138 | 129 | 121 | 113 | 106 | 100 | 95 | 89 | 85 | 80 | 76 | 72 | 69 | 66 | 63 | 60 | 57 | 55 | 52 | 50 |
| 0.26 | 160 | 149 | 139 | 130 | 122 | 115 | 108 | 102 | 97 | 92 | 87 | 82 | 78 | 75 | 71 | 68 | 65 | 62 | 59 | 57 | 54 |
| 0.27 | 172 | 161 | 150 | 141 | 132 | 124 | 117 | 110 | 104 | 99 | 94 | 89 | 85 | 80 | 77 | 73 | 70 | 67 | 64 | 61 | 59 |
| 0.28 | 185 | 173 | 162 | 151 | 142 | 134 | 126 | 119 | 112 | 106 | 101 | 96 | 91 | 87 | 82 | 79 | 75 | 72 | 69 | 66 | 63 |
| 0.29 | 199 | 185 | 173 | 162 | 152 | 143 | 135 | 127 | 120 | 114 | 108 | 103 | 97 | 93 | 88 | 84 | 81 | 77 | 74 | 71 | 68 |
| 0.30 | 213 | 198 | 185 | 174 | 163 | 153 | 144 | 136 | 129 | 122 | 116 | 110 | 104 | 99 | 95 | 90 | 86 | 82 | 79 | 76 | 72 |
| 0.31 | 227 | 212 | 198 | 185 | 174 | 164 | 154 | 146 | 138 | 130 | 123 | 117 | 111 | 106 | 101 | 96 | 92 | 88 | 84 | 81 | 77 |
| 0.32 | 242 | 226 | 211 | 198 | 185 | 174 | 164 | 155 | 147 | 139 | 132 | 125 | 119 | 113 | 108 | 103 | 98 | 94 | 90 | 86 | 82 |
| 0.33 | 258 | 240 | 224 | 210 | 197 | 185 | 175 | 165 | 156 | 148 | 140 | 133 | 126 | 120 | 115 | 109 | 104 | 100 | 95 | 91 | 88 |
| 0.34 | 273 | 255 | 238 | 223 | 209 | 197 | 185 | 175 | 165 | 157 | 148 | 141 | 134 | 128 | 122 | 116 | 111 | 106 | 101 | 97 | 93 |
| 0.35 | 290 | 270 | 252 | 236 | 222 | 209 | 197 | 185 | 175 | 166 | 157 | 149 | 142 | 135 | 129 | 123 | 117 | 112 | 107 | 103 | 99 |
| 0.36 | 307 | 286 | 267 | 250 | 235 | 221 | 208 | 196 | 185 | 176 | 166 | 158 | 150 | 143 | 136 | 130 | 124 | 119 | 114 | 109 | 104 |
| 0.37 | 324 | 302 | 282 | 264 | 248 | 233 | 220 | 207 | 196 | 185 | 176 | 167 | 159 | 151 | 144 | 137 | 131 | 125 | 120 | 115 | 110 |
| 0.38 | 342 | 318 | 298 | 279 | 262 | 246 | 232 | 219 | 207 | 196 | 185 | 176 | 167 | 159 | 152 | 145 | 138 | 132 | 127 | 121 | 116 |
| 0.39 | 360 | 335 | 313 | 294 | 275 | 259 | 244 | 230 | 218 | 206 | 195 | 185 | 176 | 168 | 160 | 153 | 146 | 139 | 133 | 128 | 122 |
| 0.40 | 379 | 353 | 330 | 309 | 290 | 273 | 257 | 242 | 229 | 217 | 206 | 195 | 185 | 177 | 168 | 160 | 153 | 147 | 140 | 134 | 129 |
| 0.41 | 398 | 371 | 346 | 324 | 304 | 286 | 270 | 255 | 241 | 228 | 216 | 205 | 195 | 185 | 177 | 169 | 161 | 154 | 147 | 141 | 135 |
| 0.42 | 417 | 289 | 364 | 340 | 320 | 300 | 283 | 267 | 252 | 239 | 227 | 215 | 204 | 195 | 185 | 177 | 169 | 162 | 155 | 148 | 142 |
| 0.43 | 437 | 408 | 281 | 357 | 335 | 315 | 297 | 280 | 265 | 251 | 237 | 225 | 214 | 204 | 194 | 185 | 177 | 169 | 162 | 155 | 149 |
| 0.44 | 480 | 447 | 418 | 391 | 367 | 345 | 325 | 307 | 290 | 275 | 261 | 247 | 235 | 224 | 213 | 203 | 194 | 186 | 178 | 170 | 163 |
| 0.45 | 502 | 468 | 437 | 409 | 384 | 361 | 340 | 321 | 304 | 287 | 272 | 259 | 246 | 234 | 223 | 213 | 203 | 194 | 186 | 178 | 171 |
| 0.46 | 524 | 489 | 457 | 428 | 402 | 378 | 356 | 336 | 317 | 300 | 285 | 270 | 257 | 245 | 233 | 222 | 212 | 203 | 194 | 186 | 178 |
| 0.47 | 547 | 510 | 477 | 447 | 419 | 394 | 371 | 350 | 331 | 314 | 297 | 282 | 268 | 255 | 243 | 232 | 222 | 212 | 203 | 194 | 186 |
| 0.48 | 571 | 532 | 497 | 466 | 437 | 411 | 387 | 365 | 345 | 327 | 310 | 294 | 280 | 266 | 254 | 242 | 231 | 221 | 212 | 203 | 194 |

*TS* = Tensile Strength 55,000 psi

$$P = \frac{t^2 * S * C}{P^2}$$

*t* = Thickness of Stayed Surface, in.

*S* = 13,800 psi

For Thicknesses 0.4375 in. and less, C=2.1

For Thicknesses larger than 0.4375 in., C=2.2

MAWP is expressed in psi

**Table S2.10.4 (US Customary Units) Maximum Allowable Working Pressure for Stayed Surfaces, Formula Per ASME Section I, PG-46.1**

| Thickness of Stayed Surfaces, mm | Staybolt Spacing (Maximum Pitch), mm | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 89 | 92 | 95 | 98 | 102 | 105 | 108 | 111 | 114 | 117 | 121 | 124 | 127 | 130 | 133 | 137 | 140 | 143 | 146 | 149 | 152 |
| 5.00 | 630 | 589 | 553 | 519 | 479 | 452 | 428 | 405 | 384 | 364 | 341 | 324 | 309 | 295 | 282 | 266 | 254 | 244 | 234 | 225 | 216 |
| 5.25 | 694 | 650 | 609 | 573 | 529 | 499 | 471 | 446 | 423 | 402 | 376 | 358 | 341 | 325 | 311 | 293 | 281 | 269 | 258 | 248 | 238 |
| 5.50 | 762 | 713 | 669 | 628 | 580 | 547 | 517 | 490 | 464 | 441 | 412 | 392 | 374 | 357 | 341 | 322 | 308 | 295 | 283 | 272 | 261 |
| 5.75 | 833 | 779 | 731 | 687 | 634 | 598 | 565 | 535 | 508 | 482 | 451 | 429 | 409 | 390 | 373 | 351 | 337 | 323 | 309 | 297 | 285 |
| 6.00 | 907 | 849 | 796 | 748 | 690 | 651 | 616 | 583 | 553 | 525 | 491 | 467 | 445 | 425 | 406 | 383 | 366 | 351 | 337 | 323 | 311 |
| 6.25 | 984 | 921 | 863 | 811 | 749 | 707 | 668 | 632 | 600 | 569 | 532 | 507 | 483 | 461 | 441 | 415 | 398 | 381 | 366 | 351 | 337 |
| 6.50 | 1 064 | 996 | 934 | 878 | 810 | 765 | 723 | 684 | 649 | 616 | 576 | 548 | 523 | 499 | 477 | 449 | 430 | 412 | 395 | 380 | 365 |
| 6.75 | 1 148 | 1 074 | 1 007 | 946 | 874 | 824 | 779 | 738 | 699 | 664 | 621 | 591 | 564 | 538 | 514 | 484 | 464 | 445 | 426 | 409 | 393 |
| 7.00 | 1 234 | 1 155 | 1 083 | 1 018 | 940 | 887 | 838 | 793 | 752 | 714 | 668 | 636 | 606 | 578 | 553 | 521 | 499 | 478 | 459 | 440 | 423 |
| 7.25 | 1 324 | 1 239 | 1 162 | 1 093 | 1 008 | 951 | 899 | 851 | 807 | 766 | 716 | 682 | 650 | 620 | 593 | 559 | 535 | 513 | 492 | 472 | 454 |
| 7.50 | 1 417 | 1 326 | 1 243 | 1 168 | 1 079 | 1 018 | 962 | 911 | 863 | 820 | 766 | 730 | 696 | 664 | 634 | 598 | 573 | 549 | 526 | 505 | 486 |
| 7.75 | 1 513 | 1 416 | 1 328 | 1 248 | 1 152 | 1 087 | 1 027 | 973 | 922 | 875 | 818 | 779 | 743 | 709 | 677 | 638 | 611 | 586 | 562 | 540 | 519 |
| 8.00 | 1 612 | 1 509 | 1 415 | 1 329 | 1 227 | 1 158 | 1 095 | 1 036 | 982 | 933 | 872 | 830 | 792 | 756 | 722 | 680 | 651 | 624 | 599 | 575 | 553 |
| 8.25 | 1 714 | 1 604 | 1 505 | 1 414 | 1 305 | 1 232 | 1 164 | 1 102 | 1 045 | 992 | 927 | 883 | 842 | 803 | 768 | 723 | 693 | 664 | 637 | 612 | 588 |
| 8.50 | 1 820 | 1 703 | 1 597 | 1 501 | 1 385 | 1 307 | 1 236 | 1 170 | 1 109 | 1 053 | 984 | 937 | 894 | 853 | 815 | 768 | 735 | 705 | 676 | 649 | 624 |
| 8.75 | 1 928 | 1 805 | 1 692 | 1 590 | 1 468 | 1 385 | 1 310 | 1 240 | 1 175 | 1 116 | 1 043 | 993 | 947 | 904 | 863 | 814 | 779 | 747 | 717 | 688 | 661 |
| 9.00 | 2 040 | 1 909 | 1 791 | 1 683 | 1 553 | 1 466 | 1 385 | 1 312 | 1 243 | 1 180 | 1 104 | 1 051 | 1 002 | 956 | 914 | 861 | 814 | 790 | 758 | 728 | 699 |
| 9.25 | 2 155 | 2 017 | 1 891 | 1 777 | 1 641 | 1 548 | 1 463 | 1 685 | 1 313 | 1 247 | 1 166 | 1 110 | 1 058 | 1 010 | 965 | 909 | 871 | 835 | 801 | 769 | 736 |
| 9.50 | 2 273 | 2 127 | 1 995 | 1 875 | 1 731 | 1 633 | 1 544 | 1 461 | 1 385 | 1 315 | 1 230 | 1 171 | 1 116 | 1 065 | 1 018 | 959 | 919 | 880 | 845 | 811 | 779 |
| 9.75 | 2 394 | 2 241 | 2 101 | 1 975 | 1 823 | 1 720 | 1 626 | 1 539 | 1 459 | 1 385 | 1 295 | 1 233 | 1 176 | 1 122 | 1 072 | 1 010 | 986 | 927 | 890 | 854 | 821 |
| 10.00 | 2 519 | 2 357 | 2 211 | 2 077 | 1 918 | 1 810 | 1 710 | 1 619 | 1 535 | 1 475 | 1 363 | 1 297 | 1 237 | 1 180 | 1 128 | 1 063 | 1 018 | 976 | 936 | 899 | 863 |
| 10.25 | 2 646 | 2 476 | 2 322 | 2 182 | 2 015 | 1 901 | 1 797 | 1 701 | 1 613 | 1 531 | 1 432 | 1 363 | 1 300 | 1 240 | 1 185 | 1 117 | 1 069 | 1 025 | 983 | 944 | 907 |
| 10.50 | 2 777 | 2 599 | 2 437 | 2 290 | 2 114 | 1 995 | 1 886 | 1 785 | 1 692 | 1 607 | 1 502 | 1 430 | 1 634 | 1 301 | 1 243 | 1 172 | 1 122 | 1 076 | 1 032 | 991 | 952 |

*TS* = Tensile Strength 380 000 kPa

*t* = Thickness of Stayed Surface, in.

*S* = 95 000 kPa

$$P = \frac{t^2 * S * C}{P^2}$$

For Thicknesses 11mm and less, C=2.1

For Thicknesses larger than 11 mm, C=2.2

MAWP is expressed in kPa

**Table S2.10.4 (Metric Units) Maximum Allowable Working Pressure for Stayed Surfaces, Formula Per ASME Section I, PG-46.1**

| Staybolt Spacing, in. | Actual Diameter of Corroded Iron Staybolts, in. | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0.35 | 0.375 | 0.4 | 0.425 | 0.45 | 0.475 | 0.5 | 1.525 | 0.55 | 0.575 | 0.6 | 0.625 | 0.65 | 0.675 | 0.7 | 0.725 | 0.75 | 0.775 | 0.8 | 0.825 | 0.85 | 0.875 | 0.9 |
| 3.5 | 59 | 68 | 77 | 87 | 97 | 108 | 120 | 133 | 145 | 159 | 173 | 188 | 203 | 219 | 236 | 253 | 270 | 289 | 308 | 327 | 347 | 368 | 389 |
| 3.625 | 55 | 63 | 72 | 81 | 91 | 101 | 112 | 124 | 136 | 148 | 161 | 175 | 189 | 280 | 220 | 236 | 252 | 269 | 287 | 305 | 324 | 343 | 363 |
| 3.75 | 51 | 59 | 67 | 76 | 85 | 95 | 105 | 115 | 127 | 138 | 151 | 164 | 177 | 261 | 205 | 220 | 236 | 252 | 268 | 285 | 303 | 321 | 339 |
| 3.875 | 48 | 55 | 63 | 71 | 79 | 89 | 98 | 108 | 119 | 130 | 141 | 153 | 166 | 245 | 192 | 206 | 211 | 236 | 251 | 267 | 283 | 300 | 318 |
| 4 | 45 | 52 | 59 | 66 | 75 | 83 | 92 | 101 | 111 | 122 | 133 | 144 | 156 | 230 | 180 | 194 | 207 | 221 | 236 | 251 | 266 | 282 | 298 |
| 4.125 | 42 | 49 | 55 | 63 | 70 | 78 | 87 | 95 | 105 | 114 | 125 | 135 | 146 | 216 | 170 | 182 | 195 | 208 | 222 | 236 | 250 | 265 | 280 |
| 4.25 | 49 | 46 | 52 | 59 | 66 | 74 | 82 | 90 | 99 | 108 | 117 | 127 | 138 | 204 | 160 | 171 | 183 | 196 | 209 | 22 | 236 | 250 | 264 |
| 4.375 | 38 | 43 | 49 | 56 | 62 | 69 | 77 | 85 | 93 | 102 | 111 | 120 | 130 | 192 | 151 | 162 | 173 | 185 | 197 | 209 | 222 | 236 | 249 |
| 4.5 | 36 | 41 | 47 | 53 | 59 | 66 | 73 | 80 | 88 | 96 | 105 | 114 | 123 | 182 | 143 | 153 | 164 | 175 | 186 | 198 | 210 | 223 | 236 |
| 4.625 | 34 | 39 | 44 | 50 | 56 | 62 | 69 | 76 | 83 | 91 | 99 | 108 | 116 | 172 | 135 | 145 | 155 | 165 | 176 | 187 | 199 | 211 | 223 |
| 4.75 | 32 | 37 | 42 | 47 | 53 | 59 | 65 | 72 | 79 | 86 | 94 | 102 | 110 | 119 | 128 | 137 | 147 | 157 | 167 | 178 | 189 | 200 | 211 |
| 4.875 | 30 | 35 | 40 | 45 | 50 | 56 | 62 | 68 | 75 | 82 | 89 | 97 | 105 | 113 | 121 | 130 | 139 | 149 | 159 | 169 | 179 | 190 | 201 |
| 5 | 29 | 33 | 38 | 43 | 48 | 53 | 59 | 65 | 71 | 78 | 85 | 92 | 100 | 107 | 115 | 124 | 133 | 142 | 151 | 160 | 170 | 180 | 191 |
| 5.125 | 27 | 32 | 36 | 41 | 45 | 51 | 56 | 62 | 68 | 74 | 81 | 88 | 95 | 102 | 110 | 118 | 126 | 135 | 144 | 153 | 162 | 172 | 182 |
| 5.25 | 26 | 30 | 34 | 39 | 43 | 48 | 53 | 59 | 65 | 71 | 77 | 83 | 90 | 97 | 105 | 112 | 120 | 128 | 137 | 145 | 154 | 164 | 173 |
| 5.375 | 25 | 29 | 33 | 37 | 41 | 46 | 51 | 56 | 32 | 67 | 73 | 82 | 86 | 93 | 100 | 107 | 115 | 122 | 130 | 139 | 147 | 156 | 165 |
| 5.5 | 24 | 27 | 31 | 35 | 39 | 44 | 49 | 54 | 59 | 64 | 70 | 76 | 82 | 89 | 95 | 102 | 110 | 117 | 125 | 133 | 141 | 149 | 158 |
| 5.625 | 23 | 26 | 30 | 34 | 38 | 42 | 47 | 51 | 56 | 62 | 67 | 73 | 79 | 85 | 91 | 98 | 105 | 112 | 119 | 127 | 135 | 143 | 151 |
| 5.75 | 22 | 25 | 29 | 32 | 36 | 40 | 45 | 49 | 54 | 59 | 64 | 70 | 75 | 81 | 87 | 94 | 100 | 107 | 114 | 121 | 129 | 136 | 144 |
| 5.875 | 21 | 24 | 27 | 31 | 35 | 39 | 43 | 47 | 52 | 56 | 61 | 67 | 72 | 78 | 84 | 90 | 96 | 103 | 109 | 116 | 123 | 131 | 138 |
| 6 | 20 | 23 | 26 | 30 | 33 | 37 | 41 | 45 | 49 | 54 | 59 | 64 | 69 | 75 | 80 | 86 | 92 | 98 | 105 | 111 | 118 | 125 | 133 |
| 6.125 | 19 | 22 | 25 | 28 | 32 | 35 | 39 | 43 | 47 | 52 | 57 | 61 | 66 | 72 | 77 | 83 | 88 | 94 | 100 | 107 | 113 | 120 | 127 |
| 6.25 | 18 | 21 | 23 | 27 | 31 | 34 | 38 | 42 | 46 | 50 | 54 | 59 | 64 | 69 | 74 | 79 | 85 | 91 | 97 | 103 | 109 | 115 | 122 |
| 6.375 | 18 | 20 | 23 | 26 | 29 | 33 | 36 | 40 | 44 | 48 | 52 | 57 | 61 | 66 | 71 | 76 | 82 | 87 | 93 | 99 | 105 | 111 | 117 |
| 6.5 | 17 | 20 | 22 | 25 | 28 | 31 | 35 | 38 | 42 | 46 | 50 | 54 | 59 | 64 | 68 | 73 | 78 | 84 | 89 | 95 | 101 | 107 | 113 |
| 6.625 | 16 | 19 | 21 | 24 | 27 | 30 | 34 | 37 | 41 | 44 | 48 | 52 | 57 | 61 | 66 | 71 | 75 | 81 | 86 | 91 | 97 | 103 | 109 |
| 6.75 | 16 | 18 | 21 | 23 | 26 | 29 | 32 | 36 | 39 | 43 | 47 | 51 | 55 | 59 | 63 | 68 | 73 | 78 | 83 | 88 | 93 | 99 | 105 |
| 6.875 | 15 | 18 | 20 | 23 | 25 | 28 | 31 | 34 | 38 | 41 | 45 | 49 | 53 | 57 | 61 | 66 | 70 | 75 | 80 | 85 | 90 | 95 | 101 |
| 7 | 15 | 17 | 19 | 22 | 24 | 27 | 30 | 33 | 36 | 40 | 43 | 47 | 51 | 55 | 59 | 63 | 68 | 72 | 77 | 82 | 87 | 92 | 97 |

$$P = \frac{\pi\left[\frac{d}{2}\right]^2 \cdot S}{p^2}$$

$S$ = 7,500 psi

$P$ = MAWP psi

$p$ = staybolt spacing, in.

$d$ = Minimum diameter of corroded staybolt, in.

**Table S2.10.4.1.a [US Customary Units]**
**Maximum Allowable Working Pressure on the Load Carrying Capacity of a Single Corroded Staybolt**

| Staybolt Spacing, mm | Actual Diameter of Corroded Iron Staybolts, mm | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 10 | 10.5 | 11 | 11.5 | 12 | 12.5 | 13 | 13.5 | 14 | 14.5 | 15 | 15.5 | 16 | 16.5 | 17 | 17.5 | 18 | 18.5 | 19 | 19.5 | 20 | 20.5 | 21 | 21.5 | 22 |
| 90 | 501 | 553 | 607 | 663 | 722 | 783 | 847 | 914 | 983 | 1 054 | 1 128 | 1 204 | 1 283 | 1 365 | 1 449 | 1 535 | 1 624 | 1 716 | 1 810 | 1 906 | 2 005 | 2 107 | 2 211 | 2 317 | 2 426 |
| 92.5 | 475 | 523 | 574 | 628 | 683 | 742 | 802 | 865 | 930 | 998 | 1 068 | 1 140 | 1 215 | 1 929 | 1 371 | 1 453 | 1 538 | 1 624 | 1 713 | 1 805 | 1 898 | 1 994 | 2 093 | 2 194 | 2 297 |
| 95 | 450 | 496 | 544 | 595 | 648 | 703 | 760 | 820 | 882 | 946 | 1 012 | 1 081 | 1 152 | 1 225 | 1 300 | 1 378 | 1 458 | 1 540 | 1 624 | 1 711 | 1 800 | 1 891 | 1 984 | 2 080 | 2 178 |
| 97.5 | 427 | 471 | 517 | 565 | 615 | 667 | 722 | 778 | 837 | 898 | 961 | 1 026 | 1 093 | 1 163 | 1 234 | 1 308 | 1 384 | 1 462 | 1 542 | 1 624 | 1 709 | 1 795 | 1 884 | 1 974 | 2 067 |
| 100 | 406 | 448 | 491 | 537 | 585 | 634 | 686 | 740 | 796 | 854 | 914 | 976 | 1 039 | 1 105 | 1 173 | 1 244 | 1 316 | 1 390 | 1 466 | 1 544 | 1 624 | 1 706 | 1 791 | 1 877 | 1 965 |
| 102.5 | 386 | 426 | 468 | 511 | 557 | 604 | 653 | 704 | 758 | 813 | 870 | 929 | 989 | 1 052 | 1 117 | 1 184 | 1 252 | 1 323 | 1 395 | 1 470 | 1 546 | 1 624 | 1 704 | 1 787 | 1 871 |
| 105 | 368 | 406 | 446 | 487 | 530 | 575 | 622 | 671 | 722 | 774 | 829 | 885 | 943 | 1 003 | 1 064 | 1 128 | 1 193 | 1 261 | 1 330 | 1 400 | 1 473 | 1 548 | 1 624 | 1 702 | 1 783 |
| 107.5 | 351 | 387 | 425 | 465 | 506 | 549 | 594 | 640 | 689 | 739 | 791 | 844 | 900 | 957 | 1 015 | 1 076 | 1 138 | 1 203 | 1 268 | 1 336 | 1 405 | 1 477 | 1 550 | 1 624 | 1 701 |
| 110 | 336 | 370 | 406 | 444 | 483 | 524 | 567 | 612 | 658 | 706 | 755 | 806 | 859 | 914 | 970 | 1 028 | 1 087 | 1 149 | 1 211 | 1 276 | 1 342 | 1 410 | 1 480 | 1 551 | 1 624 |
| 112.5 | 321 | 354 | 388 | 424 | 462 | 501 | 542 | 585 | 629 | 675 | 722 | 771 | 821 | 873 | 927 | 983 | 1 039 | 1 098 | 1 158 | 1 220 | 1 283 | 1 348 | 1 415 | 1 483 | 1 553 |
| 115 | 307 | 339 | 372 | 406 | 442 | 480 | 519 | 560 | 602 | 646 | 691 | 738 | 786 | 836 | 887 | 940 | 995 | 1 051 | 1 108 | 1 167 | 1 228 | 1 290 | 1 354 | 1 419 | 1 486 |
| 117.5 | 294 | 324 | 356 | 389 | 424 | 460 | 497 | 536 | 576 | 618 | 662 | 707 | 753 | 801 | 850 | 901 | 953 | 1 007 | 1 062 | 1 118 | 1 176 | 1 236 | 1 297 | 1 360 | 1 423 |
| 120 | 282 | 311 | 341 | 373 | 406 | 441 | 477 | 514 | 553 | 593 | 634 | 677 | 722 | 768 | 815 | 864 | 614 | 965 | 1 018 | 1 072 | 1 128 | 1 185 | 1 244 | 1 303 | 1 365 |
| 122.5 | 271 | 298 | 327 | 358 | 390 | 423 | 457 | 493 | 530 | 569 | 609 | 650 | 693 | 737 | 782 | 829 | 877 | 926 | 977 | 1 029 | 1 082 | 1 137 | 1 193 | 1 251 | 1 310 |
| 125 | 260 | 287 | 314 | 344 | 374 | 406 | 439 | 474 | 509 | 546 | 585 | 624 | 665 | 708 | 751 | 796 | 842 | 889 | 938 | 988 | 1 039 | 1 092 | 1 146 | 1 201 | 1 258 |
| 127.5 | 250 | 275 | 302 | 330 | 360 | 390 | 422 | 455 | 490 | 525 | 562 | 600 | 639 | 680 | 722 | 765 | 809 | 855 | 902 | 950 | 999 | 1 050 | 1 102 | 1 155 | 1 209 |
| 130 | 240 | 265 | 291 | 318 | 346 | 375 | 406 | 438 | 471 | 505 | 541 | 577 | 615 | 654 | 694 | 736 | 778 | 822 | 867 | 914 | 961 | 1 010 | 1 060 | 1 111 | 1 163 |
| 132.5 | 231 | 255 | 280 | 306 | 333 | 361 | 391 | 422 | 453 | 486 | 520 | 556 | 592 | 630 | 668 | 708 | 749 | 792 | 835 | 879 | 925 | 972 | 1 020 | 1 069 | 1 119 |
| 135 | 223 | 246 | 270 | 295 | 321 | 348 | 377 | 406 | 437 | 468 | 501 | 535 | 570 | 607 | 644 | 682 | 722 | 763 | 804 | 847 | 891 | 936 | 983 | 1 030 | 1 078 |
| 137.5 | 215 | 237 | 260 | 284 | 309 | 336 | 363 | 391 | 421 | 452 | 483 | 516 | 550 | 585 | 621 | 658 | 696 | 735 | 775 | 817 | 859 | 903 | 947 | 993 | 1 039 |
| 140 | 207 | 228 | 251 | 274 | 298 | 324 | 350 | 378 | 406 | 436 | 466 | 498 | 530 | 564 | 599 | 634 | 671 | 709 | 748 | 788 | 829 | 871 | 914 | 958 | 1 003 |
| 142.5 | 200 | 220 | 242 | 264 | 288 | 312 | 338 | 364 | 392 | 420 | 450 | 480 | 512 | 544 | 578 | 612 | 648 | 684 | 722 | 760 | 800 | 840 | 882 | 924 | 968 |
| 145 | 193 | 213 | 234 | 255 | 278 | 302 | 326 | 352 | 379 | 406 | 435 | 464 | 494 | 526 | 558 | 591 | 626 | 661 | 697 | 734 | 773 | 812 | 852 | 893 | 935 |
| 147.5 | 187 | 206 | 226 | 247 | 269 | 292 | 315 | 340 | 366 | 392 | 420 | 448 | 478 | 508 | 539 | 572 | 605 | 639 | 674 | 710 | 747 | 784 | 823 | 863 | 903 |
| 150 | 180 | 199 | 218 | 239 | 260 | 282 | 305 | 329 | 354 | 379 | 406 | 434 | 462 | 491 | 522 | 553 | 585 | 618 | 651 | 686 | 722 | 758 | 796 | 834 | 873 |
| 152.5 | 175 | 192 | 211 | 231 | 251 | 273 | 295 | 318 | 342 | 367 | 393 | 419 | 447 | 475 | 505 | 535 | 566 | 598 | 630 | 664 | 698 | 734 | 770 | 807 | 845 |
| 155 | 169 | 186 | 205 | 224 | 243 | 264 | 286 | 308 | 331 | 355 | 380 | 406 | 433 | 460 | 488 | 518 | 548 | 578 | 610 | 643 | 676 | 710 | 745 | 781 | 818 |
| 157.5 | 164 | 180 | 198 | 216 | 236 | 256 | 277 | 298 | 321 | 344 | 368 | 393 | 419 | 446 | 473 | 501 | 530 | 560 | 591 | 622 | 655 | 688 | 722 | 757 | 792 |
| 160 | 159 | 175 | 192 | 210 | 228 | 248 | 268 | 289 | 311 | 333 | 357 | 381 | 406 | 432 | 458 | 486 | 514 | 543 | 573 | 603 | 634 | 667 | 699 | 733 | 768 |
| 162.5 | 154 | 170 | 186 | 203 | 221 | 240 | 260 | 280 | 301 | 323 | 346 | 369 | 394 | 419 | 444 | 471 | 498 | 526 | 555 | 585 | 615 | 646 | 678 | 711 | 744 |
| 165 | 149 | 164 | 180 | 197 | 215 | 233 | 252 | 272 | 292 | 314 | 336 | 358 | 382 | 406 | 431 | 457 | 483 | 510 | 538 | 567 | 597 | 627 | 658 | 689 | 722 |
| 167.5 | 145 | 160 | 175 | 191 | 208 | 226 | 245 | 264 | 284 | 304 | 326 | 348 | 371 | 394 | 418 | 443 | 469 | 495 | 522 | 550 | 579 | 608 | 638 | 669 | 700 |
| 170 | 141 | 155 | 170 | 186 | 202 | 220 | 237 | 256 | 275 | 295 | 316 | 338 | 360 | 383 | 406 | 430 | 455 | 481 | 507 | 534 | 562 | 590 | 620 | 649 | 680 |
| 172.5 | 136 | 150 | 165 | 180 | 197 | 213 | 231 | 249 | 267 | 287 | 307 | 328 | 349 | 372 | 394 | 418 | 442 | 467 | 493 | 519 | 546 | 573 | 602 | 631 | 660 |
| 175 | 133 | 146 | 160 | 175 | 191 | 207 | 224 | 242 | 260 | 279 | 298 | 319 | 339 | 361 | 383 | 406 | 430 | 454 | 479 | 504 | 530 | 557 | 585 | 613 | 642 |
| 177.5 | 129 | 142 | 156 | 170 | 186 | 201 | 218 | 235 | 253 | 271 | 290 | 310 | 330 | 351 | 372 | 395 | 418 | 441 | 465 | 490 | 516 | 542 | 568 | 596 | 624 |
| 180 | 125 | 138 | 152 | 166 | 180 | 196 | 212 | 228 | 246 | 263 | 282 | 301 | 321 | 341 | 362 | 384 | 406 | 429 | 452 | 477 | 501 | 527 | 553 | 579 | 607 |

$$P = \frac{\pi \left[\frac{d}{2}\right]^2 \cdot S}{p^2}$$

$S$ = 51 700 kPa

$P$ = MAWP kPa

$p$ = staybolt spacing, mm

$d$ = Minimum diameter of corroded staybolt, mm

**Table S2.10.4.1.a [Metric Units]**
**Maximum Allowable Working Pressure on the Load Carrying Capacity of a Single Corroded Staybolt**

| Staybolt Spacing, in. | Actual Diameter of Corroded Steel Staybolts, in. | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0.35 | 0.375 | 0.4 | 0.425 | 0.45 | 0.475 | 0.5 | 0.525 | 0.55 | 0.575 | 0.6 | 0.625 | 0.65 | 0.675 | 0.7 | 0.725 | 0.75 | 0.775 | 0.8 | 0.85 | 0.825 | 0.875 | 0.9 |
| 3.5 | 81 | 93 | 105 | 119 | 133 | 149 | 165 | 182 | 199 | 218 | 237 | 257 | 278 | 300 | 323 | 346 | 370 | 396 | 422 | 448 | 476 | 504 | 533 |
| 3.625 | 85 | 86 | 98 | 111 | 124 | 139 | 153 | 169 | 186 | 203 | 221 | 240 | 259 | 280 | 301 | 323 | 345 | 369 | 393 | 418 | 444 | 470 | 497 |
| 3.75 | 70 | 81 | 92 | 104 | 116 | 129 | 143 | 158 | 174 | 190 | 207 | 224 | 242 | 261 | 281 | 302 | 323 | 345 | 367 | 390 | 415 | 439 | 465 |
| 3.875 | 66 | 76 | 86 | 97 | 109 | 121 | 134 | 148 | 163 | 178 | 193 | 210 | 227 | 245 | 263 | 282 | 302 | 323 | 344 | 366 | 388 | 411 | 435 |
| 4 | 62 | 71 | 81 | 91 | 102 | 114 | 126 | 139 | 153 | 167 | 182 | 197 | 213 | 230 | 247 | 265 | 284 | 303 | 323 | 343 | 364 | 386 | 408 |
| 4.125 | 58 | 67 | 76 | 86 | 96 | 107 | 119 | 131 | 143 | 157 | 171 | 185 | 200 | 216 | 232 | 249 | 267 | 285 | 303 | 323 | 343 | 363 | 384 |
| 4.25 | 55 | 63 | 71 | 81 | 90 | 101 | 112 | 123 | 135 | 148 | 161 | 174 | 189 | 204 | 219 | 235 | 251 | 268 | 286 | 304 | 323 | 342 | 362 |
| 4.375 | 52 | 59 | 67 | 76 | 85 | 95 | 105 | 116 | 128 | 139 | 152 | 165 | 178 | 192 | 207 | 222 | 237 | 253 | 270 | 287 | 305 | 323 | 341 |
| 4.5 | 49 | 56 | 64 | 72 | 81 | 90 | 100 | 110 | 121 | 132 | 143 | 156 | 168 | 182 | 195 | 209 | 224 | 239 | 255 | 271 | 288 | 305 | 323 |
| 4.625 | 46 | 53 | 60 | 68 | 76 | 85 | 94 | 104 | 114 | 125 | 136 | 147 | 159 | 172 | 185 | 198 | 212 | 227 | 241 | 257 | 273 | 289 | 306 |
| 4.75 | 44 | 50 | 57 | 65 | 72 | 81 | 89 | 99 | 108 | 118 | 129 | 140 | 151 | 163 | 175 | 188 | 201 | 215 | 229 | 243 | 258 | 274 | 290 |
| 4.875 | 42 | 48 | 54 | 61 | 69 | 77 | 85 | 94 | 103 | 112 | 122 | 133 | 143 | 155 | 166 | 178 | 191 | 204 | 217 | 231 | 245 | 260 | 275 |
| 5 | 40 | 45 | 52 | 58 | 65 | 73 | 81 | 89 | 98 | 107 | 116 | 126 | 136 | 147 | 158 | 170 | 182 | 194 | 207 | 220 | 233 | 247 | 261 |
| 5.125 | 38 | 43 | 49 | 55 | 62 | 69 | 77 | 85 | 93 | 102 | 111 | 120 | 130 | 140 | 151 | 161 | 173 | 184 | 197 | 209 | 222 | 235 | 249 |
| 5.25 | 36 | 41 | 47 | 53 | 59 | 66 | 73 | 81 | 89 | 97 | 105 | 114 | 124 | 133 | 143 | 154 | 165 | 176 | 187 | 199 | 211 | 224 | 237 |
| 5.375 | 34 | 39 | 45 | 50 | 57 | 63 | 70 | 77 | 84 | 92 | 101 | 109 | 118 | 127 | 137 | 147 | 157 | 168 | 179 | 190 | 202 | 214 | 226 |
| 5.5 | 33 | 38 | 43 | 48 | 54 | 60 | 67 | 74 | 81 | 88 | 96 | 104 | 113 | 122 | 131 | 140 | 150 | 160 | 171 | 182 | 193 | 204 | 216 |
| 5.625 | 31 | 36 | 41 | 46 | 52 | 58 | 64 | 70 | 77 | 84 | 92 | 100 | 108 | 116 | 125 | 134 | 143 | 153 | 163 | 174 | 184 | 195 | 207 |
| 5.75 | 30 | 34 | 39 | 44 | 49 | 55 | 61 | 67 | 74 | 81 | 88 | 95 | 103 | 111 | 120 | 128 | 137 | 147 | 156 | 166 | 176 | 187 | 198 |
| 5.875 | 29 | 33 | 37 | 42 | 47 | 53 | 58 | 64 | 71 | 77 | 84 | 91 | 99 | 107 | 115 | 123 | 131 | 140 | 150 | 159 | 169 | 179 | 189 |
| 6 | 27 | 32 | 36 | 40 | 45 | 51 | 56 | 62 | 68 | 74 | 81 | 88 | 95 | 102 | 110 | 118 | 126 | 135 | 143 | 153 | 162 | 172 | 182 |
| 6.125 | 26 | 30 | 34 | 39 | 44 | 49 | 54 | 59 | 65 | 71 | 77 | 84 | 91 | 98 | 105 | 113 | 121 | 129 | 138 | 146 | 155 | 165 | 174 |
| 6.25 | 25 | 29 | 33 | 37 | 42 | 47 | 52 | 57 | 62 | 68 | 74 | 81 | 87 | 94 | 101 | 109 | 116 | 124 | 132 | 141 | 149 | 158 | 167 |
| 6.375 | 24 | 28 | 32 | 36 | 40 | 45 | 50 | 55 | 60 | 66 | 71 | 78 | 84 | 90 | 97 | 104 | 112 | 119 | 127 | 135 | 143 | 152 | 161 |
| 6.5 | 23 | 27 | 31 | 34 | 39 | 43 | 48 | 53 | 58 | 63 | 69 | 75 | 81 | 87 | 94 | 100 | 107 | 115 | 122 | 130 | 138 | 146 | 155 |
| 6.625 | 23 | 26 | 29 | 33 | 37 | 41 | 46 | 51 | 56 | 61 | 66 | 72 | 78 | 84 | 90 | 97 | 103 | 110 | 118 | 125 | 133 | 141 | 149 |
| 6.75 | 22 | 25 | 28 | 32 | 36 | 40 | 44 | 49 | 54 | 59 | 64 | 69 | 75 | 81 | 87 | 93 | 100 | 106 | 113 | 121 | 128 | 136 | 143 |
| 6.875 | 21 | 24 | 27 | 31 | 35 | 39 | 43 | 47 | 52 | 56 | 61 | 67 | 72 | 78 | 84 | 90 | 96 | 103 | 109 | 116 | 123 | 131 | 138 |
| 7 | 20 | 23 | 26 | 30 | 33 | 37 | 41 | 45 | 50 | 54 | 59 | 64 | 70 | 75 | 81 | 87 | 93 | 99 | 105 | 112 | 119 | 126 | 133 |

$S$ = 11,300 psi

P = MAWP psi

$$P = \frac{\pi\left[\frac{d}{2}\right]^2 * S}{1.1 * P^2}$$

$p$ = staybolt spacing, in.

$d$ = Minimum diameter of corroded staybolt, in.

**Table S2.10.4.1.b [US Customary Units]**
**Maximum Allowable Working Pressure on the Load Carrying Capacity of a Single Corroded Steel Staybolt**

| Staybolt Spacing, mm | Actual Diameter of Corroded Steel Staybolts, mm | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 10 | 10.5 | 11 | 11.5 | 12 | 12.5 | 13 | 13.5 | 14 | 14.5 | 15 | 15.5 | 16 | 16.5 | 17 | 17.5 | 18 | 18.5 | 19 | 19.5 | 20 | 20.5 | 21 | 21.5 | 22 |
| 90 | 688 | 758 | 932 | 909 | 990 | 1 074 | 1 162 | 1 253 | 1 348 | 1 446 | 1 547 | 1 652 | 1 760 | 1 872 | 1 987 | 2 106 | 2 228 | 2 353 | 2 482 | 2 614 | 2 750 | 2 889 | 3 032 | 3 178 | 3 328 |
| 92.5 | 651 | 718 | 788 | 861 | 937 | 1 017 | 1 100 | 1 186 | 1 276 | 1 368 | 1 465 | 1 564 | 1 666 | 1 772 | 1 881 | 1 993 | 2 109 | 2 228 | 2 350 | 2 475 | 2 604 | 2 735 | 2 870 | 3 009 | 3 150 |
| 95 | 617 | 680 | 747 | 816 | 889 | 964 | 1 043 | 1 125 | 1 209 | 1 297 | 1 388 | 1 483 | 1 580 | 1 680 | 1 783 | 1 890 | 1 999 | 2 112 | 2 228 | 2 346 | 2 468 | 2 593 | 2 721 | 2 852 | 2 987 |
| 97.5 | 586 | 646 | 709 | 775 | 844 | 915 | 990 | 1 068 | 1 148 | 1 232 | 1 318 | 1 407 | 1 500 | 1 595 | 1 693 | 1 794 | 1 898 | 2 005 | 2 115 | 2 228 | 2 343 | 2 462 | 2 584 | 2 708 | 2 835 |
| 100 | 557 | 614 | 674 | 737 | 802 | 870 | 941 | 1 015 | 1 092 | 1 171 | 1 253 | 1 338 | 1 426 | 1 516 | 1 609 | 1 706 | 1 804 | 1 906 | 2 010 | 2 118 | 2 228 | 2 340 | 2 456 | 2 574 | 2 695 |
| 102.5 | 563 | 584 | 641 | 701 | 763 | 828 | 896 | 966 | 1 039 | 1 114 | 1 193 | 1 274 | 1 357 | 1 443 | 1 532 | 1 623 | 1 717 | 1 814 | 1 914 | 2 016 | 2 120 | 2 228 | 2 338 | 2 450 | 2 566 |
| 105 | 505 | 557 | 611 | 668 | 727 | 789 | 854 | 921 | 990 | 1 062 | 1 137 | 1 214 | 1 293 | 1 375 | 1 460 | 1 547 | 1 637 | 1 729 | 1 824 | 1 921 | 2 021 | 2 133 | 2 228 | 2 335 | 2 445 |
| 107.5 | 482 | 531 | 583 | 637 | 694 | 753 | 814 | 878 | 945 | 1 013 | 1 084 | 1 158 | 1 234 | 1 312 | 1 393 | 1 476 | 1 561 | 1 649 | 1 740 | 1 833 | 1 928 | 2 025 | 2 125 | 2 228 | 2 332 |
| 110 | 460 | 507 | 557 | 609 | 663 | 719 | 778 | 839 | 902 | 968 | 1 036 | 1 106 | 1 178 | 1 253 | 1 330 | 1 410 | 1 491 | 1 575 | 1 662 | 1 750 | 1 841 | 1 934 | 2 030 | 2 128 | 2 228 |
| 112.5 | 440 | 485 | 532 | 582 | 634 | 688 | 744 | 802 | 862 | 925 | 990 | 1 057 | 1 126 | 1 198 | 1 272 | 1 348 | 1 426 | 1 506 | 1 589 | 1 673 | 1 760 | 1 849 | 1 941 | 2 034 | 2 130 |
| 115 | 421 | 464 | 510 | 557 | 606 | 658 | 712 | 767 | 825 | 885 | 947 | 1 012 | 1 078 | 1 146 | 1 217 | 1 290 | 1 364 | 1 441 | 1 520 | 1 601 | 1 684 | 1 770 | 1 857 | 1 947 | 2 038 |
| 117.5 | 403 | 445 | 488 | 533 | 581 | 630 | 682 | 735 | 791 | 848 | 908 | 969 | 1 033 | 1 098 | 1 166 | 1 235 | 1 307 | 1 381 | 1 456 | 1 534 | 1 614 | 1 695 | 1 779 | 1 865 | 1 952 |
| 120 | 387 | 426 | 468 | 511 | 557 | 604 | 654 | 705 | 758 | 813 | 870 | 929 | 990 | 1 053 | 1 118 | 1 184 | 1 253 | 1 324 | 1 396 | 1 471 | 1 547 | 1 625 | 1 706 | 1 788 | 1 872 |
| 122.5 | 371 | 409 | 449 | 491 | 534 | 580 | 627 | 676 | 727 | 780 | 835 | 892 | 950 | 1 010 | 1 073 | 1 137 | 1 202 | 1 270 | 1 340 | 1 411 | 1 484 | 1 560 | 1 637 | 1 716 | 1 796 |
| 125 | 356 | 393 | 431 | 471 | 513 | 557 | 602 | 650 | 699 | 749 | 802 | 856 | 912 | 970 | 1 030 | 1 092 | 1 155 | 1 220 | 1 287 | 1 355 | 1 426 | 1 498 | 1 572 | 1 648 | 1 725 |
| 127.5 | 343 | 378 | 415 | 453 | 493 | 535 | 579 | 624 | 671 | 720 | 771 | 823 | 877 | 933 | 990 | 1 049 | 1 110 | 1 173 | 1 237 | 1 303 | 1 370 | 1 440 | 1 511 | 1 584 | 1 426 |
| 130 | 330 | 363 | 399 | 436 | 475 | 515 | 557 | 601 | 646 | 693 | 741 | 792 | 844 | 897 | 952 | 1 009 | 1 068 | 1 128 | 1 190 | 1 253 | 1 318 | 1 385 | 1 453 | 1 523 | 1 595 |
| 132.5 | 317 | 350 | 384 | 420 | 457 | 496 | 536 | 578 | 622 | 667 | 714 | 762 | 812 | 964 | 917 | 971 | 1 028 | 1 086 | 1 145 | 1 206 | 1 269 | 1 333 | 1 399 | 1 466 | 1 535 |
| 135 | 306 | 337 | 370 | 404 | 440 | 477 | 516 | 557 | 599 | 642 | 688 | 734 | 782 | 832 | 883 | 936 | 990 | 1 046 | 1 103 | 1 162 | 1 222 | 1 284 | 1 348 | 1 413 | 1 479 |
| 137.5 | 295 | 325 | 356 | 390 | 424 | 460 | 498 | 537 | 577 | 619 | 663 | 708 | 754 | 802 | 851 | 902 | 954 | 1 008 | 1 063 | 1 120 | 1 178 | 1 238 | 1 299 | 1 362 | 1 426 |
| 140 | 284 | 313 | 344 | 376 | 409 | 444 | 480 | 518 | 557 | 597 | 639 | 683 | 727 | 774 | 821 | 870 | 921 | 972 | 1 026 | 1 080 | 1 137 | 1 194 | 1 253 | 1 313 | 1 375 |
| 142.5 | 274 | 302 | 332 | 363 | 395 | 429 | 463 | 500 | 538 | 577 | 617 | 659 | 702 | 747 | 793 | 840 | 889 | 939 | 990 | 1 043 | 1 097 | 1 153 | 1 209 | 1 268 | 1 327 |
| 145 | 265 | 292 | 321 | 350 | 381 | 414 | 448 | 483 | 519 | 557 | 596 | 636 | 678 | 721 | 766 | 811 | 858 | 907 | 956 | 1 007 | 1 060 | 1 113 | 1 168 | 1 224 | 1 282 |
| 147.5 | 256 | 282 | 310 | 339 | 369 | 400 | 433 | 467 | 502 | 538 | 576 | 615 | 655 | 697 | 740 | 784 | 829 | 876 | 924 | 973 | 1 024 | 1 076 | 1 129 | 1 183 | 1 239 |
| 150 | 248 | 273 | 299 | 327 | 356 | 387 | 418 | 451 | 485 | 520 | 557 | 595 | 634 | 674 | 715 | 758 | 802 | 847 | 894 | 941 | 990 | 1 040 | 1 092 | 1 144 | 1 198 |
| 152.5 | 239 | 264 | 290 | 317 | 345 | 374 | 405 | 436 | 469 | 503 | 539 | 575 | 613 | 652 | 692 | 733 | 776 | 820 | 864 | 911 | 958 | 1 006 | 1 056 | 1 107 | 1 159 |
| 155 | 232 | 256 | 280 | 307 | 334 | 362 | 392 | 422 | 454 | 487 | 522 | 557 | 593 | 631 | 670 | 710 | 751 | 793 | 837 | 881 | 927 | 974 | 1 022 | 1 072 | 1 122 |
| 157.5 | 225 | 248 | 272 | 297 | 323 | 351 | 379 | 409 | 440 | 472 | 505 | 539 | 575 | 611 | 649 | 688 | 727 | 768 | 810 | 854 | 898 | 943 | 990 | 1 038 | 1 087 |
| 160 | 218 | 240 | 263 | 288 | 313 | 340 | 368 | 396 | 426 | 457 | 489 | 523 | 557 | 592 | 629 | 666 | 705 | 745 | 785 | 827 | 870 | 914 | 959 | 1 006 | 1 053 |
| 162.5 | 211 | 233 | 255 | 279 | 304 | 330 | 356 | 384 | 413 | 443 | 475 | 507 | 540 | 574 | 610 | 646 | 683 | 722 | 761 | 802 | 844 | 886 | 930 | 975 | 1 021 |
| 165 | 205 | 226 | 248 | 271 | 295 | 320 | 346 | 373 | 401 | 430 | 460 | 491 | 524 | 557 | 591 | 626 | 663 | 700 | 738 | 778 | 818 | 860 | 902 | 946 | 990 |
| 167.5 | 199 | 219 | 240 | 263 | 286 | 310 | 335 | 362 | 389 | 417 | 447 | 477 | 508 | 540 | 574 | 608 | 643 | 679 | 717 | 755 | 794 | 834 | 875 | 918 | 961 |
| 170 | 193 | 212 | 233 | 255 | 277 | 301 | 326 | 351 | 378 | 405 | 434 | 463 | 493 | 525 | 557 | 590 | 624 | 660 | 696 | 733 | 771 | 810 | 850 | 891 | 933 |
| 172.5 | 187 | 206 | 226 | 248 | 270 | 292 | 316 | 341 | 367 | 394 | 421 | 450 | 479 | 510 | 541 | 573 | 606 | 641 | 676 | 712 | 749 | 787 | 825 | 865 | 906 |
| 175 | 182 | 200 | 220 | 240 | 262 | 284 | 307 | 331 | 356 | 382 | 409 | 437 | 466 | 495 | 526 | 557 | 589 | 622 | 656 | 691 | 727 | 764 | 802 | 841 | 880 |
| 177.5 | 177 | 195 | 214 | 234 | 255 | 276 | 299 | 322 | 346 | 372 | 398 | 425 | 453 | 481 | 511 | 541 | 573 | 605 | 638 | 672 | 707 | 743 | 780 | 817 | 856 |
| 180 | 172 | 190 | 208 | 227 | 248 | 269 | 290 | 313 | 337 | 361 | 387 | 413 | 440 | 468 | 497 | 526 | 557 | 588 | 621 | 654 | 688 | 722 | 758 | 795 | 832 |

$$P = \frac{\pi \left[\frac{d}{2}\right]^2 \cdot S}{1.1 \cdot p^2}$$

$S$ = 78 000 kPa

$P$ = MAWP kPa

$p$ = staybolt spacing, mm

$d$ = Minimum diameter of corroded staybolt, mm

**Table S2.10.4.1.b [Metric Units]**
**Maximum Allowable Working Pressure on the Load Carrying Capacity of a Single Corroded Steel Staybolt**

## S2.10.5 CONSTRUCTION CODE

To address the many pressure-related components and features of construction encountered in firetube boilers, a reprint of the 1971 Edition of Section I of ASME Boiler Code, Part PFT, is available for information only. Copies of these referenced ASME sections may be obtained by contacting the National Board of Boiler and Pressure Vessel Inspectors, 1055 Crupper Ave., Columbus, OH 43229 or www.nationalboard.org. This Supplement may be used for actual repairs/alterations and inspection/evaluation of boilers.

## S2.10.6 NOMENCLATURE

The nomenclature for the terms used in the above equations is:

p = maximum pitch measured (inches or mm) between straight lines, (horizontal, vertical, or inclined) passing through the centers of staybolts in different rows.
*l* = the pitch of stays in one row, passing through the center of staybolts, these lines may be horizontal, vertical, or inclined and measured in inches or mm.
w = the distance between two rows of staybolts, inches or mm.
h = the hypotenuse of a square or rectangle, defined as either $\sqrt{2p^2}$ or, $\sqrt{l^2 + w^2}$ inches or mm.
d = minimum diameter of corroded staybolt, inches or mm
R = inside radius of the weakest course of shell or drum, in inches or mm.
TS= ultimate tensile strength of shell plates, psi (MPa)
t = minimum thickness of shell plate in the weakest course, inches or mm.
P = calculated MAWP psi (MPa).
S = maximum allowable stress value, psi (MPa).
$d_0$ = outside diameter of firetube; if tapered use the largest outside diameter.
*f* = length of firetube, inches, measured between circumferential joints
C = 2.1 for welded stays or stays screwed through plates not over 7/16 in. (11 mm) in thickness with ends riveted over.
C = 2.2 for welded stays or stays screwed through plates over 7/16 in. (11 mm) in thickness with ends riveted over.
C = 2.5 for stays screwed through plates and fitted with single nuts outside of plate, or with inside and outside nuts, omitting washers.
C = 2.8 for stays with heads not less than 1.3 times the diameter of the stays screwed through plates, or made a taper fit and having the heads formed on the stays before installing them and not riveted over, said heads being made to have true bearing on the plate.
C = 3.2 for stays fitted with inside and outside nuts and outside washers where the diameter of washers is not less than 0.4p and thickness not less than t.

**Note**: The ends of stays fitted with nuts shall not be exposed to the direct radiant heat of the fire.

$C_1$ & $C_2$ = constants, see Table S2.10.3.1
E = the efficiency of the longitudinal riveted joint.

See Table S2.10.6 for efficiencies (E), which are the average for the different types of riveted joints.

### TABLE S2.10.6
EFFICIENCIES (E), AVERAGES FOR RIVETED JOINTS

| Type of Riveting | Lap | Butt |
|---|---|---|
| Single | 58 | |
| Double | 74 | 82 |
| Triple | 78 | 88 |
| Quadruple | | 94 |

**Note**: The efficiency of a particular joint depends upon the strength of the plate and rivet, thickness of the plates, and the diameter of the rivets. The 1971 Edition of Section I of the ASME Code, Appendix A-1 through A-7, provides a method for calculating a specific joint efficiency that may be used with the concurrence of the Jurisdiction.

FS = Factor of safety
FS = 4 For stayed surfaces
FS = 6 For riveted lap joints
FS = 5 For riveted buttstrap joints

**Note:** A Jurisdiction may mandate a higher design margin or permit a lower design margin, but in no case may the factor of safety be less than four.

### S2.10.7 LIMITATIONS

a) The maximum allowable working pressure shall be the lesser of that calculated in accordance with NBIC Part 2, S2.10, or the MAWP established by the original manufacturer.

b) The shell or drum of a boiler in which a “lap seam crack” extending parallel to the longitudinal joint and located either between or adjacent to rivet holes, when discovered along a longitudinal riveted joint for either butt or lap joint, shall be permanently discontinued for use under steam pressure, unless it is repaired with jurisdictional approval.

### S2.10.8 BOILER INSULATION AND JACKETING

a) The pressure retaining item shall be subjected to ultrasonic thickness testing (UT) per S2.6.2 to establish a baseline thickness for all of the boiler components. The original Manufacturer’s Data Report may be used to establish baseline thickness. Recurring UT inspections per S2.6.2 f) may be taken at the bottom of the barrel and around the bottom of the firebox.

b) Should removal of the insulation and jacket be requested by the Inspector, agreement should be obtained by the owner or user, Inspector and jurisdiction if required.



### S2.11 BOILER INSPECTION GUIDELINE

a) The following form may be used as a guideline for documentation and inspection of historical boilers. Jurisdictions may require additional inspections and documentation to those noted in this guide. The owner or user and Inspector should be aware and understand jurisdictional requirements where the historical boiler will be operated.

Jurisdiction Number _____

Owner _____

Location _____

Make _____

Year _____

Engine No. _____

Heating Surface _____

Design Pressure _____

Current Operating Pressure _____

Inspector _____

Safety Valve(s) Setting _____

Total Safety Valve Capacity _____

b) As a minimum, the inspection shall include consideration of the following:

1) Smoke Box

a. Front Tubesheet

1. Check condition of front tubesheet and thickness around handhole openings.

2. Check condition of threaded openings and plugs.

3. Check condition of rivets between front tubesheet and barrel.

b. Tubes

1. Are tubes beaded back to the tubesheet?

2. Are there signs of leakage?

c. Check condition of smoke box shell (especially around lower surfaces).

d. Check inside condition of barrel and outside diameter of tubes for corrosion and scale.

e. Check back side of tubesheet (especially area in contact with handhole gasket and area where tubesheet joins barrel).

f. Check tubesheet supports (through stays, supports or strong backs).

g. Check inside rivet heads on lap or buttstrap joints, if possible.

h. Check front bolster (front axle) attachment points inside barrel. Note thinning of the lower smokebox section of the barrel is critical if the steering bolster attaches fully or partially to this thinned area.

2) Barrel (shell)

a. Check front bolster attachment points on the outside of the barrel, both within and without the present boundary.

b. Check condition of tubesheet rivets on outside of barrel.

c. Check condition of threaded openings and plugs in openings.

d. Check radius rod attachment point.

e. Check attachment points of studs, castings, brackets, accessories, etc.

f. Check piping and nozzle openings on shell (feedwater nozzles, steam outlet, water column, etc.).

g. Check handhole openings in barrel.

h. Lap seam or buttstrap

1. Check for leakage around riveted seams and joint rivets.

2. Confirm joint efficiency based on number of rows of rivets and type of joint.

i. Identify and check any external contour that does not appear normal.

j. Insulation or insulation jacket (lagging)

1. Does jacket cover any critical areas or make them difficult to observe? (Normally the jacket will need to be removed for inspection of the barrel.)

2. Is barrel pitted or corroded under jacket?

3) Wrapper Sheet

a. Check handhole openings (material thickness, gasket area, etc.).

b. Check for seepage around attachment points (wing sheets, axle supports, etc.).

c. Check condition of riveted seams joining wrapper to throat sheet and rear head.

d. Check condition of riveted seams joining throat sheet to barrel.

e. Check for external shapes or contours that do not appear normal.

f. Check for seepage around staybolt heads.

g. Check condition of staybolt heads.

h. Check condition of threaded openings. (May need to remove nipples and plugs).

i. Check internal surfaces for cracks, pits, material thickness, and scale.

j. Check staybolt thickness and condition.

k. Check for scale and mud buildup in waterlegs and wet bottoms.

l. Check for buildup of dirt and grease between or behind attaching brackets such as wing sheets.

m. For dry bottom boilers:

1. Check riveted seams at bottom of waterlegs in ash pan area (ogee ring).

2. Do you need to remove ash pans and grates to observe above seams?

3. Check condition of grate support brackets.

n. For wet bottom boilers:

1. Check ash pan area for pits and staybolt head condition.

2. Check inside bottom of wrapper and staybolt condition.

3. Check condition of lap seam in wrapper.

4. Check condition of ash pan drain tube if present.

5. Check condition of drain plug and plug threads.

6. Check condition of studs, especially studs holding hitches to the bottom sheet.

o. Check for condition of blowdown valve. Check for size and type.

4) Steam Dome

a. Check for condition of drain back holes in shell if possible.

b. Check condition of main steam stop valve.

c. Check condition of piping on the steam dome and the condition of the steam outlet piping on the steam dome.

d. Check condition of the steam dome seams and seams between the steam dome and the boiler shell.

1. Is seepage present?

2. Can interior seams be observed?

e. Check the condition of pressure gage.

1. Is there a siphon and what is its condition?

2. Is the gage readable from the operator's position?

3. Has the gage been calibrated or checked against another gage?

4. If a shutoff valve is present, its handle shall indicate open position.

5. Checked gage for correct range and pressure.

f. Check for condition of safety valve.

1. Does the safety valve have its own inlet/outlet piping with no intervening block valves and no possibility of isolation?

2. Check that the inlet pipe size is not smaller than the valve inlet size.

3. Check that the outlet pipe size is not smaller than the valve outlet size.

4. Is the safety valve a National Board capacity certified, ASME "V"/National Board "VR" stamped valve of proper set pressure and capacity rating for the boiler heating surface?

5. Does the safety valve have a try lever (hand lifting lever)?

6. Is the safety valve sealed with factory seals at the top pressure adjustment cap and at the blowdown ring adjustment point?

5) Water Column and Gage Glass

a. Is the gage glass calibrated to the level of the crownsheet?

b. Check condition of try-cocks, gage glass stop valves, gage glass drain valve, and water column drain valve.

c. Check condition of gage glass (cracks or scratches).

d. Check the upper and lower gage glass packing for signs of leakage.

6) Firebox

a. Check for bulging between staybolts and warping of the boiler plate (determine possible causes).

b. Check riveted seams around the fire door.

c. Check for sediment buildup over the fire door opening at the rear head.

d. Check for sediment buildup over the peephole opening in the wrapper sheet (where applicable).

e. Check condition of fusible plug. (The plug must be removed for observation.)

1. Is it stamped ASME standard?

2. Check condition of top surface for scale and bottom surface for tin corrosion. (May need to brush it off)

3. Check for signs of leakage between the tin center and brass casing.

f. When the fusible plug is removed, check crownsheet thickness at that location and thread condition. Are weld repairs required?

g. A fireside fusible plug must project a minimum of 3/4 in. (17.8 mm) into the waterside.

h. Fireside fusible plug may not extend into fire area more than 1 in. (25 mm).

i. A gage glass calibration can only be done when the crownsheet and fusible plug and gage glass can be seen and measured. A recommended minimum water level may be determined as follows: With engine (boiler) sitting on level ground and water just observable at the bottom of the gage glass, the crownsheet should be covered by at least 2-1/2 in. (64 mm) of water on a full-size boiler.

j. Check staybolt condition, especially near top surface of crownsheet.

k. Check through stays, strong backs, knee braces, etc., on rear head.

l. Check handhole openings, threaded openings and plugs in rear head.

m. Check condition of firebox tubesheet and check if tubes are beaded back to the tubesheet.

n. Check condition of staybolt heads inside the firebox.

o. Check condition or design of crownsheet. Is it flat-topped or able to trap water? Is it free of scale?

7) External Plumbing (see NBIC Part 2, S2.7.1)

a. Is black pipe (as opposed to galvanized pipe) used throughout?

b. Check for use of schedule 80 black pipe required between boiler and first valve.

c. Are fittings and valves of proper pressure rating for maximum allowable working pressure?

d. Are isolation valves present to shut off individual system lines (blower, injector, main steam, blowdown, etc.)?

e. Are two separate feedwater systems present and operable?

f. Check piping for freeze damage.

g. Are piping support brackets present where needed?

h. Fittings dates are to be stamped, stenciled, or recorded on boiler records (boiler log).

i. Piping shall have a 20-year life, except for the main steam line, which shall be evaluated periodically as to remaining service life. As an alternative, all boiler piping may be ultrasonically examined for adequate thickness to determine the remaining service life.

8) Ultrasonic Thickness Testing (every fifth year).

9) Hydrostatic Pressure Test (minimum every three years or as required by the Jurisdiction).

   a. Hydrostatic pressure test should be between maximum calculated allowable working pressure and 1.25 times maximum allowable working pressure with metal temperature at 60°F-120°F. (16°C-49°C).

   b. A calibrated pressure gage shall be used when hydrostatically pressure testing a boiler. The boiler gage may be compared (calibrated) with the calibrated pressure gage at this time.

   c. All safety valves shall be removed during the hydrostatic testing of the boiler.

10) Safety Valve Testing

   a. Safety valves should be removed from the boiler for testing and/or repair at intervals required by the Inspector or the Jurisdiction.

   b. Safety valves may be try lever checked for operability with the boiler under steam pressure of at least 75% of the set pressure of the safety valve.

   c. Safety valves may also be tested initially, periodically and after any repair or adjustment as noted in the External Operating Test listed below.

11) External Operating Test (every third year)

   a. The safety valve should be tested by having the operator raise the boiler pressure to the safety valve popping point and popping point pressure and blowdown observed to be within manufacturer's tolerances.

   b. Feedwater devices (two injectors, or one injector and one pump) tested for operability.

   c. Gage glass stop and drain valves and gage cocks checked in service.

   d. Blowdown valve(s) tested as operational and discharging to a safe location.

   e. Operation of the steam engine by the operator satisfactory, including a driving test.

   f. The external operating test to be recorded in the boiler records (boiler log).



## S2.12 INITIAL BOILER CERTIFICATION REPORT FORM, see Pg.178

Form C-1 may be used to document the initial inspection for historical boilers. (Form C-1 is located at the end of this supplement.)

## S2.13 GUIDELINES FOR HISTORICAL BOILER STORAGE

The historical boiler guidelines published herein list the general recommendations for storage of historical boilers. The exact procedures used by the owner/operator must be based on the conditions and facilities at the storage site.

### S2.13.1 STORAGE METHODS

a) The methods for preparing a historical boiler for storage depend upon several factors, including:

   1) The anticipated length of time the historical boiler will be stored;

   2) Whether storage will be indoors or outdoors;

   3) Anticipated weather conditions during the storage period;

4) The availability of climate-controlled storage;

5) Type of fuel used; and

6) Equipment available at the storage site.

b) Indoor storage can be categorized into two types: indoor with climate control and indoor without climate control.

c) Outdoor storage can also be categorized into two types: outdoors during a warm time of year or in a geographic location where it can reasonably be expected to be above freezing during storage, and outdoors during a time period or in a geographic location where it can be expected that freezing temperatures will occur during storage.

d) Historical boilers may be stored using the “wet method” or the “dry method.”

e) Before any method of storage, the boiler must be thoroughly washed out, with mud and scale removed from the mudring, crownsheet, bottom of the barrel, and the top of the firing door.

### S2.13.1.1 WET STORAGE METHOD

a) When utilizing the “wet storage method,” the boiler is completely filled with treated water to exclude air.

**Note**: This method cannot be used if the historical boiler is exposed to freezing weather during storage.

b) Chemicals may be added to the storage water to further inhibit corrosion. However, depending on the chemical used, the treated water may have to be disposed of as a hazardous waste to prevent chemical contamination of the surrounding property.

c) The procedure applies only to the sections of the boiler that contain water. The firebox interior, cylinders, piping, and auxiliary equipment of the historical boilers still require draining, preservation, and dry storage.

### S2.13.1.2 DRY STORAGE METHOD

a) When utilizing the “dry storage method” the boiler is completely emptied of water, dried out, and allowed to stand empty. Several variations of the “dry method” may be used. These include but are not limited to:

1) Airtight storage with a moisture absorbent placed in trays in the boiler;

2) Airtight storage with the boiler filled with inert gas to exclude oxygen; and

3) Open-air storage with the mudring washout plugs or handholes removed to enable air circulation for evaporation of formed moisture.

b) Each variation has positive and negative points that must be taken into account before use. If the boiler is filled with inert gas such as nitrogen, care must be taken because this method can result in asphyxiation of personnel if the gas escapes the boiler through a leaking valve, washout plug, or handhole and enters a pit, sump, or enclosed room. In addition, the boiler must be completely vented to remove gas, then tested and declared gas-free before personnel may enter.

c) Although the use of dry storage with several washout plugs or handholes removed for air circulation is the most common method, there are some potential drawbacks. The boiler interior may be subject to moisture forming from condensation created from humidity changes in the ambient air. Small animals may take up residence inside if screens are not used to cover handholes or washouts.

d) Before storage, the boiler must be thoroughly washed out, with mud and scale removed from the mudring, crownsheet, bottom of the barrel, and top of the firing door. Any mud or loose scale left in the boiler will retain moisture, leading to corrosion. After washing, water must be removed and the boiler dried before storage. A portable gas or electric heater placed in the firebox to aid evaporation and drying along with a vacuum used to siphon water out via the lower washout plugs or handholes is recommended.

**Note**: Use of the drying-out procedure of building a small wood fire in the firebox is not recommended because of the danger of overheating the firebox sheets.

e) The typical railroad dry storage method required blowdown of the boiler until empty while steam pressure registered on the gage and removal of the washout plugs or handholes while the shell plates were hot and there was no steam pressure. This allowed the heat remaining in the boiler plates to evaporate any remaining water in the boiler. However, this method may result in staybolt damage from temperature change and requires extreme care, if used.

f) Oil should not be applied to the interior surfaces of the boiler because it is difficult to remove. Further, the oil must be removed before steaming or it will form scale and contribute to foaming.

## S2.13.2 RECOMMENDED GENERAL PRESERVATION PROCEDURES

a) When the historical boiler is under steam, inspect piping, fittings, and appliances for steam and water leaks that may introduce moisture into the lagging. Repair leaks as necessary and remove wet lagging insulation.

b) Remove grates and ash pan bottom if dry bottom. Remove washout plugs and handhole plates. Mark handhole plates and washout plugs for proper relocation.

c) Thoroughly wash the boiler and firebox and remove mud and scale from the mudring, crownsheet, bottom of the barrel, and top of the firing door. Any mud or loose scale left in the boiler will retain moisture leading to corrosion.

d) To protect the boiler interior during storage, dry the boiler by using compressed air to blow out as much water as possible. A portable heater placed in the firebox to warm the boiler to 200°F (95°C) along with a vacuum used to siphon water out via the lower washout plugs or handholes can aid evaporation and drying of any moisture that collects in low or impossible-to-drain locations without harming the sheets.

**Caution**: To prevent a buildup of steam pressure during the drying process, an opening in the upper part of the boiler should be opened to enable the moisture to escape. In addition, the driving wheels should be blocked and the throttle and cylinder cocks should be opened to permit any steam that forms to escape.

After drying, it will be necessary to either vent the boiler or to place containers of desiccant inside the boiler through the dome cap to absorb any condensation that may occur during storage. Venting the boiler to allow air circulation is accomplished by leaving two or more of the lower washout plugs or handholes out and opening the vent valve on the top of the boiler. A vent line consisting of two 90° elbows and pipe nipples should be installed in the vent valve to locate the opening to the downward direction in order to keep rain or snow from entering the open valve.

e) To prepare a historical boiler for storage, the following should be completed:

1) If the historical boiler will be stored outdoors, inspect the boiler jacket and confirm it is tight with no gaps leading into the lagging or shell. Pay close attention to areas at shell openings such as for studs, safety valves, etc. Repair gaps or damaged jacket sections as necessary. Consideration should be given to covering the entire historical boiler and equipment with a tarp. Otherwise, jacket openings should be covered to prevent the entrance of rain or snow. Where necessary, apply a waterproof covering over the exposed or open sections.

2) If the historical boiler will be stored outdoors, the smokestack should be sealed by applying a wood and sheet rubber cover held in place by clamps or a through bolt.

3) If the historical boiler will be stored outdoors, the safety valves should either be covered or removed, with plugs or caps installed in the holes if the valves are removed. The governor and lubricators should be covered.

4) Clean tubes using tube brush or scraper. After cleaning use a long air nozzle or vacuum to remove any loose coal or ash.

5) Empty and clean the smokebox and front tubesheet of all coal, ash, or burnt oil. This work is especially critical at the bottom section of the smokebox and front tubesheet rivet flange. The smokebox door should be sealed by applying a gasket or sealant and any other air openings in the smokebox sealed. The exhaust nozzle should be sealed by applying a wood and sheet rubber cover held in place by clamps.

6) Thoroughly clean the firebox sheets of coal, ash, and clinker.

7) The potential for corrosion of the smokebox interior, front tubesheet, and fireside of the firebox sheets can be further minimized by applying a coating of light oil, outdoor paint, or primer. Inspection of the smokebox, front tubesheet, and firebox sheet must be accomplished before painting since it will cover up many types of defects. The coating will burn off quickly when the historical boiler is returned to service.

8) Empty and completely clean the grates and ash pan of coal and ash. This work is especially critical at the sections between the grate bearers, rivets, and firebox sheets; and from the grate segment air openings.

9) Appliances and piping that might contain water or condensation should be drained and blown dry using dry compressed air. Remove injectors and store in a warm place. Refer to NBIC Part 2, S2.13.3, *Use of Compressed Air to Drain Historical Boiler Components*, for details.

10) The cylinder castings, valve cavities, and steam lines must be drained of moisture and blown dry. A typical method:

    Pressurizing the boiler with compressed air. Using the throttle to regulate the airflow, allow the air to blow through the dry pipe and discharge into the cylinders. The cylinder cocks must be open.

    **Note**: This may have to be performed several times to discharge the moisture from the cylinders and steam pipes.

    Refer to NBIC Part 2, S2.13.3, *Use of Compressed Air to Drain Historical Boiler Components*, for additional information.

11) Drain and wash tender water spaces. The tank should be inspected afterward and any remaining water removed by siphon or vacuum. When dry, spray the water space with outdoor paint or a commercial rust preventative. Oil should not be used. Drain and dry the tender tank hoses and clean screens.

12) On coal or wood burners, remove coal or wood. Spray any exposed surfaces of the tender fuel space with outdoor paint or a commercial rust preventative. If the historical boiler is to be stored outdoors for a long term, cover the coal space with a tarp or a roof.

13) After cleaning thoroughly, coat connecting rods, cross heads, valve gear, guides, piston rods, and exposed feedwater pump components with water-resistant grease or a rust preventative. If the historical boiler is to be stored outdoors for a long term, grease should be applied to junction of rod and pin in valve gear and rods to prevent water entering.

14) If the historical boiler is moved after this is applied, it will be necessary to reapply the coating to piston rods and guides.

**Note**: Heavy oil or unrefined oil such as any of the Bunker types (Bunker 6, etc.) should not be used for preservation of any components because the sulfur contained in it can accelerate corrosion. Standard motor oil or journal oil will not stick to wetted surfaces. Surfaces to be so coated must be dry. If moisture is a problem, steam cylinder oil should be applied.

15) All openings in the boiler should be covered to ensure water and contaminants cannot enter the boiler. Handholes and plugs left out for air circulation should be covered with screen to prevent small animals from entering and taking up residency in the boiler. Secure all openings and covers on the top of the water tender to prevent accidental opening with the potential for water and contaminants to enter.

16) If the historical boiler is to be stored outdoors with questionable or no security, remove and store all cab gages, water glasses, lubricators, brass handles, whistle, headlight, tools, spare parts, and any other items that thieves or vandals might attack.

17) Inspect stored historical boiler regularly for signs of rust, corrosion, damage, deterioration, vandalism, or animal invasion and immediately take any corrective measures necessary.

### S2.13.3 USE OF COMPRESSED AIR TO DRAIN HISTORICAL BOILER COMPONENTS

a) The process of using air pressure to drain and empty auxiliary components such as the cylinders and piping completely of water offers several advantages over other methods.

b) The air compressor must be equipped with a suitable filter to enable it to supply oil-free air because the introduction of air that contains oil into the water/steam parts of the boiler will promote the formation of scale and water foaming when the historical boiler is returned to service.

c) The air compressor must be a large enough size to provide the volume and pressure of air required.

d) If the boiler is pressurized with compressed air, the air pressure must be raised slowly to prevent distorting or overstressing the firebox sheets or staybolts because the normal expansion of the boiler that occurs under steam pressure is not present when air pressure is used.

e) When pressurizing the boiler with air, the pressure should never exceed three-quarters of the maximum allowable working pressure. Air shall never be used for pressure testing the boiler.

f) Components are drained by pressurizing the boiler to one-half to three-quarters of the maximum allowable working pressure with compressed air, then operating each component individually until the exhaust from it contains no moisture.

g) When necessary, specific pipe lines can be drained by breaking the line at each end, attaching the air line to it directly, then blowing the line out.

### S2.13.4 RETURN TO SERVICE

a) When returning a historical boiler to service, the boiler, firebox, and tender tank shall be ventilated to remove a potentially hazardous atmosphere from the firebox interior before personnel enter it. In addition, the atmosphere in the firebox shall be verified to be safe for human occupancy before personnel enter it. For the boiler this can be accomplished by removing the washout plugs or handholes and placing a fan or air blower on top of a steam dome opening to force air into the boiler. For the firebox this can be accomplished by opening the smokebox door and firebox door and placing a fan or air blower at either location to force air through. Failure to do this could result in asphyxiation of the first personnel to enter the boiler or firebox.

b) Perform a complete boiler flush to remove scale that has flaked off during storage as a result of the expansion and contraction of the metal due to temperature changes.

c) Clean handhole plate gasket surfaces (both boiler and handhole plate). These surfaces must be flat and free of scale, rust, and dirt in order to seal.

d) Inspect feedwater inlet connection to boiler. There should be a tee at each inlet; remove plug and inspect for lime deposits and clean if necessary. This should be done once a year; more often if conditions warrant it.

e) Remove gage glass and valves, and inspect these connections for lime deposits and clean if necessary. This should be done once a year; more often if conditions warrant it.

f) After inspection, replace glass (clean if necessary). Also inspect gage glass sealing washers and replace if necessary.

g) During cold weather, the historical boiler should be moved into a heated area and the boiler allowed to warm up in the air for several days until it is the same temperature as the air.

h) The initial fire-up should be done slowly to allow even heating of the boiler.

i) Before movement, the cylinder(s) should be warmed up by allowing a small quantity of steam to blow through them and out the cylinder cocks and exhaust passage(s). This is necessary to reduce the stress in the casting from thermal expansion of the metal.

j) Steam should be discharged through the cylinder cocks for several minutes to aid removal of any solvent, debris, or rust that may have formed in the steam pipes, cylinder, valve chest, and dry pipe.

k) All appliances should be tested under steam pressure before the historical boiler is moved or put under load.



## S2.14 SAFETY PROCEDURES[1]

This chapter of text covers procedures in certain situations or emergencies that may occur.

### S2.14.1 EXPERIENCE

a) Reading check lists and procedures can be of some value to get you thinking about what you are doing, but nothing can replace the experience gained by working beside conscientious and knowledgeable engineers. Ask questions, observe, read, listen, study, and think.

b) Safe operations depend upon thorough attention to detailed routines. Having procedures thought out, planned, and practiced before they are needed could minimize accidents and improve public safety. Know your abilities as well as the limitations of the machine that you are operating. In most cases knowing and keeping your machine in top operating condition can prevent most emergency situations from occurring. However, sometimes problems or situations beyond your control do occur. In any situation the first rule to remember is to keep a cool head. Haste and panic can never solve any emergency.

c) Don't be afraid to ask for help or advice. A lot of shows and public demonstrations have a designated individual in the area to ensure safe operation and assistance should a problem arise.

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### S2.14.2 STOPPING ENGINE IN AN EMERGENCY

a) Know how to stop the engine suddenly. For example, if someone or something runs out in front of the engine or some problem happens with whatever it is belted up to:

   1) Close throttle.

   2) Reverse valve quadrant position.

   3) Open throttle for a moment (this will quickly stop your engine).

   4) Close throttle.

   5) Open cylinder cocks.

b) Steam traction engines do not have brakes, so this is a maneuver worth knowing and practicing. However, it should be practiced with the dome valve shut as this method of stopping the engine tends to be very hard on gears and castings. In regards to belt work, it is extremely important that total undivided attention be given to what it is belted up to. Be prepared to shut down quickly should something happen.

### S2.14.3 WATER GLASS BREAKAGE

Having a properly guarded water glass will prevent objects from coming in contact with the glass. However, water glasses do break. If the machine is operating when water glass breakage occurs:

a) Close throttle.

b) Set valve quadrant to neutral (middle notch).

c) Disengage clutch.

d) Close damper.

e) Locate bottom water glass valve and shut off.

   1) The first four procedures will be difficult if the water glass is mounted back by the operator's platform.

   2) The bottom water glass valve is essential to locate and close first. This valve is below the waterline and can take the water dangerously close to the crownsheet if water is allowed to escape unchecked. This is where having the automatic type gage valves would be most desirable. Most traction engines do not have automatic-type gage valves. Caution must be exercised at this time because 300 °F (150 °C) steam and water will be spraying in every direction! There will be an inability to see much of anything except a cloud of water vapor. Use a shovel or a coat or something to deflect the spray to be able to find that lower valve.

f) Next, close the top gage valve; this one should just be blowing steam and obscuring visibility. There is no serious problem with steam being released because this valve is above the water line.

g) Next, use the try-cocks to determine water level of boiler. If bottom try-cock blows water, then inject water and replace water glass. However, if bottom try-cock does not blow water, and only blows steam, do not inject water and proceed to kill fire immediately. Do not move engine. Another method of determining the water level in the boiler other than using the try-cocks is to wet down a burlap sack and lay it on the barrel part of the boiler. Quickly pull it away and there will be a "sweat line" of where the actual water level is.

### S2.14.4 RUNAWAY ENGINE AND GOVERNOR OVER SPEED

a) Probable cause: governor malfunction. Usually the governor belt either slips or breaks. Know the governor belt condition and keep its tension snug but not too tight. Also, packing nut could be too tight, causing a binding on valve spindle; more often this will cause the engine not to respond to load and usually will not “run away.”

b) What to do in a runaway situation: Never leave the operator’s platform while engine is at governed speed.

   In the case of a runaway engine:

   1) Quickly close the throttle;

   2) Move forward/reverse lever to center of quadrant;

   3) Open cylinder cocks;

   4) Close dome valve; and

   5) Close damper and steam down (this is not a boiler emergency; once the engine has stopped there should be no danger).

c) In the unlikely event the throttle were to jam in conjunction with governor malfunction:

   1) Move forward/reverse lever to center of quadrant. This will stop the engine even though steam is still being sent to the valve chest;

   2) Close the dome valve; this would be the same as closing the throttle. Steam flow would then be stopped and the engine should be safe;

   3) Close damper and steam down.

### S2.14.5 KILLING A FIRE

This is an important procedure to know, should a low water situation ever occur.

a) Close all dampers. This will stop incoming air, which supports fire. Capping the smokestack is an additional way of checking draft to fire. However, it will cause a lot of smoke to emit around fire door.

b) Shovel dry sand or dry earth on the fire; this should immediately cool the fire to a safe level. Have a pile of dry sand or dirt in or around the steam engine area should a situation occur. It is important to remember that when trying to extinguish a fire, never stir the fire; this will only intensify the fire’s heat.

c) Close the fire door.

d) Close the dome valve.

e) Leave the engine alone. It is especially important not to move the engine as this could slosh water onto a possibly overheated crownsheet.

### S2.14.6 INJECTOR PROBLEMS

Injector problems are the number one reason for boiler operation malfunctions. An injector can be a very sensitive device. The ability to identify the reasons why it’s not working is the most important thing a steam engineer needs to know. The following are various problems and their causes:

a) Failure to raise water from supply tank.

1) Suction pipe clogged or tank supply valve turned off.

2) Leaks in suction pipe or hose, allowing air to enter above the level of water supply. A common problem when rubber or plastic hoses are used on suction side of injector.

3) Water supply too hot. Hot water will prevent injector from lifting water.

4) Obstruction in the lifting or combining tubes of the injector.

b) Injector lifts water but will not force it into the boiler.

1) Choked suction pipe or strainer/incomplete obstruction.

2) Supply valve not opened all the way.

3) Boiler valve closed.

4) Boiler check valve stuck closed.

5) Obstruction in delivery tube on injector.

6) Leaking injector overflow check valve.

7) Injector choked with lime.

c) Other injector problems.

1) Usually you have a hot injector because of improper operation. This is where a removable rubber hose on your water suction is handy. Remove hose, turn steam valve on to injector and put your thumb over suction side of injector. You should feel a smooth, steady suction. If not, wrap a rag around injector body and soak rag with cool water. Your objective is to cool down the injector. Now turn steam back on to injector, allowing cool air to suck into injector. At the same time, place suction hose back onto water supply line and it should go. Remember to tighten suction side connections so you don't lose your vacuum.

2) If injector still does not lift after following the previous instructions, it probably has some foreign matter in the lifting or combining tube. Simply remove bottom square nut on injector body, taking care not to lose flat washer that will come out with injector combining tube, clean and re-install. This should restore injector to working order.

3) When having injector problems, watch your injector overflow. Steam only and no water at overflow usually is an indication of a water lifting problem (no water to the injector). Steam and water at the overflow is usually a delivery problem, meaning your injector is lifting water but not forcing it into boiler.

4) The problem with delivery is usually associated with a stuck boiler check valve. After assuring yourself that the isolation valve to the boiler is open, try lightly tapping on the boiler check valve. More than likely though you will have to disassemble and clean boiler check valve; scale may be is holding the check valve from opening. This can be done with steam pressure on the boiler, providing the valve to the boiler holds pressure and the boiler check valve has been properly piped in. A boiler check valve may not close, causing steam and hot water to blow back through injector and into your feedwater tank. Again, you would have to turn off the valve to the boiler, disassemble and clean the check valve. If the injector will not force water into the boiler, there may be an obstruction in the delivery/combining tube of the injector. Remove bottom nut of the injector, disassemble and clean as explained above.

### S2.14.7 FOAMING OR PRIMING BOILER

a) A foaming boiler is usually caused by dirty or impure water in the boiler. Oils, detergent, etc., are the biggest problems and have no business being on the waterside of a boiler. A good rule of thumb is, “If you wouldn’t drink it, don’t put it in your boiler.” Foaming can be especially bad because you have no way of discerning your water level. The water glass and try-cocks will appear full. Foaming is usually really intensified with a heavy fire and a heavy engine load. Reduce or stop your engine load and reduce your fire until it settles down, steam down, wash out your boiler, and refill it with clean water. The first indication of a foaming or priming boiler is usually a “wet stack” and a discernable difference in the exhaust sound. Open cylinder cocks immediately and close throttle and determine your water level.

b) Priming is similar to foaming; you’re pulling water into your engine. This is especially bad because it can wash the oil from valves and cylinders and risk severe damage to the engine. Priming is caused more from carrying too-high a water level. It also occurs from working steam while ascending and descending hills. Know the machine you are operating, and what the safe water level is.

c) If an engine starts priming (it will show a wet stack), open cylinder cocks, reduce throttle, get engine to level area, and determine the water level. If possible, safely blowdown boiler to proper water level. Ensure no bystanders are close-by for safety.

### S2.14.8 HANDHOLE GASKET BLOWS OUT

a) Special care should be taken to ensure proper installation of handhole gaskets to prevent a blowout.

b) New gaskets need special attention on the first fire-up. When installing, ensure plate surface and mating surface on boiler are free of loose scale and debris. Firmly snug the gasket after it is properly centered on the handhole. Do not over-tighten as this tends to cut the gasket. A common cause of handhole gasket blowout is improper fitting of gasket to handhole plate. It is very important that the gasket fits center of handhole plate very snug. When steaming up, carefully “follow up” gaskets by ensuring nut stays snug. Special care must be exercised to ensure that there is no rotation of the handhole plate or gasket. Caution should be used if boiler has any pressure built up on it. The best time to follow up on handhole gaskets is when steam is almost down after first fire-up. It is important to snug them up before boiler cools, because as a boiler cools, it forms a vacuum, and if handholes are loose, they can collapse and drain your boiler.

c) If a handhole gasket blows out:

    1) Close damper. Prepare to steam down. If there is a large fire, be prepared to kill the fire. Depending on how fast the boiler is losing water and where on the boiler the handhole is leaking. Under no circumstance attempt to operate engine! Periodic operation of the injector is recommended to keep water level up until fire-down is complete.

    2) Do not attempt to remove handhole plate and gasket until steam is down. Carefully remove handhole plate and gasket. Inspect for cause of blowout.

### S2.14.9 TUBE BURST

Tubes will deteriorate and corrode over time. Usually a pit in the tube surface works its way through the tube and a pinhole develops. Rarely will a tube actually “burst”. Usually just a small leak occurs. If the leak occurs on firebox end or if leak is a large one, it usually puts the fire out. Leave the engine on a level surface and let it cool down. If the leak is toward the smoke box end of the boiler, water will come out of the smoke box door. Watch water level, close damper and prepare to steam down, or kill the fire if it hasn’t died out so already depending on how fast the boiler is losing water. Do not continue to operate the engine.

### S2.14.10 LEAKING VALVES

Several situations can cause a leaking valve. The most common would be a piece of scale or debris between valve seat and valve disc/plug. Another reason would be a break between valve stem and disc/plug (on a globe-type valve). Assuming scale on the valve seat, try opening and closing the valve to try and dislodge any debris. If the valve is broken or disc/plug has pulled off the end of the valve stem, there is nothing that can be safely done. Determining when to steam down or kill the fire will depend on the rate which the boiler is losing water. In most cases a normal steam down procedure will be required.

### S2.14.11 BROKEN PIPES

Broken pipes on an engine normally will not occur if engine has been piped with proper materials and correct procedures have been followed. Close attention should be paid to pipe and pipe fittings and their condition. However, should a pipe or pipe fitting break, carefully try and locate a up-line valve and isolate the break. Follow normal steam down procedures. If there is no up-line valve that can be shut off, kill the fire immediately.

### S2.14.12 SAFETY VALVE PROBLEMS

Testing of this critical safety device should be done each time the boiler is fired up. This is essential to ensure its continued safe operation. In the event the safety valve does not open at its preset pressure and trying to manually trip open valve lever is unsuccessful, close the damper and follow steam-down procedure. After closing damper, start the injector. This will decrease the steam pressure. Under no circumstance should the blowdown valve be used to release pressure (blowing down will lower the water level considerably). Killing the fire should not be necessary provided the water level is at a safe level and the steam pressure is dropping from running the injector. Do not continue to run engine; remove the valve and send to a certified shop for repair or replace the valve.



### S2.14.13 SAFETY VALVE OPENS BUT WILL NOT CLOSE

This problem is more prevalent than valves that don't open. There is no immediate danger in a safety valve that won't close; the boiler is only losing steam. Try to manually open the valve a few times under pressure. This may seat the valve. Bringing your steam pressure down by approximately 25 psi (170 kPa) will let the valve seat. If after dropping the pressure and it still does not seat, there may be an obstruction in the valve or a binding in the action of the valve. Follow normal steam-down procedure. Remove valve and send to a certified shop for repairs or replace the valve.

### S2.14.14 LEAKING PIPE PLUGS

Usually threads were not properly cleaned before installation or thread tape/sealant was not properly applied. Under no circumstance should plugs be tightened with boiler under pressure. Usually the leak is very small and does not mean any immediate danger. Follow normal steam-down procedure.

### S2.14.15 MELTED GRATES

a) Closing damper with a hot coal fire restricts air flow to the grates. Although it is rare for a grate to melt from this, it is possible to warp or ruin a good set of grates. Grates need air flow to keep them cool. Closing damper all the way with a hot coal fire should only be done in an emergency.

b) Carrying ashes too high in ash pan is usually the reason for melted grates. The hot coals in the ash pan touching the grates and the restricted air flow is going to damage the grates. In some cases a grate bar can entirely melt out leaving a huge hole in your fire bed and an intense fire burning in your ash pan. Follow normal steam-down procedure.

### S2.14.16 FIRING OF HISTORICAL BOILERS WITH LIQUID OR GASEOUS FUELS.

Hand firing of historical boilers with liquid or gaseous fuels poses significant additional safety concerns beyond those encountered when firing with solid fuels for which these boilers were originally designed, such as coal, straw or wood. The cautionary notes listed below are provided as examples to remind the owner or user that additional safety concerns do exist when firing historical boilers with these alternate fuels. These notes are not meant to be all-inclusive so each boiler's fuel system should be designed appropriately.

a) JURISDICTIONAL ACCEPTANCE: The owner or user shall check with the Jurisdiction as applicable to determine if this alternative firing method is allowed.

b) OWNER OR USER KNOWLEDGE: The owner or user shall have an extensive knowledge of the fuel used, fuel transfer system, on board fuel storage, burner, firing controls, emergency shut off devices and procedures.

c) PURGING: To prevent a firebox explosion, the furnace shall be purged of combustible gasses prior to applying the fuel ignition source.

d) FLAME IMPINGEMENT: Direct flame impingement of the metal surfaces within the furnace can damage the boiler. Installation of refractory or fire brick in the firebox is a common practice to prevent this potential damage.

e) LOW WATER: The owner or user shall have a procedure in place to immediately shut off the fuel supply to the burner when a boiler low water condition occurs.

f) FUEL CONTAINMENT: The fuel storage system shall be suitably designed with the appropriate shut off devices for the specific fuel product. The mounting method and proximity of the fuel storage container to the furnace shall be considered to prevent the fuel from accidental ignition.

g) FUEL SYSTEM: The fuel delivery system and routing from fuel source to the burner shall be suitably designed for the specific fuel product including appropriate emergency shut off devices.

h) FUEL AIR MIXTURE: The burner utilized shall be designed to operate within the confines of the boiler furnace and provide the proper fuel/air mixture.

i) SAFETY VALVE: The boilers minimum relieving capacity shall be computed for the type of fuel used.

j) COMPRESSED NATURAL GAS (CNG) vs LIQUID PETROLEUM GAS (LPG): CNG is lighter than air and LPG is heavier than air. The owner or user should understand the properties of the fuels to ensure the gas will not accumulate in the boiler (see Purging above).

### S2.15 TABLES AND FIGURES

a) TABLE S2.8.1, Minimum Pounds of Steam per hour per Square Foot of Heating Surfaces

b) TABLE S2.10.2, Sizes for Rivets Based on Plate Thickness

c) TABLE S2.10.3.1, Maximum Allowable Working Pressure for Cylindrical Components – Single-Riveted Lap Joint

d) TABLE S2.10.3.2, Maximum Allowable Working Pressure for Cylindrical Components – Double-Riveted Lap Joint

e) TABLE S2.10.3.3, Maximum Allowable Working Pressure for Cylindrical Components – Triple-Riveted Lap Joint

f) TABLE S2.10.3.4, Maximum Allowable Working Pressure for Cylindrical Components – Buttstrap Double- Riveted Lap Joint

g) TABLE S2.10.3.5, Maximum Allowable Working Pressure for Cylindrical Components – Buttstrap Triple-Riveted Lap Joint

h) TABLE S2.10.3.6, Maximum Allowable Working Pressure for Cylindrical Components – Buttstrap Quadruple-Riveted Lap Joint

i) TABLE S2.10.4, Maximum Allowable Working Pressure for Stayed Surfaces

j) TABLE S2.10.4.1, Maximum Allowable Working Pressure Based on Load Capacity of a Single-Riveted Staybol

## The National Board of Boiler and Pressure Vessel Inspectors
## INITIAL BOILER CERTIFICATION REPORT (Form C-1)

| BOILER INFORMATION | |
|---|---|
| JURISDICTION NO. | Owner |
| MANUFACTURER | Owner ADDRESS |
| YEAR BUILT | Owner CITY/STATE |
| BOILER TYPE | USER |
| ENGINE NO. | USER ADDRESS |
| OTHER NO. | USER CITY/STATE |
| HEATING SURFACE | OPERATOR & LICENSE NO. |

| BARREL INFORMATION | |
|---|---|
| INSIDE DIAMETER | SEAM TYPE |
| TUBE SIZE/NUMBER | SEAM EFFICIENCY (from Table S2.10.3) |
| TENSILE STRENGTH OF SHELL | MAXIMUM PITCH OF SEAM RIVETS |
| MIN. THICKNESS OF SHELL | JACKET FULLY REMOVED FOR INSPECTION |
| MIN. THICKNESS OF TUBESHEET | MAWP OF BARREL (from Table S2.10.3) |

| FIREBOX AND WRAPPER SHEET |
|---|
| STAYBOLT DIAMETER (Base of Threads) OF THINNEST STAYBOLT |
| STAYBOLT PITCH (Max) AT CROWNSHEET |
| TYPE OF STAYBOLT (Telltale?) |
| MINIMUM THICKNESS OF STAYED SURFACE |
| MAWP OF STAYED SURFACES (from Table S2.10.4.1) |
| TYPE OF BOTTOM (Ogee, Wet Bottom, etc.) |
| CONDITION OF THREADED MOUNTING STUDS |
| GRATES, GRATE SUPPORTS, DAMPERS, ASHPAN — SATISFACTORY? |
| CLEANED FOR INSPECTION? |

| SAFETY EQUIPMENT AND CONTROLS | | | | |
|---|---|---|---|---|
| SAFETY VALVE (per S2.8.1) | MANUFACTURER | SET PRESSURE | CAPACITY | SIZE |
| FUSIBLE PLUG (per S2.8.4) | NEW “ASME” PLUG | OLD PLUG REMOVED FOR CROWN INSPECTION? | | |
| FEED METHODS | INJECTOR(S) BRAND/SIZE | PUMP TYPE | PREHEATER TYPE | |
| WATER COLUMN | | DRAIN | WATER LEVEL VERIFIED? | |
| GAGE GLASS (per S2.8.2) | | GUARD | TYPE | |
| TRY-COCKS (per S2.8.3) | | NUMBER | OPERABLE? | |
| PRESSURE GAGE (per S2.8.5) | | DIAL RANGE | SIPHON TYPE | |

## INITIAL BOILER CERTIFICATION REPORT (Form C-1) *continued*

| VALVES AND PIPING (per S2.9 and S2.9.1) | |
|---|---|
| MAIN STEAM (dome) VALVE | MAIN STEAM PIPING |
| THROTTLE VALVE | PIPE NIPPLES AT SHELL |
| FEEDLINE STOP VALVE(s) | FEEDLINE CHECK VALVES |
| FEEDWATER PIPING TO INJECTORS & PIPING | BLOWDOWN PIPING |
| STEAM PIPING TO INJECTORS & PIPING | BLOWDOWN VALVES |
| INJECTOR ISOLATION (steam & water) VALVES | PIPING SUPPORTS |
| BLOWER VALVE | BLOWER PIPING |

| EXISTING REPAIRS AND ALTERATIONS |
|---|
| |
| |
| |
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| EXTERNAL VISUAL INSPECTION FINDINGS |
|---|
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| |

| INTERNAL VISUAL INSPECTION FINDINGS |
|---|
| |
| |
| |
| |

| MAWP CALCULATIONS USING ULTRASONIC THICKNESS MEASUREMENTS | |
|---|---|
| BARREL: P = (TS x Tmin x E)/(R X FS) [per Table S2.10.3] | FIREBOX: P = ($T^2$ x S x C/Pitch $Max^2$) [per Table S2.10.4] |
| HYDROSTATIC PRESSURE TEST ( per S2.6.1) | |
| TEST PRESSURE — PSI | TEST TEMPERATURE — °F |
| TEST DATE | TEST PROBLEMS |

(Page 2)

## INITIAL BOILER CERTIFICATION REPORT (Form C-1) *continued*

| OPERATING INSPECTION AT PRESSURE | |
|---|---|
| ABSENCE OF LEAKS | TEST OF INJECTOR(S) & PUMP (if used) |
| TEST OF TRY-COCKS | OPERATION OF THROTTLE & GOVERNOR |
| TEST OF BLOWDOWN VALVE | TEST OF SAFETY VALVE(S) |
| | VALVE POPPING POINT & BLOWDOWN |

| NOTES |
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(Page 3)



This form may be obtained from The National Board of Boiler and Pressure Vessel Inspectors, 1055 Crupper Ave., Columbus, OH 43229NB-405 Rev. 0

## SUPPLEMENT 3
## INSPECTION OF GRAPHITE PRESSURE EQUIPMENT

### S3.1 SCOPE

a) This supplement provides requirements and guidelines for inservice inspection of pressure equipment manufactured from impervious graphite materials.

b) The impervious graphite (carbon, graphite, or graphite compound) used for the construction of graphite pressure vessels is a composite material, consisting of “raw” carbon or graphite that is impregnated with a resin using a tightly controlled pressure/heat cycle(s). The interaction between the raw material and the resin is the determining factor when considering the design characteristics of the material. The design characteristics include the strengths (flexural, compressive, and tensile), permeability, co-efficient of thermal expansion, thermal conductivity, and ultimately, the safe operating life of the vessel.

c) The process used in the manufacturing of the raw material is well documented. The expertise developed in this field allows for many different grades to be manufactured to meet the specific needs of various industries, including corrosive chemical-processing pressure vessels. In the chemical processing industry the properties of the raw material are dictated by the manufacturer of the impregnated material, based on the pressure/temperature cycle and the type of resin used for impregnation. The raw material requirements are defined and communicated to the manufacturer of the raw material. The cycle and resin type may vary from manufacturer to manufacturer, and also for each “grade” of impregnated material a manufacturer produces.

d) After over a century of experience with graphite pressure equipment, the essential variables of the process have been defined and apply universally to all manufacturers of impervious graphite equipment. Therefore, by requiring the essential variables of the resin impregnation cycle to be identified and verified, it is possible to assign a “lot” number to all certified materials at completion of the resin impregnation process. This can be done with the assurance of meaningful and consistent test results.



### S3.2 APPLICATION

Due to inherent resistance to chemical attack, graphite pressure equipment is often used in corrosive applications, which may include lethal service.

### S3.3 OPERATIONS

The owner shall maintain controlled conditions for use of graphite pressure equipment, including the use of temperature and pressure recorders and/or operating logs. The owner shall maintain operating procedures, and ensure that pressure and temperature are controlled. A thermal or pressure spike may damage the graphite or metal components.

### S3.4 INSERVICE INSPECTION

a) The guidelines provided in NBIC Part 2, Section 1 shall apply to graphite pressure equipment, except as modified herein.

b) Graphite pressure vessels, pressure parts, and vessel components shall receive an external visual examination biennially. All accessible surfaces should be chemically cleaned. Cleaning fluids containing strong oxidants shall not be used.

c) Typical indicators that necessitate graphite pressure equipment inspection, evaluation, and repair include:

1) Cross-contamination of either process or service fluids;

2) Observation of external leaking;

3) Observation of reduced rate or excessive pressure drop; and

4) Reduction of heat-transfer performance.

d) Cracks, bulges, blisters, delaminations, spalling conditions, and excessive erosion are cause for repair or replacement. Any surface discoloration should be recleaned and examined more closely to determine if a delamination or spalling condition exists.

e) Other typical discontinuities include chipping, erosion, baffle cutting due to vibration, and cement deterioration. All passageways are susceptible to fouling.

# SUPPLEMENT 4
# INSPECTION OF FIBER-REINFORCED THERMOSETTING PLASTIC PRESSURE EQUIPMENT

## S4.1 SCOPE

This supplement provides specific requirements and guidelines for inspection of fiber-reinforced thermosetting plastic pressure equipment.

## S4.2 INSERVICE INSPECTION

NBIC Part 1, Section 1, shall apply to inspection of fiber-reinforced plastic (FRP) equipment, except as modified herein. This supplement covers vessels and tanks only and was not written to cover piping and ductwork, although some of the information contained herein may be used for the inspection of piping and ductwork.

## S4.3 GENERAL

a) Typical FRP equipment consists of the structural laminate (pressure-retaining material) and a liner (corrosion barrier) to protect the structural laminate (see NBIC Part 2, Figure S4.3). The structural laminate is defined as one or more layers of reinforced resin material bonded together. In addition to damage from mechanical sources, FRP material may be susceptible to damage from acids, alkalis, compounds containing fluorine, solvents, and hot, clean water.

b) For equipment fabricated with a liner, the primary purpose of a process side inspection is to ensure the integrity of the liner to prevent chemical attack and degradation of the structural laminate. For equipment fabricated without a liner, the purpose of a process side inspection is to determine the condition of the structural laminate.

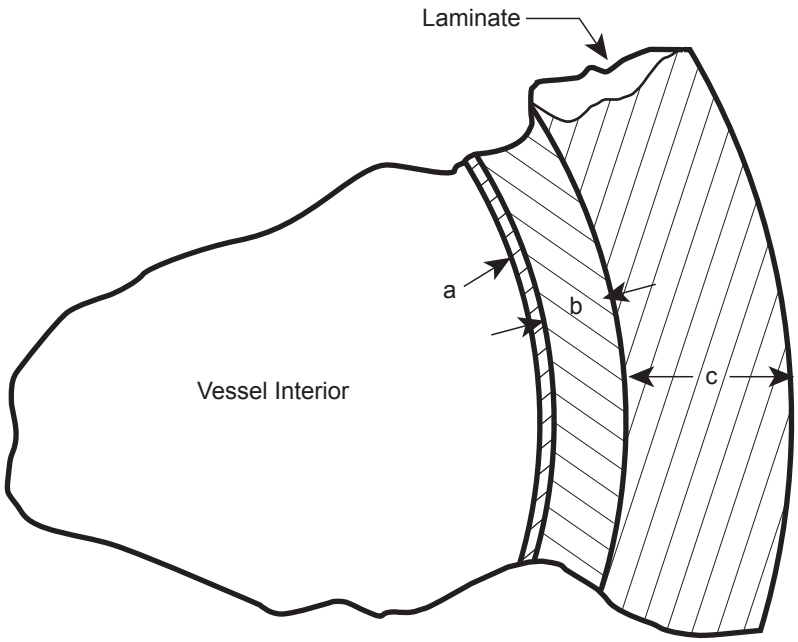
c) In addition to chemical attack, the laminate is also susceptible to damage from:

    1) Excessive service temperatures;

    2) Mechanical or service abuse; and

    3) Ultraviolet light (See NBIC Part 2, S4.7.2).

**FIGURE S4.3**
TYPICAL VESSEL SHELL




| | |
|---|---|
| a | = innermost layer |
| b | = interior layer |
| c | = structural laminate |
| a + b | = corrosion barrier (liner) |



## S4.4 VISUAL EXAMINATION

a) Exposed surfaces shall be visually examined for defects and mechanical or environmental damage in the liner or the laminate. Classification and acceptance of any defects in the liner or laminate shall be according to NBIC Part 3, Table S4.12.

b) Defects to look for include:

1) Cracks;

2) Separation of secondary edges;

3) Leaks, especially around nozzles;

4) Discolored areas;

5) Areas of mechanical damage, such as impacts or gouges;

6) Surface deterioration;

7) fiber exposure;

8) Cracked or broken attachments;

9) Damage due to dynamic loading;

10) Defective supports;

11) Delaminations; and

12) Blisters.

## S4.5 INSPECTOR QUALIFICATIONS

The “R” Stamp Holder’s Inspector shall have the following qualifications:

a) No fewer than five years of current verifiable documented experience in an occupational function that has a direct relationship to reinforced thermoplastic (RTP) fabrication and inspection, following customer or national standards, and be directly involved in the following activities:

1) The development of plans, drawings, procedures, inspection requirements, acceptance criteria, and personnel qualification requirements;

2) Fabrication, construction, and supervision of personnel in the production of assemblies or subassemblies;

3) Detection and measurement of nonconformities by application of visual or other nondestructive evaluation processes to written procedures;

4) Supervision of personnel engaged in material and component examination;

5) Repairs of equipment or supervision of personnel performing repairs;

6) Preparation of written procedures for assembly, acceptance, nondestructive evaluation, or destructive tests;

7) Qualification of secondary bonders, laminators, and welders to applicable codes, standards, or specifications;

8) Operation techniques or activities used to fulfill quality control requirements for RTP fabrication or assembly; and

9) Train the occupational skills of fabrication or assembly of RTP equipment.

b) The Inspector shall meet the following visual and educational requirements:

1) Ability to read a Jaeger Type No. 1 standard chart at a distance of not less than 12 inches (305 mm);

2) Capability of distinguishing and differentiating contrast between colors;

3) Visual acuity which must be checked annually to ensure natural or corrected near distance vision; and

4) High school graduate or holder of a state- or military-approved high school equivalency diploma.

c) The employer of the Inspector shall certify that the employee complies with the above qualification requirements.

## S4.6 ASSESSMENT OF INSTALLATION

An observation shall be made of the condition of the complete installation.

### S4.6.1 PREPARATION

An observation shall be made of the condition of the complete installation, including maintenance and operation, as a guide in forming an opinion of the care the equipment receives. The history of the equipment shall be established, and shall include: date built, service history, maintenance, and a review of previous inspection records. Process conditions shall be reviewed to identify areas most likely to be attacked. Surface cleaning procedures and requirements shall also be reviewed.

### S4.6.2 LEAKAGE

Any leak shall be thoroughly investigated and corrective action initiated. Repairs shall be in accordance with NBIC Part 3, Supplement 4, *Repair and Alteration of Fiber-Reinforced Thermosetting Plastic Pressure Equipment*.

### S4.6.3 TOOLS

The following tools may be required by the inspector:

a) Adequate lighting, including overall lighting and a portable lamp for close inspections;

b) Handheld magnifying glass;

c) Barcol hardness tester;

d) Small pick or pen knife;

e) Small quantity of acetone and cotton swabs;

f) Camera with flash capability; and

g) Liquid penetrant testing kit.

## S4.7 EXTERNAL INSPECTION

An external inspection is performed to determine if FRP pressure equipment is in a condition to operate safely.

### S4.7.1 INSULATION OR OTHER COVERINGS

It is not necessary to remove insulation and corrosion resistant covers for examination of the pressure equipment, if the coverings show no sign of mechanical impact, gouging, scratching, leaks, etc., and there is no reason to suspect any unsafe condition behind them. Where insulation coverings are impervious, such as a sealed fiberglass jacket, it is recommended that weep or drain holes be installed at the bottom of the insulation jacket as a means to detect leakage.

### S4.7.2 EXPOSED SURFACES

a) Exposed surfaces of pressure equipment are subject to mechanical, thermal, and environmental damage. Exposed surfaces may show damage from impact, gouging, abrasion, scratching, temperature excursions, etc. Sunlit areas may be degraded by ultraviolet light with a resulting change in surface color and increased fiber prominence, but with no loss in physical properties. Overheating may also cause a change in color.

b) The location of external damage should be noted so that the opposing internal surface at that location can be examined. For example, an impact load applied to the outer surface may be transmitted through the laminate, causing a star crack in the inner surface. See NBIC Part 2, Figure S4.7.2.

c) Areas that should be closely examined are:

1) Nozzle attachments;

2) Gusset attachments;

3) Flanges;

4) Secondary joints;

5) Hold-down lugs;

6) Lifting lugs; and

7) Attachments.

### S4.7.3 STRUCTURAL ATTACHMENTS

a) Attachments of legs, saddles, skirts, or other components shall be examined for cracks where the component attaches to or contacts the vessel and the component itself. See NBIC Part 2, Figure S4.7.3-a.

b) Piping loads on nozzles may be excessive; therefore, all nozzles shall be closely examined for cracks as shown in NBIC Part 2, Figures S4.7.3-b and S4.7.3-c.



## S4.8 INTERNAL INSPECTION

An internal inspection is performed to determine the condition of internal surfaces and the pressure integrity of the item.

### S4.8.1 GENERAL

FRP surfaces shall be dry and clean for the inspection. Every effort shall be made to minimize damage to the liner during inspection. Defects to look for include:

a) Indentations;

b) Cracks;

c) Porosity;

d) Exposed fibers;

e) Lack of resin;

f) Delaminations;

g) Thinning at points of fluid impingement;

h) Blisters;

i) Scratches;

j) Gouges; and

k) Discolorations.

### S4.8.2 SPECIFIC AREAS OF CONCERN

All surfaces shall be examined with both direct and oblique illumination. Color differences, opacity, stains, wetness, roughness, or any deviation from the original surface (original cutout sample) condition shall be noted and investigated. Liquid level lines shall be defined so the laminate condition in both the wet and dry zones can be determined. The following areas should be closely examined for cracks, porosity, or chemical attacks on the liner or laminate:

a) Fittings;

b) Changes in shape;

c) Baffles;

d) Secondary overlays;

e) Nozzles;

f) Cut edges; and

g) Supports/internal structures and areas of attachment.

## S4.9 INSPECTION FREQUENCY

Frequency of inspections is established to determine how often inspections shall be performed to ensure safe operation of FRP equipment.

### S4.9.1 NEWLY INSTALLED EQUIPMENT

a) The following factors should be considered when determining the frequency of inspection of FRP equipment that is new and recently placed into service:

   1) The distance between the FRP equipment and personnel or critical equipment;

   2) Substance contained in the vessel is of such a nature that if abruptly released it could threaten the health or safety of personnel;

   3) Contains chemicals or is subject to conditions known to degrade or shorten the life of FRP laminates;

   4) Past experience has shown that the service application warrants more frequent internal and external inspections; and

   5) Insurance or jurisdictional requirements.

b) FRP equipment should be externally inspected:

   1) Once every 2 to 3 years after introduction of process fluid. All findings are to be documented in the equipment inspection file for comparison to future inspection;

   2) If upsets outside the vessel design conditions in the process occur, external inspections shall be performed to ensure equipment integrity; or

   3) If prior experience (i.e., if equipment was recently replaced using same material/construction) dictates that inspection frequency other than that listed is acceptable (through previous inspections and records), then the inspection frequency may be altered.

c) FRP equipment should be internally inspected:

1) One year after the introduction of process fluid to establish any changes due to service and chemical environment;

2) After the initial first-year inspection, subsequent inspections are to be established based on those results. Subsequent inspection intervals shall be documented. It is suggested to document inspections using photographs;

3) When some conditions may exist where entry is prohibited and alternate means of inspection considered;

4) If prior experience (i.e., if equipment was recently replaced using same material/construction) dictates that inspection frequency other than that documented is acceptable, then the inspection frequency may be altered; or

5) If upsets outside the vessel design conditions in the process occur, internal inspections shall be performed to ensure equipment integrity.

### S4.9.2 PREVIOUSLY REPAIRED OR ALTERED EQUIPMENT

a) The following factors should be considered when determining the frequency of inspection for FRP equipment.

1) The distance between the FRP equipment and personnel or critical equipment;

2) Substance contained in the vessel is of such a nature that if abruptly released it could threaten the health or safety of personnel;

3) Equipment contains chemicals or is subject to conditions known to degrade or shorten the life of FRP laminates;

4) Past experience has shown that the service application warrants more frequent internal and external inspections; and

5) Insurance or jurisdictional requirements.

b) FRP equipment should be externally inspected:

1) Annually — all findings are to be documented in the equipment inspection file for comparison to future inspection;

2) If upsets outside the vessel design conditions in the process occur, external inspections need be performed to ensure equipment integrity; or

3) If prior experience (i.e., if equipment was recently replaced using same material/construction) dictates that inspection frequency other than that listed is acceptable (through previous inspections and records), then the inspection frequency may be altered.

c) FRP equipment should be internally inspected:

1) One year after the introduction of process fluid to establish any changes due to service and chemical environment;

2) If upsets outside the vessel design conditions in the process occur, internal inspections need be performed to ensure equipment integrity;

3) Following the initial first-year inspection, subsequent inspections are to be established based on those documented results and the results documented. It is suggested to document the interior inspection using photographs;

4) If prior experience (i.e., if equipment was recently replaced using same material/construction) dictates that inspection frequency other than that listed is acceptable (through previous inspections and records), then the inspection frequency may be altered; or

5) Some conditions may exist where entry is prohibited and alternate means of inspection must be considered.

## S4.10 PHOTOGRAPHS OF TYPICAL CONDITIONS

The figures listed in S4.11 contain photographs of typical conditions that may exist in inservice FRP vessels and piping. These surface conditions can be similar to or different from those encountered in practice. Also, differing causes of surface degradation can result in similar surface appearances.

**Note:** NBIC Part 2, Figures S4.7.2, S4.7.3-a, S4.7.3-b, and S4.10-j through S4.10-r, were reprinted with permission of the Copyright Owner, © MATERIALS TECHNOLOGY INSTITUTE, INC. (2002). The captions of the figures were revised by the NBIC Committee.

Color photographs are available on the National Board website, www.nationalboard.org under the 'National Board Inspection Code' tab.

### FIGURE S4.7.2

STAR CRACK IN CORRODED LINER. POSSIBLE CAUSE IS EXTERNAL IMPACT.

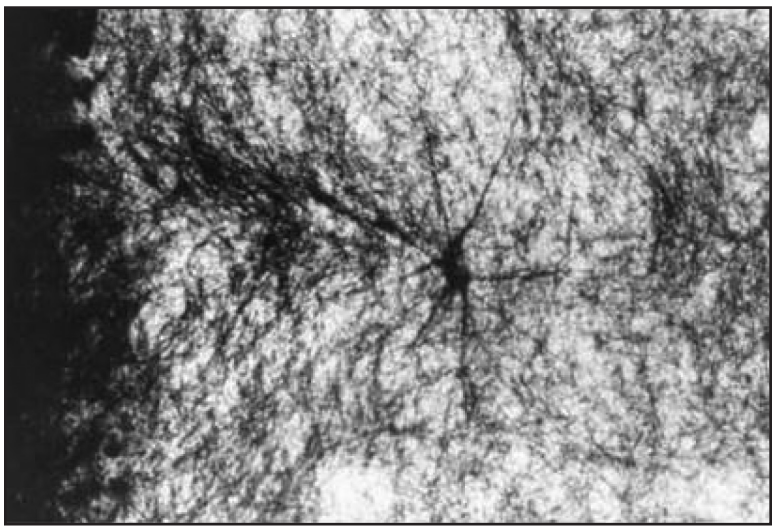


**FIGURE S4.7.3-a**

GUSSET CRACK. POSSIBLE CAUSES ARE EXCESSIVE LOAD DUE TO UNSUPPORTED VALVE, PIPE, OR OVERSTRESS AND AGE.




**FIGURE S4.7.3-b**

CRACKED FLANGE. POSSIBLE CAUSES ARE INCORRECT MATCH-UP OF FLANGES, OVER-TORQUE OF BOLTS AT FIT-UP, MANUFACTURING DEFECT, OR EXCESSIVE PIPING LOADS.



**FIGURE S4.7.3-c**

CRACKED FLANGE. POSSIBLE CAUSE IS BOLTING DISSIMILAR FLANGES TOGETHER (FULL-FACED FLANGE WITH RAISED-FACE FLANGE).

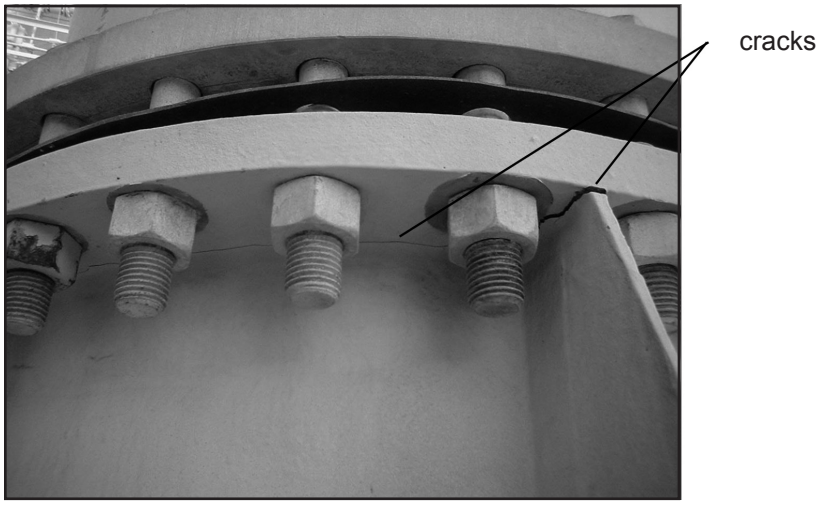



**FIGURE S4.10-a**

EXCESSIVE HEAT. POSSIBLE CAUSES ARE LOCALIZED HIGH-TEMPERATURE EXCURSIONS.

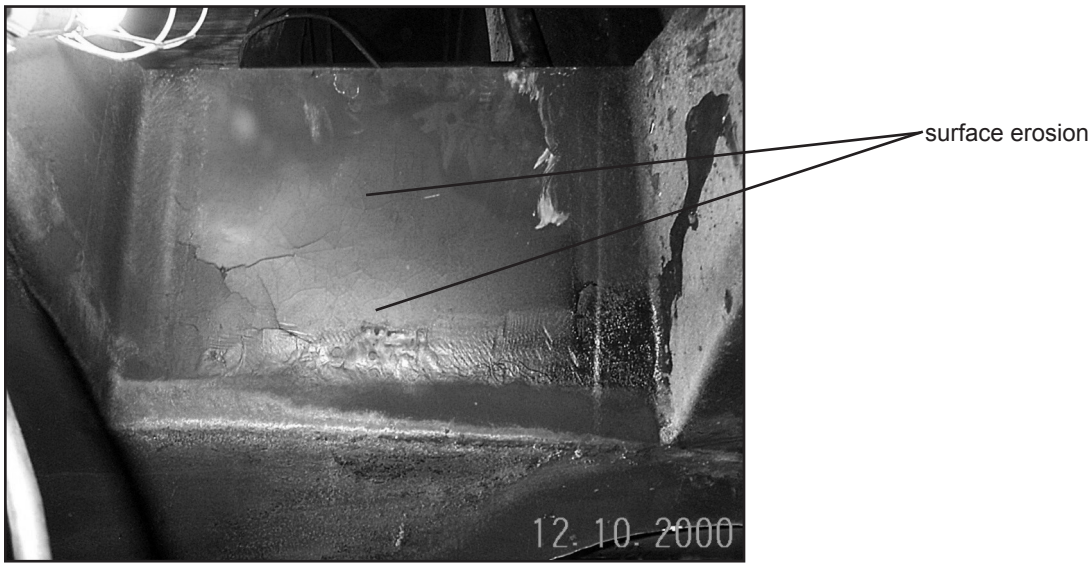


**FIGURE S4.10-b**

LAMINATE VOIDS AT OVERLAYS.

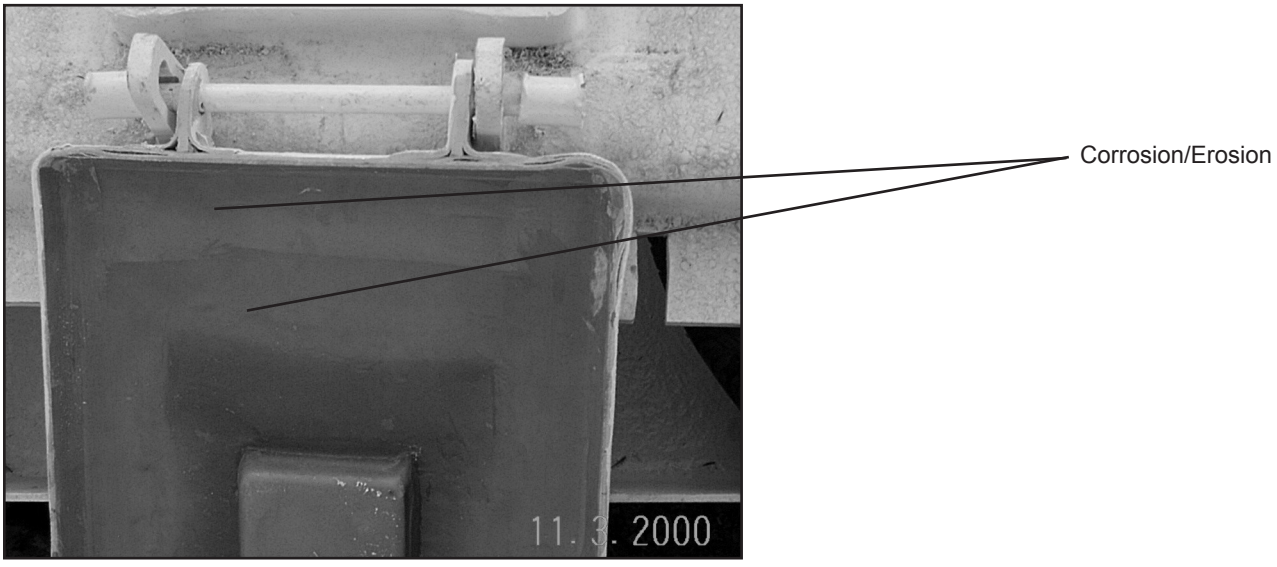



**FIGURE S4.10-c**

SURFACE DETERIORATIONS. POSSIBLE CAUSES ARE EXPOSURE TO HOT WATER AND/OR STEAM AND CHEMICAL ATTACK.



**FIGURE S4.10-d**

BLISTERS. POSSIBLE CAUSE IS EXPOSURE TO STEAM OR PURIFIED HOT WATER.




**FIGURE S4.10-e**

SURFACE EROSION. POSSIBLE CAUSES ARE HIGH FLOW RATE OF FLUIDS, EROSION DUE TO PARTICULATES IN FLUID, AND CHEMICAL ATTACK/SOFTENING OF RESIN.

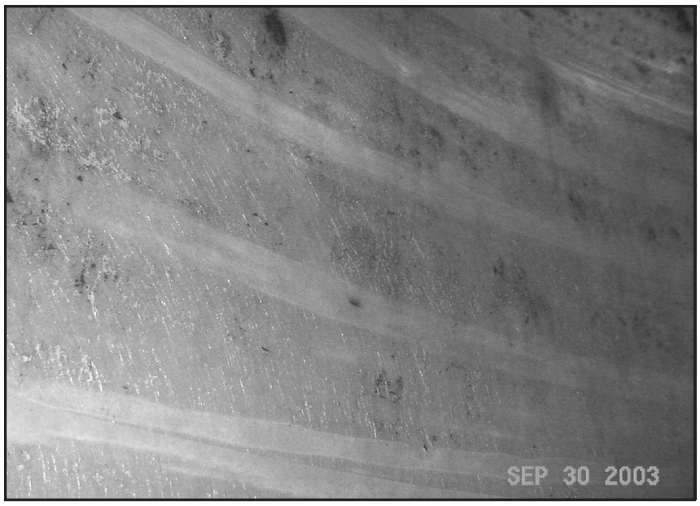


**FIGURE S4.10-f**

CORROSION/EROSION.

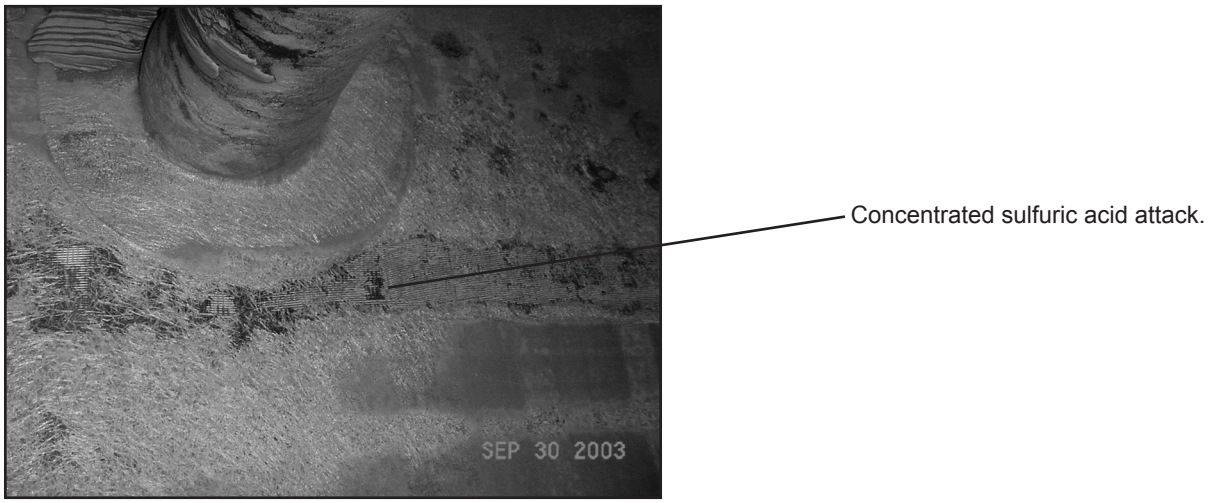



**FIGURE S4.10-g**

CRACKS. POSSIBLE CAUSE IS IMPACT FROM AN EXTERNAL SOURCE.



**FIGURE S4.10-h**

CORROSION (LOSS OF VEIL).

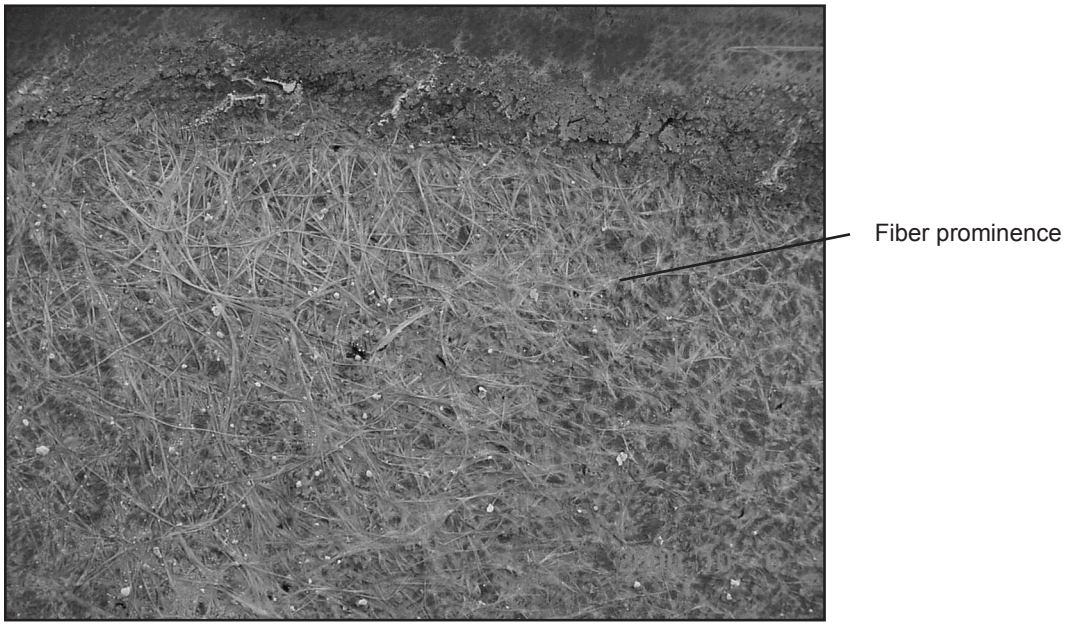



**FIGURE S4.10-i**

SHELL FRACTURE. POSSIBLE CAUSE IS EXTERIOR IMPACT.

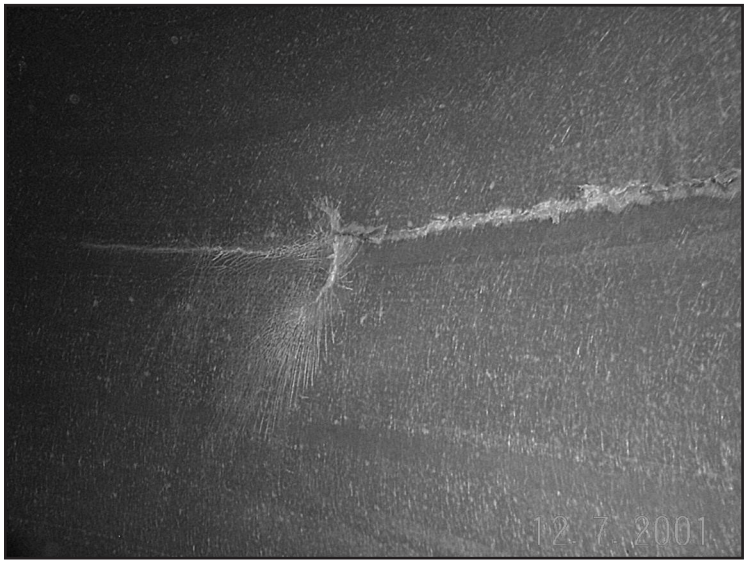


**FIGURE S4.10-j**

CONCENTRATED SULFURIC ACID ATTACK.



**FIGURE S4.10-k**

BLISTER.

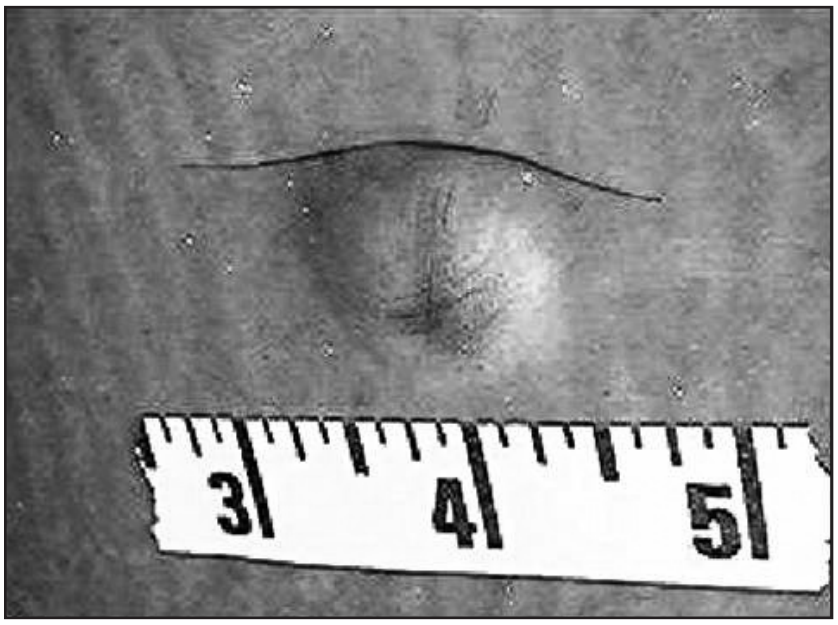


**FIGURE S4.10-l**

FIBER PROMINENCE. POSSIBLE CAUSE IS EXPOSURE TO SUNLIGHT AND NO UV PROTECTION.

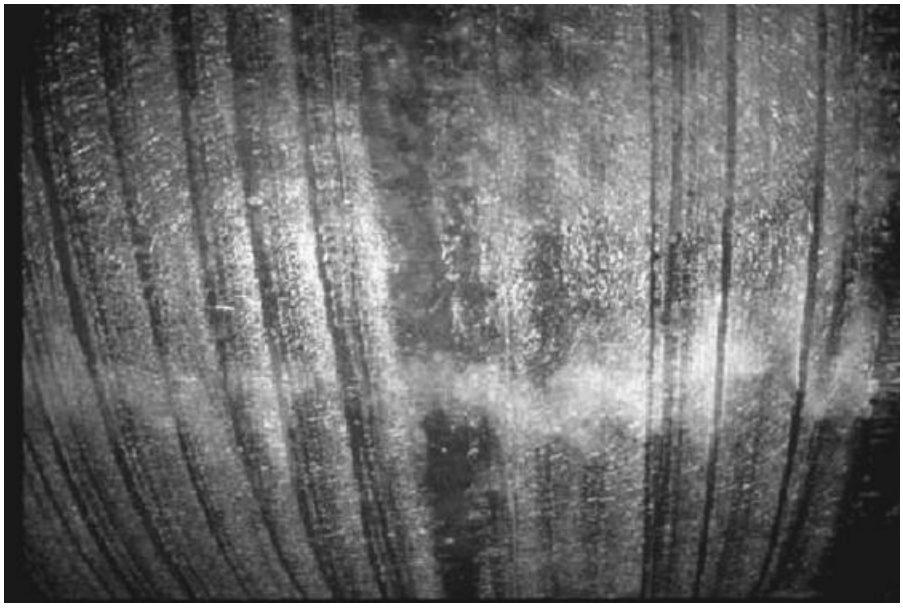


**FIGURE S4.10-m**

COLOR CHANGE.

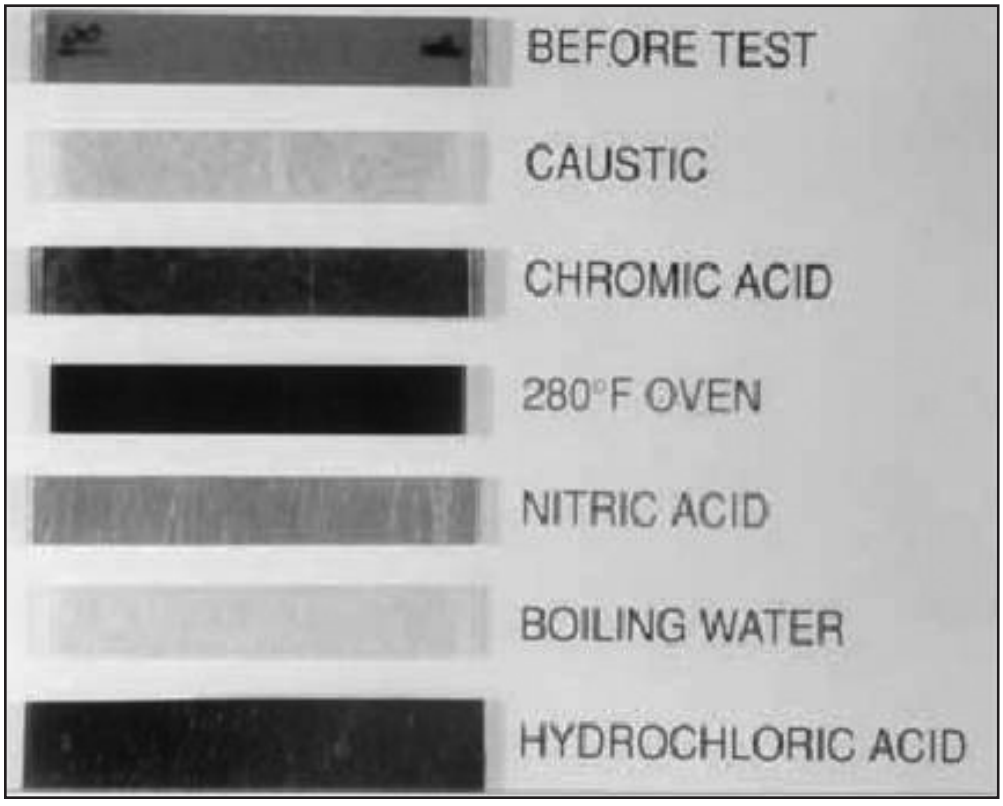


**FIGURE S4.10-n**

CUT EDGE EVALUATION.

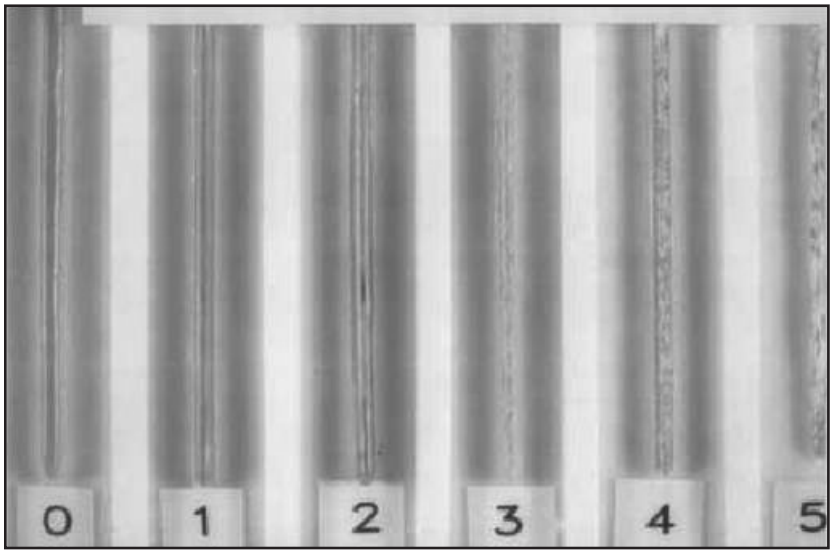



**FIGURE S4.10-o**

EROSION IN THE LINER.



**FIGURE S4.10-p**

GOUGE. POSSIBLE CAUSE IS MECHANICAL DAMAGE.

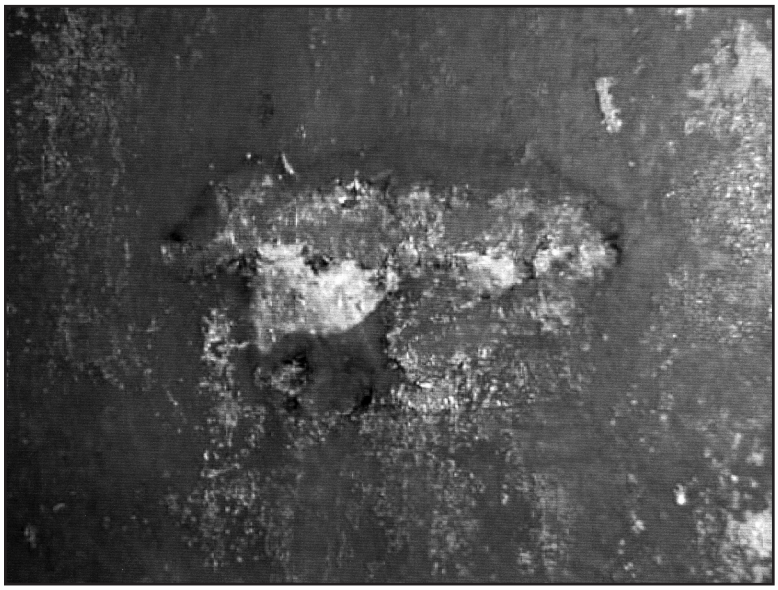


**FIGURE S4.10-q**

CRACKS AT THE KNUCKLE. POSSIBLE CAUSE IS INADEQUATE ANCHORING OF VESSEL.



**FIGURE S4.10-r**

SULFURIC ACID ATTACK AND THERMAL SHOCK.

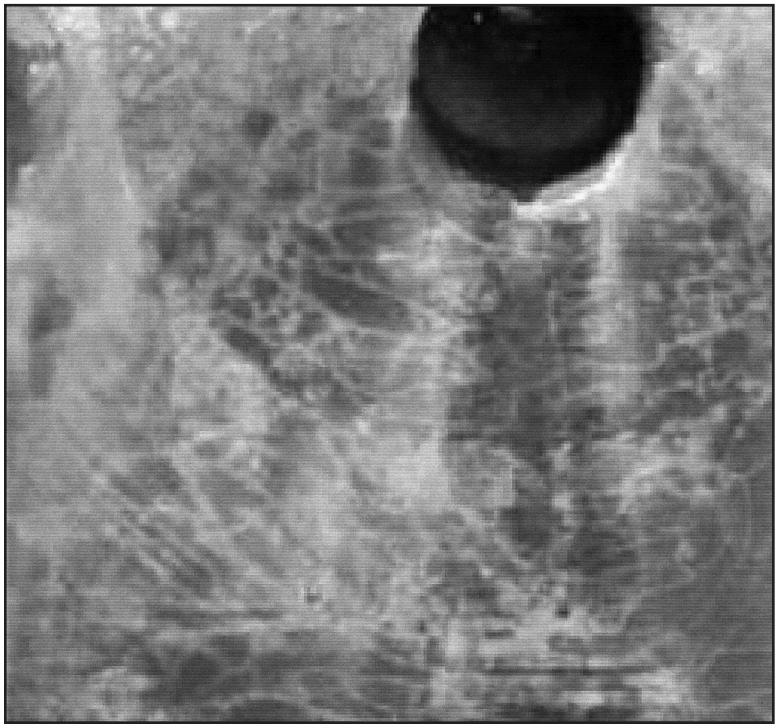


**FIGURE S4.10-s**

AIR BUBBLES BEHIND THE VEIL (SHOWN AFTER CHEMICAL EXPOSURE).

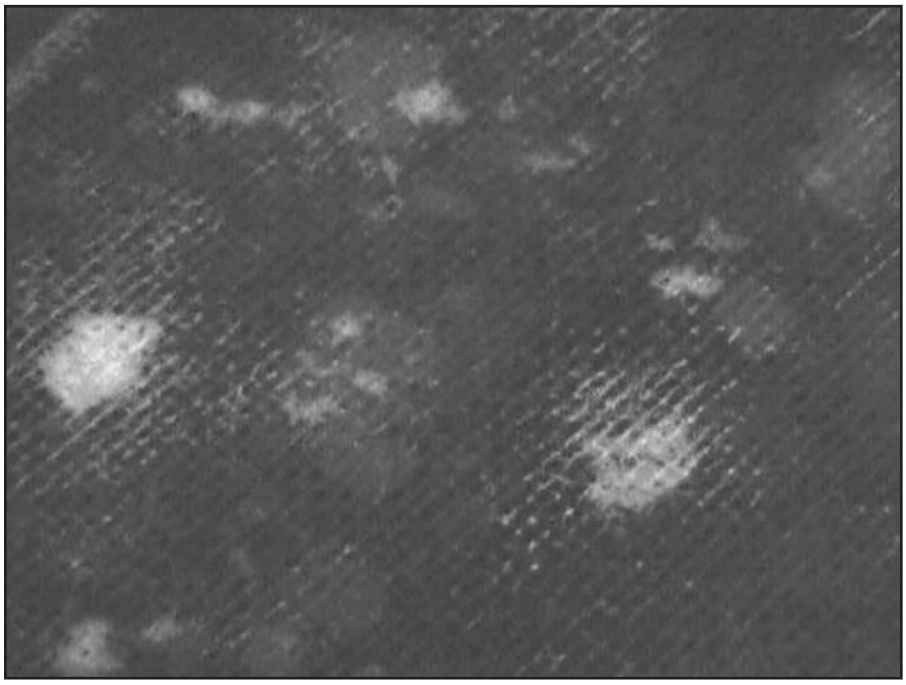


**FIGURE S4.10-t**

DELAMINATIONS AND BLISTERS. POSSIBLE CAUSES ARE EXPOSURE TO HIGH HEAT OR IMPROPER SURFACE PREPARATION OF LINER PRIOR TO STRUCTURAL APPLICATION.



**FIGURE S4.10-u**

FLANGE CRACKING.

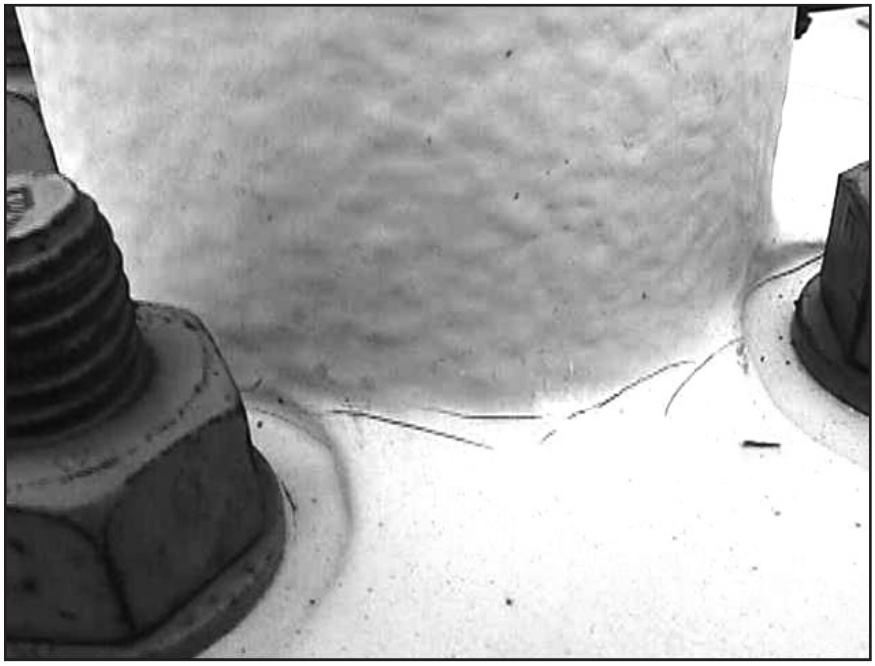


**FIGURE S4.10-v**

ELASTOMERIC GASKET EXTRUDING. POSSIBLE CAUSES ARE EXCESSIVE BOLT TORQUE OR IMPROPER BOLTING SEQUENCE.





**FIGURE S4.10-w**

INCORRECT GUSSET ATTACHMENT. POSSIBLE CAUSES ARE GUSSETS NOT EXTENDING OUT FROM FLANGE A MINIMUM OF 30° FROM THE AXIS OF NOZZLE NECK, OR GUSSET ATTACHMENTS USED AS PART OF THE FLANGE THICKNESS.

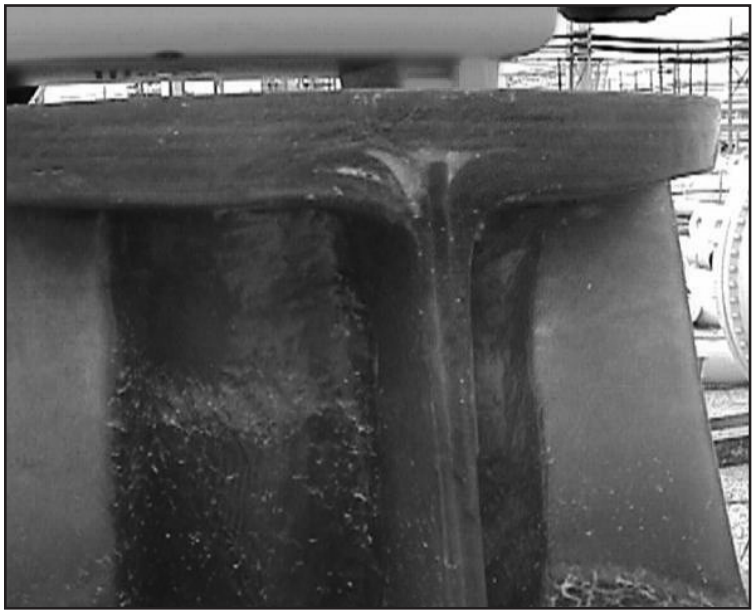


**FIGURE S4.10-x**

STAR CRACK. POSSIBLE CAUSE IS EXTERNAL IMPACT.

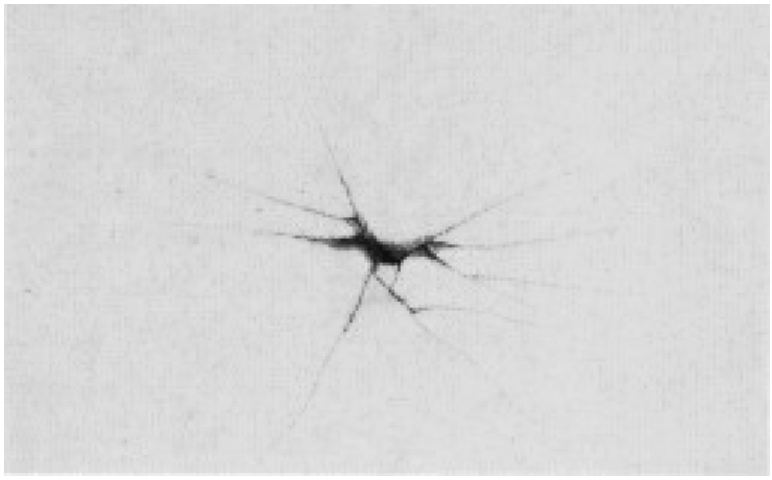
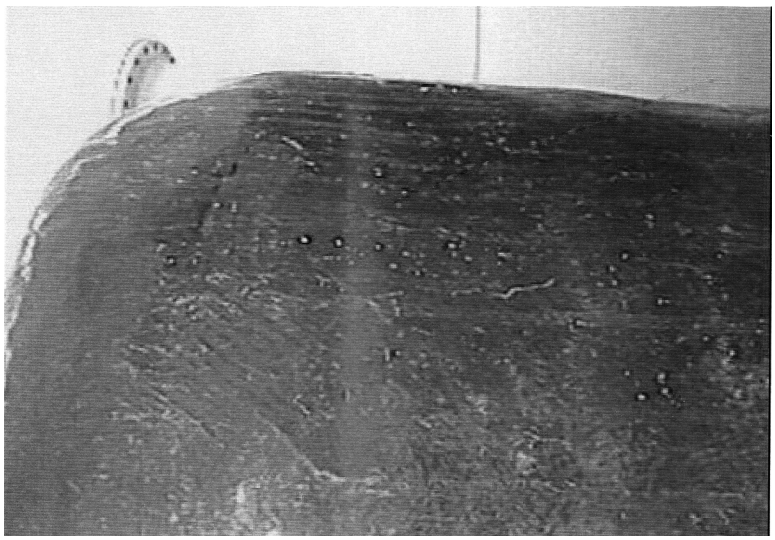


**FIGURE S4.10-y**

EXCESSIVE USE OF PUTTY.



## S4.11 TABLES AND FIGURES

a) FIGURE S4.3, Typical vessel shell

b) FIGURE S4.7.2 , Star crack in corroded liner

c) FIGURE S4.7.3-a, Gusset crack

d) FIGURE S4.7.3-b, Cracked flange

e) FIGURE S4.7.3-c ,Cracked flange

f) FIGURE S4.10-a, Excessive heat

g) FIGURE S4.10-b, Laminate voids at overlays

h) FIGURE S4.10-c, surfaces deteriorations

i) FIGURE S4.10-d, Blisters

j) FIGURE S4.10-e, Surface corrosion

k) FIGURE S4.10-f, Corrosion/erosion

l) FIGURE S4.10-g, Cracks

m) FIGURE S4.10-h, Corrosion (loss of veil)

n) FIGURE S4.10-i, Shell fracture

o) FIGURE S4.10-j, Concentrated sulfuric acid attack

p) FIGURE S4.10-k, Blister

q) FIGURE S4.10-l, Fiber prominence

r) FIGURE S4.10-m, Color change

s) FIGURE S4.10-n, Cut edge evaluation

t) FIGURE S4.10-o, Erosion in liner

u) FIGURE S4.10-p, Gouge

v) FIGURE S4.10-q, Cracks at the knuckle

w) FIGURE S4.10-r, Sulfuric acid attack and thermal shock

x) FIGURE S4.10-s, Air bubbles behind the veil

y) FIGURE S4.10-t, Delaminations and blisters

z) FIGURE S4.10-u, Flange cracking

aa) FIGURE S4.10-v, Elastomeric gasket extruding

ab) FIGURE S4.10-w, Incorrect gusset attachment

ac) FIGURE S4.10-x, Star crack

ad) FIGURE S4.10-y, Excessive use of putty

## SUPPLEMENT 5 (23)
## INSPECTION OF YANKEE DRYERS

### S5.1 SCOPE (23)

This supplement provides guidelines for the inservice inspection of a yankee dryer as defined in NBIC Part 1, Supplement 1.

a) A yankee dryer is a rotating steam-pressurized cylindrical vessel commonly used in the paper industry. It is characterized by a center shaft connecting the heads. While traditionally made of cast iron, some yankee dryers are made of bolted or welded steel.

b) Yankee dryers are primarily used in the production of tissue-type paper products. When used to produce machine-glazed (MG) paper, the dryer is termed an MG cylinder. A wet paper web is pressed onto the finished dryer surface using one or two pressure (pressing) rolls. Paper is dried through a combination of mechanical dewatering by the pressure roll(s); thermal drying by the pressurized yankee dryer; and a steam-heated or fuel-fired hood. After drying, the paper web is removed from the dryer.

c) The dryer is typically manufactured in a range of outside diameters from 8 to 23 ft. (2.4 m to 7 m), widths from 8 to 28 ft. (2.4 m to 8.5 m), pressurized and heated with steam up to 160 psi (1,100 kPa), and rotated at speeds up to 7,000 ft./min (2,135 m/min). Typical pressure roll loads against the yankee dryer are up to 600 pounds per linear inch (105 kN/m). A thermal load results from the drying process due to difference in temperature between internal and external shell surfaces. The dryer has an internal system to remove steam and condensate. These vessels can weigh up to 220 tons (200 tonnes).

d) The typical yankee dryer is an assembly of several large components. The cylindrical shell is commonly ASME SA-278 gray cast iron or SA-516 steel. Internally, shells may be smooth bore or ribbed. Heads, center shafts, and journals may be gray cast iron, ductile cast iron, or steel.

### S5.2 ASSESSMENT OF INSTALLATION (23)

a) The Inspector verifies that the owner or user is properly controlling the operating conditions of the dryer.

b) The dryer is subjected to a variety of loads over its life. Some of the loads exist individually, while others are combined. Consideration of all the loads that can exist on a yankee dryer is required to determine the maximum allowable operating parameters. There are four loads that combine during normal operation to create the maximum operating stresses, usually on the outside surface of the shell at the axial center line. These are:

   1) Pressure load due to internal steam pressure;

   2) Inertial load due to dryer rotation;

   3) Thermal gradient load due to the drying of the web; and

   4) Pressure roll load (line or nip load) due to pressing the wet web onto the dryer.

c) Steam pressure, inertial, and thermal gradient loads impose steady-state stresses. These stresses typically change when the dryer shell thickness (effective thickness for ribbed dryers) is reduced to restore a paper-making surface, the grade of tissue is changed, or speed of the dryer is changed.

d) The pressure roll(s) load imposes an alternating stress on the shell face. The resulting maximum stress is dependent on the magnitude of the alternating and steady-state stresses.

e) ASME Section VIII, Div. 1, only provides specific requirements for the analysis of pressure loads. Although the code requires analysis of other loads, no specific guidance for thermal, inertial, or

pressure roll loads is provided. Hence, additional criteria must be applied by the manufacturer to account for all the steady-state and alternating stresses.

f) To maintain product quality, the dryer surface is periodically refurbished by grinding. This results in shell thickness reduction. Therefore, the manufacturer does not provide a single set of maximum allowable operating parameters relating steam pressure, rotational speed, and pressure roll load for a single design shell thickness. The manufacturer, or another qualified source acceptable to the Inspector, instead provides a series of curves that graphically defines these maximum allowable operating parameters across a range of shell thicknesses. This document is known as the “De-Rate Curve.” See NBIC Part 2, Figure S5.2. In cases where no derate curve is provided, the manufacturer, or another qualified source, may provide a set of operating conditions and a minimum shell thickness.

g) Thermal spray (metallizing) materials may be applied to extend and improve dryer operations and provide a more wear resistant surface. Thermal spray coatings are often applied to the exterior of steel shells and may be applied to cast iron shells. Once applied, the metallization may be ground periodically before it is removed or replaced. Thermal spray coatings do not add strength to the component and are not included in shell thickness calculation. Grinding that reduces thickness of the pressure containing shell material to which metallization has been applied must be evaluated for any necessary pressure and safety device re-settings.

h) In addition to the loads on the dryer due to normal operation, other nonstandard load events can occur. These nonstandard load events should be recorded in an operation or maintenance log. Examples of nonstandard load events include:

   1) Local or overall thermal loads due to exceeding the warm-up rate;

   2) Local or overall thermal loads due to exceeding the cool-down rate;

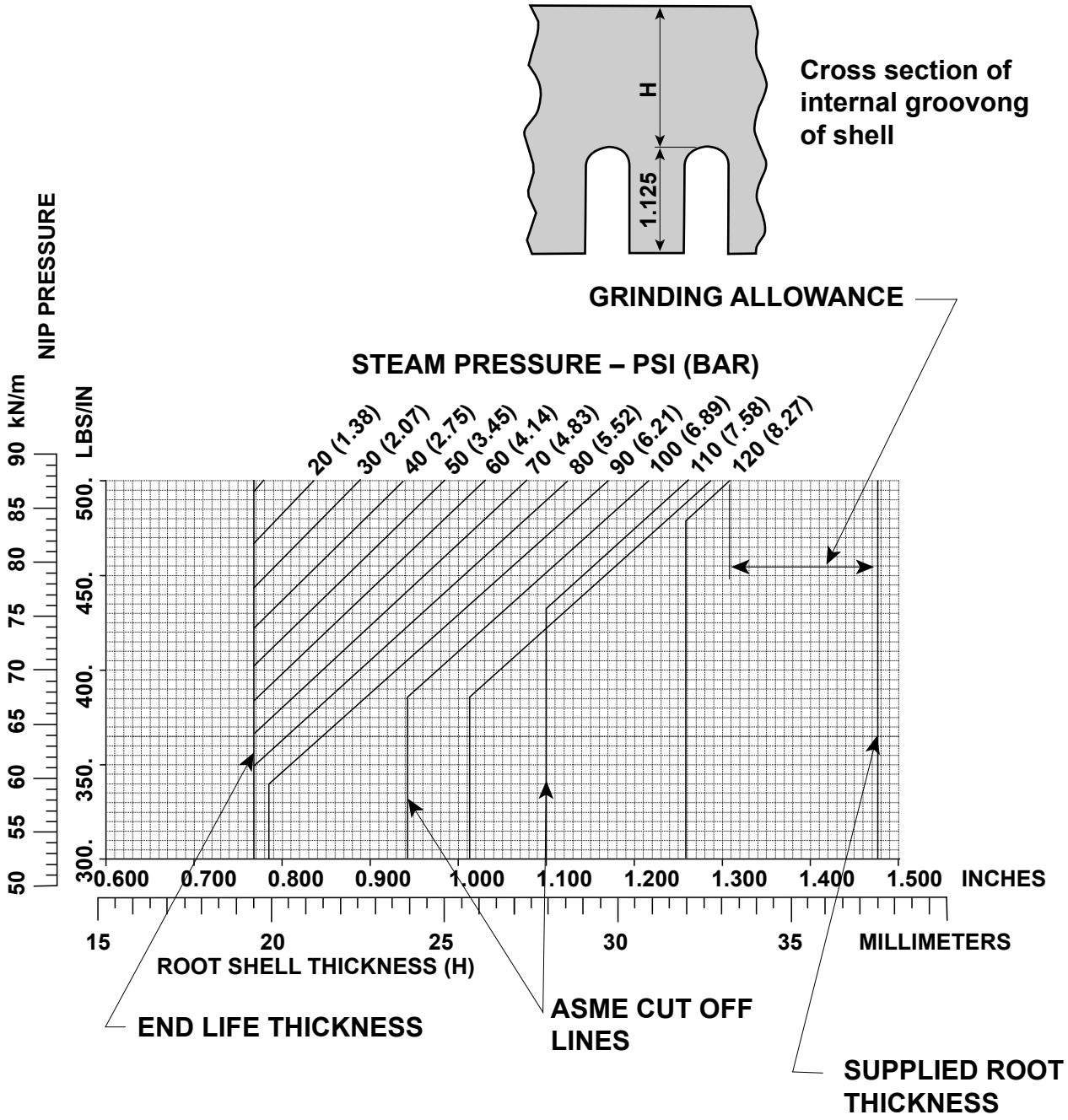
   3) Thermal load due to inappropriate use or malfunctioning auxiliary heating devices causing localized heating;

   4) Thermal load due to the misapplication or uncontrolled application of water or other fluids for production, cleaning, or firefighting; and

   5) Impact load.

i) If nonstandard load events have occurred, then the Inspector should ensure that an appropriate risk-based assessment of the dryer has been performed.

**FIGURE S5.2**
DE-RATE CURVE




## S5.2.1 DETERMINATION OF ALLOWABLE OPERATING PARAMETERS (23)

a) A yankee dryer is designed and intended to have its shell thickness reduced over the life of the vessel through routine wear and grinding. The yankee dryer shell is ground on the outside surface to restore the quality or shape of the papermaking surface, essential to the manufacturing of tissue or other paper products.

b) Design documentation is required that dictates the maximum allowable operating parameters as shell thickness is reduced. Calculations used to determine those parameters are in accordance with ASME

Code requirements for primary membrane stress and design criteria based upon other relevant stress categories; (e.g., fatigue and maximum principal stress). Calculation of these parameters requires that the respective stresses, resulting from the imposed loads, be compared to the appropriate material strength properties. Hence, knowledge of the applied stresses in the shell and the tensile and fatigue properties of the material are essential.

c) Yankee dryers are subjected to a variety of loads that create several categories of stress. Yankee dryers are designed such that the stress of greatest concern typically occurs on the outside surface at the axial centerline of the shell.

1) Steam Pressure Load — The internal steam pressure is one of the principal design loads applied to the yankee dryer. The steam pressure expands the shell radially, causing a predominately circumferential membrane tensile stress. Because the shell is constrained radially by the heads at either end of the shell, the steam pressure also causes a primary bending stress in the vicinity of the head-to-shell joint. The ends of the shell are in tension on the inside and compression on the outside due to the steam pressure. The steam pressure also causes a bending stress in the heads.

2) Inertia Load — The rotation of the yankee dryer causes a circumferential membrane stress in the shell similar to that caused by the steam pressure load. This stress is included in the design of the shell and increases with dryer diameter and speed.

3) Thermal Gradient Load — The wet sheet, applied to the shell, causes the outside surface to cool and creates a thermal gradient through the shell wall. This thermal gradient results in the outside surface being in tension and the inside surface in compression. With this cooling, the average shell temperature is less than the head temperature, which creates bending stresses on the ends of the shell and in the heads. The ends of the shell are in tension on the outside and compression on the inside.

a. Other thermal loading also occurs on a yankee dryer. The use of full width showers for a variety of papermaking purposes affects the shell similar to a wet sheet. The use of edge sprays produces high bending stress in the ends of the shell due to the mechanical restraint of the heads.

b. Warm-up, cool-down, hot air impingement from the hood, moisture profiling devices, firefighting, and wash-up can all produce non-uniform thermal stresses in the pressure-containing parts of the yankee dryer. Heating or cooling different portions of the yankee dryer at different rates causes these non-uniform stresses.

4) Line Load — The line load from the contacting pressure roll(s) results in an alternating, high cycle, bending stress in the shell. This stress is greatest at the centerline of the shell. The load of the pressure roll deflects the shell radially inward causing a circumferential compressive stress on the outside surface and a tensile stress on the inside. Because the shell has been deflected inward at the pressure roll nip, it bulges outward about 30 degrees on each side of the nip. The outward bulge causes a tensile stress on the outside shell surface at that location and a corresponding compressive stress on the inside. Since the shell is passing under the pressure roll, its surface is subjected to an alternating load every revolution.

## (23) S5.2.2 ALLOWABLE OPERATING PARAMETERS AND SHELL THICKNESS

a) The maximum allowable operating parameters are a function of shell thickness and are addressed in one of the following two manners in the industry.

1) Adjusted throughout life of dryer

The maximum allowable operating parameters are reduced throughout the life of the dryer as the shell thickness is reduced. This method is commonly used for cast iron shells.

Required design documentation called a de-rate curve dictates the maximum allowable operating

parameters based on imposed loads over a range of shell thicknesses. The documentation shall be obtained from the original dryer manufacturer or from another qualified source acceptable to the Inspector.

After the maximum allowable operating parameters are adjusted per the de-rate curve, the appropriate load limiting devices are reset (e.g., steam safety relief valve, line load limiting device).

2) Held constant throughout life of dryer

The maximum allowable operating parameters are held constant throughout the life of the dryer, until the shell thickness is reduced to a minimum end-of-life value. This method is commonly used for steel shells.

Required design documentation dictates the maximum allowable operating parameters and the minimum shell thickness. The documentation shall be obtained from the original dryer manufacturer or from another qualified source acceptable to the Inspector.

b) The current shell thickness and maximum allowable operating conditions shall be documented throughout the life of the yankee dryer.

## S5.3 DETERIORATION AND DAMAGE (23)

Three types of deterioration or damage typically encountered in yankee dryers are local thinning, cracking, and corrosion. Many times, the mechanisms are interrelated, one being the precursor of another.

### S5.3.1 LOCAL THINNING (23)

a) Internally, a Local Thin Area (LTA) can occur on the pressure-retaining surfaces due to steam and condensate erosion, mechanical wear and impact, and removal of material flaws. These assume features ranging from broad shallow areas washed out by erosion, to more groove-like flaws, including gouges and indentations from contacting metal parts.

b) Externally, the process is typically one of wear-corrosion in circumferential bands. Except on the shell edges, local thinning never achieves significant depth because the papermaking process will tolerate only the smallest departure from surface contour. On the shell edges, beyond the papermaking surface, wear-corrosion may advance to comparatively greater depths. However, the stresses are far less in this area than under the papermaking surface, so the wear is inconsequential in considerations of load-carrying ability. Only in the instance of steam leakage between flanges has the resultant local thinning ever been implicated in yankee failure.

c) Steam leakage is detrimental to the long-term structural integrity of the vessel, in that the escaping steam, under high velocity, erodes ever-widening paths in the surfaces over which it passes, thinning the cross-section. Steam cutting of connecting bolts is another possible outcome. Either result reduces load-carrying capacity of the part. A safety hazard can also be created for operating personnel, who may be burned by the high-velocity steam jets.

### S5.3.2 CRACKING (23)

Yankee dryers are subject to both low-cycle and high-cycle fatigue loading; consequently, considerable emphasis is placed upon crack detection and timely remediation of cracks. Possible causes include:

a) Exceeding Maximum Allowable Operating Conditions (23)

Yankee dryers are designed to operate within the limitations set down by ASME Section VIII and the safety factors inherent to the documentation provided by the vessel manufacturer or equally qualified source. Failure to maintain operation within the parameters established by those criteria can lead to cracking.

### (23) S5.3.2.1 JOINTS AND BOLTED CONNECTIONS

a) Joint Interface Corrosion

Jacking forces, which develop from the expansion of corrosion products between head-to-shell flanges, cause flange separation and create leakage paths between the flanges and/or through the bolt holes. The products of corrosion occupy a larger volume than the base metal. The forces created by this expansion are sufficient to cause cracking in flanges or bolts. Without remediation, expansion will continue until failure occurs. Corrosion products form in the presence of moisture in the crevice created between flanges, wherever the clamping force is insufficient to maintain contact between the mating surfaces.

b) Insufficient Joint Clamping Force

Through inadequate design, improper assembly, loss of washer/gasket, or stress corrosion cracking of connecting bolts, the clamping force between mating flanges is insufficient to retain internal pressure.

c) Washer/Gasket Functional Loss

Deterioration, caused by corrosion or gasket damage provides a path for escaping steam and condensate.

d) Flange Machining Variation

Variations in surface contour of flange faces may create leakage paths.



### (23) S5.3.2.2 THROUGH-WALL LEAKAGE

Cast iron inherently exhibits shrinkage porosity. Where porosity linkages occur between internal and external surfaces, a path for steam leakage is made available. Such leakage in a cast iron shell is largely an operational issue, as holes are formed in the paper product, demanding expedient attention. Steel shells are not cast, and any through-wall leakage would likely be due to a through-wall crack which should be addressed immediately.

### (23) S5.3.2.3 IMPACT FROM OBJECTS PASSING THROUGH THE PRESS NIP

An object passing through the nip can create a localized impact that leads to elevated stress within fatigue loaded material.

### S5.3.2.4 STRESS MAGNIFICATION AROUND DRILLED HOLES

Surface defects, caused by porosity and indentations, are frequently repaired with driven plugs, having some level of interference fit. Pumping ports, threaded for a tapered pipe fitting, are often installed as a standard yankee design feature for sealant injection into flange interfaces. When installed, both produce an area of increased stress, local to the hole's edge. In the case of driven plugs, this stress can be exaggerated by excessive interference fits and by closely-grouped or overlapping plugs. Over-torque of threaded, tapered plugs can cause cracks to develop at the periphery of the hole.

### (23) S5.3.2.5 EXCESSIVE LOCAL HEATING AND COOLING

Transient thermal stresses are usually the highest encountered by a yankee dryer. Temperature differential through and between parts can be of such magnitude as to exceed the strength of the material. When abnormal thermal loads occur, nondestructive examination is crucial to ensure the vessel's

fitness-for-service. Micro-structural change and transient thermal stresses, sufficiently high to cause cracking in yankee dryers, have resulted, or could result, from:

a) Bearing failure;

b) Rapid warm-up;

c) Excessive steam temperature;

d) Heat from fires;

e) Application of water sprays to fight fires and remove paper jams;

f) Continuous and excessive local cooling from water sprays;

g) Operating heating or cooling systems while the yankee dryer is stationary; (e.g., high-temperature air impingement hoods, infra-red heating devices, coating showers);

h) Welding and electrical arcs; or

i) Excessive local temperature due to improper thermal spray application.

### S5.3.2.6 STRESS-CORROSION CRACKING OF STRUCTURAL BOLTS

Stress-corrosion cracking (SCC) is the result of the combination of a corroding agent, material sensitivity, tensile stress, and temperature. At stress levels sufficiently high to induce SCC in the presence of a corrosive medium, attack proceeds along or through grain boundaries perpendicular to the direction of maximum tensile stress. Cracking can initiate with little or no evidence of general corrosion.

### S5.3.3 CORROSION (23)

Corrosion culminates with a failure in component functionality by diminishing load-carrying capacity or by generating forces beyond the material's strength. In addition to SCC, corrosion-jacking of joints, wear-corrosion, and deterioration of washers described above, oxygen pitting, and general corrosion wastage need to be considered as potential failure causes. These latter two corrosion conditions are the result of inadequate boiler water treatment.

### S5.4 INSPECTIONS (23)

a) The yankee dryer should be inspected internally and externally at least one time every two years. The degree and frequency of inspection should be determined based on OEM recommendations, owner/user experience, and risk-based considerations.

b) As appropriate, the following items should be included depending on material of construction and design:

   1) Head-to-shell joint;

   2) Shell out-of-roundness;

   3) Shell centerline thickness;

   4) Tilt of head flange;

   5) Integrity and security of internal parts;

   6) Spigot fit of flanged joints (head-to-shell, head-to-journal);

7) Integrity of structural bolts and studs;

8) Previously identified areas of deterioration and damage; and

9) Welds within pressure-retaining items.

c) When a nonstandard load event occurs, or a material non-conformity is noted, an inspection should be performed to assess fitness for continued service. This inspection may involve testing methods not typically used in routine inspections and may also involve removal of material samples for destructive testing.

## (23) S5.5 NONDESTRUCTIVE EXAMINATION

a) Nondestructive examination (NDE) methods shall be implemented by individuals qualified and experienced with the material to be tested using written NDE procedures. For cast yankee dryers, cast-iron knowledge and experience are essential.

b) Typical nondestructive examination methods should be employed to determine indication length, depth, and orientation (sizing) of discontinuities in yankee dryers. Magnetic particle, specifically the wet fluorescent method, and dye penetrant methods are applicable in the evaluation of surface-breaking indications. Ultrasonic testing is the standard method for evaluation of surface-breaking and embedded indications. Radiographic methods are useful in the evaluation of embedded indications. Acoustic emission testing can be used to locate and determine if a linear indication is active, i.e., propagating crack. Metallographic analysis is useful in differentiating between original casting discontinuities and cracks.

c) When nondestructive examination produces an indication, the indication is subject to interpretation as false, relevant, or non-relevant. If it has been interpreted as relevant, the necessary subsequent evaluation will result in a decision to accept, repair, replace, monitor, or adjust the maximum allowable operating parameters.

d) The inspection shall include review of the NDE history.

## (23) S5.6 PRESSURE TESTING

a) Water pressure testing in the field is not recommended because of the large size of the yankee dryers and the resulting combined weight of the yankee dryer and the water used in testing. This combined weight can lead to support structure overload. Several failures of yankee dryers have occurred during field pressure testing using water. If this test must occur, the following review is recommended:

1) The testing area should be evaluated for maximum allowable loading, assuming the weight of the yankee dryer, the weight of the water filling the yankee dryer, and the weight of the support structure used to hold the yankee dryer during the test.

2) The building and supporting structures should be assessed for overload.

3) The yankee manufacturer should be contacted to provide information on building the yankee dryer support structure for the water pressure test. Typically, the yankee dryer is supported on saddles that contact the yankee dryer shell at each end near the head-to-shell joint. The manufacturer can provide information on saddle sizing and location so that the yankee dryer is properly supported for the test.

b) Steam or air is recommended when pressure testing is performed. Acoustic emission testing is recommended in conjunction with pressure testing when there are concerns for deterioration or fitness for service.

# SUPPLEMENT 6
# CONTINUED SERVICE AND INSPECTION OF DOT TRANSPORT TANKS

## S6.1 SCOPE

This supplement provides requirements and guidelines for continued service inspections of transport tanks, i.e., cargo tanks, rail tanks, portable tanks, and ton tanks that transport dangerous goods as required in the Code of Federal Regulations, Title 49, Parts 100 through 185, and the United Nations Recommendations for Transport of Dangerous Goods-Model Regulations. This supplement, where applicable, shall be used in conjunction with other applicable Parts of the *National Board Inspection Code* (NBIC) and ASME Section XII, *Rules for Construction and Continued Service of Transport Tanks.*

## S6.2 TERMINOLOGY

a) The terminology used in this supplement in some cases may be in conflict with terms and definitions normally used for inspection, repair, and alteration of pressure-retaining items. Considering these differences, this supplement includes a definition section, listing definitions and terms specified in CFR 49, Parts 100 through 185.

b) When conflicts are identified between this part and the regulations of the Competent Authority regarding the examination, inspection, testing, repair, and maintenance for the continued qualification of transport tanks, the regulations of the Competent Authority take precedence.

c) Rules for repairs, alterations, and modifications of transport tanks are provided in NBIC Part 3, *Repairs and Alterations*, Supplement 6.

## S6.3 ADMINISTRATION

a) The Competent Authority's requirements describe the frequency, scope, type of inspection (internal, external, or both), type of examination (nondestructive, spark test, etc.), and the documentation requirements for the inspection.

b) For transport tanks under the Jurisdiction of the Department of Transportation, the Registered Inspector shall have a thorough knowledge of the Code of Federal Regulations, Title 49, Parts 100 through 185.

## S6.4 INSPECTION

This section establishes the appropriate methods to be used for continued service inspections. Specific requirements for inspections of repairs, alterations, and modifications to transport tanks are located in NBIC Part 3, *Repairs and Alterations*, Supplement 6.

### S6.4.1 SCOPE

This section describes the duties, qualifications, and responsibilities of the Registered Inspector, and the scope of inspection activities permitted.

### S6.4.2 GENERAL REQUIREMENTS FOR INSPECTORS

a) The Inspector shall be a Registered Inspector and qualified as a National Board Commissioned Inspector, Authorized Inspector (AI), Qualified Inspector (QI), or a Certified Individual (CI), as applicable, to perform continued service inspections. The Registered Inspector is a position established by CFR 49 Parts 100 through 185 for Continued Service Inspections. This Inspector's duties and responsibilities are identified in this supplement and subject to DOT regulations, not ASME QAI-1.

b) For continued service inspections, the owner or user's designated and qualified Registered Inspector can be used to perform inspections and testing in accordance with the Code of Federal Regulations, Title 49, Parts 100 through 185, Transportation, as stated below.

c) Inspections for continued service of transport tanks shall be performed by the type of inspector identified below for the specific class of vessel as defined in the applicable Modal Appendices of ASME Section XII and as required by the Competent Authority. Inspectors shall be a Registered Inspector and meet the following additional requirements:

1) For Class 1 vessels, Inspectors shall be designated as an Authorized Inspector regularly employed by an ASME accredited Authorized Inspection Agency (AIA). The AIA, supervisors, and inspectors shall meet the qualifications and duties as required in the latest edition of ASME QAI-1 Qualification for Authorized Inspection.

2) For Class 2 vessels, Inspectors shall be designated as Qualified Inspectors regularly employed by an ASME accredited Qualified Inspection Organization (QIO). The QIO, supervisors, and inspectors shall meet the qualifications and duties as required in the latest edition of ASME QAI-1, Qualifications for Authorized Inspection.

3) For Class 3 vessels, Inspectors shall be designated a Certified Individual (CI) employed full or part time by an ASME Section VIII or Section XII Certificate Holder or contractor to the Certificate Holder manufacturing DOT Transport Tanks. The CI shall meet the qualifications and duties as required in the latest edition of ASME QAI-1, Qualification for Authorized Inspection.

4) Authorized Inspection Agencies may provide inspection services for Class 2 and Class 3 vessels. Qualified Inspection Organizations may provide inspection services for Class 3 vessels.

5) Users may perform continued service inspections including repairs and alterations if the user possesses a valid Owner-User Inspection Organization (OUIO) Certificate of Authorization (NB-371) issued by the National Board of Boiler and Pressure Vessel Inspectors, inspectors have a current and valid NB Commission, and are employed by the OUIO.



## S6.4.3 REGISTRATION OF INSPECTORS

Each Inspector performing duties and responsibilities for continued service inspections or as specified in this section and 49 CFR Part 180 is required to meet the qualification requirements of NBIC Part 2, S6.4.4 through S6.4.7.

## S6.4.4 QUALIFICATIONS OF INSPECTORS

Registered Inspector (RI) means a person registered with the US Department of Transportation (DOT) in accordance with Subpart F of Part 107 of 49 CFR who has the knowledge and ability to determine whether a transport tank conforms to the applicable DOT specification. A Registered Inspector may or may not be an employee of the approved facility. In addition, Registered Inspector means a person who meets, at a minimum, any one of the following:

a) Has an engineering degree and one year of work experience;

b) Has an associate degree in engineering and two years of work experience;

c) Has a high school diploma or GED and three years of work experience; and

d) Has at least three years of experience in performing the duties of a Registered Inspector by September 1, 1991, and was registered with the DOT by December 31, 1995.

### S6.4.5 CODES OF CONSTRUCTION

a) The Registered Inspector is responsible to ensure that all repairs, alterations or modifications (including re-rating) are performed in accordance with the original code of construction of the transport tank.

b) For repairs, alterations, or modifications, the original code of construction for DOT vessels shall be either ASME Section VIII Division I or Section XII.

### S6.4.6 INSPECTOR DUTIES FOR CONTINUED SERVICE INSPECTIONS

a) Inspectors performing Continued Service Inspections required by the Code of Federal Regulations (CFR), Title 49, Part 180 shall be a Registered Inspector. The Inspector shall satisfy the following requirements:

   1) Has satisfied DOT requirements as a Registered Inspector;

   2) Has successfully completed the National Board's web-based training program for Registered Inspectors and been issued a National Board certificate of completion;

   3) Has received authorization from DOT as a Registered Inspector; and

   4) Has been registered by DOT for the classification(s) of Transport Tanks to be inspected.

b) Inspectors performing Continued Service Inspections meeting the requirements of NBIC Part 2, S6.13 (Cargo Tanks), S6.14 (Portable Tanks), or S6.15 (Ton Tanks), and 49 CFR, Part 180 shall perform all inspections and tests required by this Section and any additional requirements, as applicable in 49CFR Part 180. The Inspections and tests shall be documented as follows:

   1) All inspections and tests shall be conducted, as applicable, in accordance with NBIC Part 2, S6.13, S6.14, and S6.15;

   2) All inspections and tests shall be documented in an Inspection Report as required by NBIC Part 2, S6.5;

   3) All inspection and test reports shall be maintained by the owner, user, or shipper of the transport tank in accordance with NBIC Part 2, S6.5; and

   4) All inspection and test reports shall be available for review by an authorized representative of the Department of Transportation.

c) The requirements for inspections are provided for each classification of transport tanks as specified in NBIC Part 2, S6.4.6.1, Cargo Tanks, S6.4.6.2, Portable Tanks and S6.4.6.3, Ton Tanks.

### S6.4.6.1 INSPECTOR DUTIES FOR CONTINUED SERVICE INSPECTION OF CARGO TANKS

a) Cargo tanks constructed in accordance with a DOT Specification that are required to be tested or inspected can not be used for transportation until the required test or inspection has been successfully completed.

   1) The Registered Inspector shall inspect cargo tanks in accordance with S6.13, and in conjunction with the requirements of 49 CFR Parts 180.401 through 180.417.

   2) The Registered Inspector in the performance of their duties shall ensure that the following requirements for Periodic Inspection and test frequencies in S6.13 are properly satisfied as specified by:

      a. Periodic Inspection and Test frequencies: NBIC Part 2, Table S6.13; and

b. Pressure Test Requirements for Cargo Tank by specification: NBIC Part 2, Table S6.13.6.

b) Additional criteria for material thickness requirements for a cargo tank specification are listed, as applicable for material type (ferrous and non ferrous) in various tables in NBIC Part 2, S6.13.

### S6.4.6.2 INSPECTOR DUTIES FOR CONTINUED SERVICE INSPECTION OF PORTABLE TANKS

a) Portable tanks constructed in accordance with DOT, United Nations (UN), or Inter Modal (IM) specifications that are required to be tested or inspected cannot be used for transportation until the required test or inspections have been successfully completed.

b) The Registered Inspector shall inspect portable tanks in accordance with NBIC Part 2, S6.14, in conjunction with the requirements of 49CFR, Parts 180.601 to 180.605.

c) The Registered Inspector in the performance of their duties shall ensure that the following requirements for Inspection Intervals and Pressure Test Requirements in NBIC Part 2, S6.14, are properly satisfied as specified by:

1) Inspection Intervals: NBIC Part 2, Table S6.14; and

2) Pressure Testing Requirements: NBIC Part 2, Table S6.14.6.

### S6.4.6.3 INSPECTOR DUTIES FOR CONTINUED SERVICE INSPECTIONS OF TON TANKS

a) Ton Tanks constructed in accordance with DOT 106A or DOT 110A requirements that are required to be tested and inspected cannot be used for transportation until the required test and inspection has been made.

b) The Registered Inspector, shall inspect ton tanks in accordance with NBIC Part 2, S6.15, in conjunction with the requirements of 49CFR, Part 180.519.

c) The Registered Inspector, in the performance of his or her duties, shall ensure that the requirements for Ton Tank Periodic Inspection and Test Frequencies in NBIC Part 2, Table S6.15.3 are properly satisfied.

d) Additional criteria for material thickness, safety valve, and acceptable material with acceptable tensile strength and elongation requirements for ton tanks, are listed in the following tables of NBIC Part 2, S6.15:

1) Thickness of Plate and Safety Valve Requirements: NBIC Part 2, Table S6.15.1-a;

2) Acceptable materials with acceptable tensile strength and elongation requirements: NBIC Part 2, Table S6.15.1-b.

### S6.4.7 CONTINUED SERVICE, INSPECTION FOR DOT TRANSPORT TANKS SCOPE

This supplement details frequencies of testing requirements, type of tests required, acceptance criteria, and inspection reports of transport tanks.

### S6.4.7.1 ADMINISTRATION

The Competent Authority's requirements describe the frequency, scope, type of inspection, and documentation requirements for the inspection and are noted in the US Code of Federal Regulations, Title 49 CFR, Parts 100 through 185.

### S6.4.7.2 INSPECTION AND TEST REQUIRED FREQUENCIES

Inspection and frequencies for periodic testing of cargo tanks are found in NBIC Part 2, S6.13; portable tanks S6.14; and ton tanks S6.15.

### S6.4.7.3 EXTERNAL VISUAL AND PRESSURE TESTS

External visual inspection tests shall be performed in accordance with NBIC Part 2, S6.13.1, for cargo tanks; S6.14.5 for portable tanks; and NBIC Part 2, S6.15.2, for ton tanks. The pressure tests for cargo tanks shall be as specified in S6.13.6; S6.14.6, for portable tanks; and NBIC Part 2, S6.15.3, for ton tanks.

### S6.4.7.4 LEAK TIGHTNESS TESTING OF TRANSPORT TANKS

#### S6.4.7.4.1 CARGO TANKS

a) Each cargo tank must be tested for leaks in accordance with NBIC Part 2, Table S6.13, *Periodic Inspections and Tests,* and per the requirements in NBIC Part 2, S6.13.9. The minimum leakage test pressure of 80% of MAWP may be accepted by provisions of the Competent Authority (see 49 CFR 180.407[h]).

b) All external and accessible portions of piping up to the first closure when offered for transportation shall be tested for leak tightness.

    1) All closure fittings must be in place during the leak tightness test.

    2) The leak tightness test pressure must be maintained for at least 5 minutes.

    3) All sources of leakage must be properly repaired.

    4) A cargo tank that fails to retain leakage test pressure may not be returned to service as a specification cargo tank.

#### S6.4.7.4.2 PORTABLE TANKS

Each portable tank's piping must be tested for leaks in accordance with the inspection intervals in NBIC Part 2, Table S6.14, and per the procedures in NBIC Part 2, S6.14.6.

a) The minimum leakage test pressure is as specified in NBIC Part 2, Table S6.14.6.

b) All closure fittings must be in place during the leak tightness test.

c) The test pressure must be maintained for at least 5 minutes.

d) All sources of leakage must be properly repaired.

e) A portable tank that fails to retain leakage test pressure may not be returned to service as a specification portable tank.

#### S6.4.7.4.3 TON TANKS

Each ton tank shall be tested at intervals specified in NBIC Part 2, Table S6.15.3, by procedure at pressures specified for the classification of the tank.

### S6.4.7.4.4 LEAK TIGHTNESS TESTING OF VALVES

#### S6.4.7.4.4.1 CARGO TANKS

Cargo tank valves shall be periodically visually inspected in accordance with the applicable provisions in NBIC Part 2, S6.13 and leak tested at time intervals specified in Table S6.13. This test should coincide with the leak test for piping as specified in NBIC Part 2, S6.4.7.4.1, and shall include:

a) All valves under pressure shall be leak tested at the pressure specified, for leakage through the valve, and externally (e.g., valve bonnet).

b) During the inspection a suitable method must be used for detecting the existence of leaks. This method must consist either of coating the entire surface of all joints under pressure with a solution of soap and water, or using other equally sensitive methods.

c) All emergency devices and valves including self-closing stop valves, excess flow valves and remote closure devices must be free from corrosion, distortion, erosion, and external damage that will prevent safe operation. Remote closure devices and self-closing stop valves must be functioned to demonstrate proper operation.

#### S6.4.7.4.4.2 PORTABLE TANKS

Portable tank valves shall be periodically visually inspected in accordance with the applicable provisions of NBIC Part 2, S6.14.3, and leak tested at time intervals specified in NBIC Part 2, S6.14. Leak tightness testing requirements are as specified in NBIC Part 2, Table S6.14.6, and shall include:

a) Piping, valves, and gaskets must be free from corroded areas, defects, and other conditions, including leakage, that might render the portable tank unsafe for filling, discharge, or transportation;

b) All emergency valves shall be free from corrosion, distortion, and any damage or defect that could prevent their normal operation;

c) Remote closure devices and self-closing stop valves must be operated to demonstrate proper function;

d) For testing of internal self-closing stop valves see Appendix A and B of 49CFR180; and

e) The intermediate periodic inspection and test shall include an internal and external inspection, unless exempted, and an external inspection of the portable tank and fittings, leakage test, and test for satisfactory operation of all service equipment.

#### S6.4.7.4.4.3 TON TANKS

Ton tank valves shall be periodically visually inspected in accordance with the applicable provisions of NBIC Part 2, S6.15.2 and leak tested in accordance with the provisions of NBIC Part 2, S6.15.3 and S6.15.3.1. This test should coincide with the tank retest intervals as stipulated in NBIC Part 2, Table S6.15.3.

### S6.4.7.5 LEAK TIGHTNESS TESTING OF SAFETY RELIEF DEVICES

#### S6.4.7.5.1 CARGO TANKS

a) All reclosing pressure relief devices for cargo tanks shall be visually inspected per NBIC Part 2, S6.13.2 e) and pressure tested for leak tightness as stipulated in NBIC Part 2, S6.13.6 b) at frequencies specified in NBIC Part 2, Table S6.13.

**Note**: When performing this test, all reclosing pressure relief valves, including emergency relief vents, and normal vents shall be removed for inspection and tested as follows:

b) Leakage test for any venting device required for the interval specified in NBIC Part 2, Table S6.13, must include testing the device in place, except that any venting device set to discharge at less than the leakage pressure must be removed or rendered inoperative during the test.

c) Non-reclosing relief device discs should be evaluated for replacement at the time of the pressure test intervals.

### S6.4.7.5.2 PORTABLE TANKS

Portable tanks subject to a five-year periodic inspection and leak tightness test, except for DOT Specification 56 and 57 Portable Tanks, shall include:

a) All re-closing pressure relief devices must be removed from the tank and tested separately unless they can be tested while installed on the portable tank.

b) If a leakage test is specified being less than the MAWP, the re-closing pressure relief valves can be tested in place.

c) Visual inspection shall include all emergency devices to ensure that they are free from corrosion, distortion, and any damage or defects that could prevent the devices from operating as designed.

d) For Specification 57 Portable Tanks, during the air test, the pressure relief device may be removed or left in place. If the relief device is left in place during the test, the device's discharge opening shall be plugged. (See Special Requirements for testing of pressure relief devices for Specifications 51 and 56 Portable Tanks in NBIC Part 2, S6.14.6.2.)

e) For Specification 60 Portable Tanks, re-closing pressure relief devices may be removed from the tank and tested separately unless they can be tested while installed in the portable tank.

f) If portable tanks are fitted with non-reclosing relieving devices, consideration for replacing the discs for these devices should be evaluated at the time of the leak tightness test interval.

### S6.4.7.5.3 TON TANKS

Each ton tank designed to be removed from tank cars for filling and emptying shall have their safety relief devices, if fitted, tested and subjected to a periodic inspection and test at frequencies established in NBIC Part 2, Table S6.15.3.

1) All pressure relief devices shall be retested by air or gas for the start-to-discharge and vapor tightness requirements.

2) For ton tanks fitted with rupture discs and fusible plugs, the inspection of these devices and disposition must be as described in NBIC Part 2, S6.15.3.3.

## S6.4.7.6 TESTING OF MISCELLANEOUS PRESSURE PARTS

### S6.4.7.6.1 CARGO TANKS

Cargo tanks provided with manholes (or handholes) shall be inspected in accordance with NBIC Part 2, S6.13.2 and all major structural attachments as defined in CFR180.407(d)(2)(viii), including the upper coupler (fifth wheel) assembly and ring stiffeners shall be inspected in accordance with NBIC Part 2, S6.13.3. Other miscellaneous items shall comply with the following:

a) Cargo tanks equipped with linings that protect the cargo tank from the commodity being transported shall be inspected, unless exempted, in accordance with the provisions of NBIC Part 2, S6.13.5.

b) For cargo tanks equipped with a heating system, the heating system shall be pressure tested as required by NBIC Part 2, S6.13.6.4.

c) Delivery hoses for MC330 and MC331 cargo tanks shall be leak tightness tested. Any conditions as noted in NBIC Part 2, S6.13.9, which exist for the delivery hose, shall be unacceptable and prevent its continued use.

d) New or replaced delivery hose assemblies shall meet all of the requirements of NBIC Part 2, S6.13.10. In addition to this requirement, for commodities transported in MC330 and MC331, the delivery hose assemblies may be installed or carried on the cargo tank. The operator is required to perform inspections as required in 49CFR180.416.

#### S6.4.7.6.2 PORTABLE TANKS

For portable tanks, the periodic visual inspection shall include:

a) The operation of tightening devices for manhole and handhole covers, or the gaskets are operative and there is no leakage at the manhole or handhole cover or gasket at leakage pressure.

b) The framework structural supports and the lifting device located on the portable tank shall be in satisfactory condition.

#### S6.4.7.6.3 TON TANKS

Visual inspection of ton tanks shall include damaged chimes or protective rings, if so fitted.



### S6.4.7.7 ACCEPTANCE CRITERIA

All defects or deficiencies discovered during the inspection process of a transport tank shall be documented in the Inspection Report and discussed with the owner or user of the transport tank at the time of the inspection. Defects or deficiencies shall be corrected using appropriate methods, and tested prior to returning the transport tank to service. (See NBIC Part 2, S6.10)

### S6.4.7.8 INSPECTION REPORT

#### S6.4.7.8.1 CARGO TANKS

Cargo tank Inspection Reports, as a minimum, shall include the information specified in NBIC Part 2, S6.13.6.7 and S6.13.8 (as applicable) and 49 CFR 180.417.

#### S6.4.7.8.2 PORTABLE TANKS

Portable tank Inspection Reports shall satisfy the requirements of NBIC Part 2, S6.14.9, in addition to those of 49 CFR Part 180.605.

#### S6.4.7.8.3 TON TANKS

Ton tank Inspection Reports shall satisfy the requirements of NBIC Part 2, S6.15.3.6 in addition to those of 49 CFR Part 180.519.

## S6.5 STAMPING AND RECORD REQUIREMENTS FOR DOT TRANSPORT TANKS IN CONTINUED SERVICE

This section provides for preparation, distribution and maintenance of inspection records and stamping requirements for Continued Service Inspections of Transport Tanks, i.e., cargo tanks, portable tanks, and ton tanks.

### S6.5.1 GENERAL

To ensure that transport tanks can maintain their authorization to transport hazardous materials by the mode of transport permitted by the competent authority (DOT), the specification transport tank's owner or user shall satisfy, as applicable, that the records and stamping requirements of this supplement and Code of Federal Regulations, Title 49, Part 180 (49 CFR 180) have been satisfied.

### S6.5.2 STAMPING

a) Transport tanks represented as manufactured to a DOT specification or a United Nations (UN) standard shall be marked on a non-removable component of the transport tank with specification markings conforming to the applicable specification. The specification marking is required to be located in an unobstructed area with letters and numerals identifying the standard or specification. Unless otherwise specified by Part 178.3 of the Code of Federal Regulations, the markings must identify the name and address or symbol of the transport tank manufacturer or, where specifically authorized, the symbol of the approval agency certifying compliance with a UN standard.

b) Symbols required by the Department of Transportation (DOT) must be with the approval of the DOT Associate Administrator. Duplicative symbols are not authorized. Stamping and symbol requirements for transport tanks that are under different rules than CFR 49, Parts 100 through 185, shall comply with the applicable competent authority's rules and regulations.

c) The detailed markings, i.e., stamped, embossed, burned, printed, etc., size of the markings, capacities, etc., are specified in Part 178.3 of the Code of Federal Regulations, Title 49, as follows:

    1) ASME-Stamped Transport Tanks

        a. Transport tanks stamped with the ASME Section XII Code Symbol shall satisfy the applicable requirements of that code. Transport tanks manufactured prior to the adoption of ASME Section XII by the Competent Authority were manufactured in accordance with ASME Section VIII, Div. 1. Stamping with the ASME Section VIII, Div. 1 "U" Code Symbol Stamp is dependent on pressure and/or media limitations.

        b. When the stamping on a transport tank becomes indistinct or the nameplate is lost or illegible, but traceability to the original transport tank is still possible. To satisfy this requirement, as a minimum, original source data from the manufacturer of the vessel or records in possession of the tank Owner should be used to establish traceability to the stamping with the concurrence of the Inspector, and approval of the Competent Authority, and if required the Jurisdiction. The Inspector shall instruct the Owner or user to have the stamped data replaced. All restamping shall be done in accordance with the original code of construction (ASME Section XII, or ASME Section VIII, Div. 1, as applicable). Request for permission to restamp or replace the nameplate shall be made to the Competent Authority and, if required, the Jurisdiction. Application must be made on the *Replacement of Stamped Data Form*, NB-136 (See NBIC Part 2, 5.5.2). Proof of the stamping and other such data, as is available, shall be furnished with the request. When traceability cannot be established, the Competent Authority shall be contacted.

2) Restamping or replacement of nameplates

Restamping or replacement of the nameplate as authorized by the Competent Authority shall only be done in the presence of the Inspector, i.e., AI, QI, CI, or National Board Commissioned Inspector, as required by ASME Section XII and the applicable Modal Appendix, or as required by the Competent Authority. For transport tanks manufactured to ASME Section VIII, Division 1, restamping or replacement shall only by done in the presence of an Authorized Inspector or a National Board Commissioned Inspector.

## S6.5.3 OWNER OR USER REQUIRED RECORDS FOR CARGO TANKS

a) Each owner or user of a DOT Specification cargo tank shall retain the appropriate ASME Manufacturer's Data Report, Form T-1, for Section XII Transport Tanks, or Form U-1A for Section VIII, Division 1 Pressure Vessels, and related papers certifying that the DOT Specification cargo tank identified in the documents was manufactured and tested in accordance with the applicable tank specification.

1) In addition to the appropriate ASME Manufacturer's Data Report, the required documents shall include any certification of emergency discharge control systems required by 49 CFR 173.315(n) or 49 CFR 180.405(m).

a. The Certificate of Compliance issued by the cargo tank motor vehicle manufacturer (CTMVM) and all preceding certificates issued by preceding manufacturers signed and dated by a Registered Inspector or Company Official or Design Certifying Engineer as required by 49 CFR 178.337-18(a)(1) or (a)(2) as appropriate. The certificate must contain a statement indicating whether or not the cargo tank was postweld heat treated for anhydrous ammonia service as specified in 49 CFR 178.337-1(f);

b. Cargo tank fabrication drawings;

c. Piping drawing that identifies the location, make, model, and size of each valve and the arrangement of all piping associated with the cargo tank motor vehicle;

d. Assembly drawing;

e. Pressure test report for the piping, valves and fittings;

f. Hose certification; and

g. Certification of emergency discharge control systems.

2) The documents required by 49 CFR shall be retained throughout ownership of the cargo tank and for one year after relinquishing ownership.

3) In the event of a change in ownership, the prior owner shall retain non-fading photocopies of these documents for one year.

4) Users of a cargo tank that are not the owner shall retain a copy of the vehicle certification report as long as the cargo tank motor vehicle is used by the user and for one year thereafter.

5) The required documents specified in this Section shall be maintained at the owner's or users' principal place of business, or at a location where the cargo tank is housed or maintained.

6) Items 4) and 5) do not apply if the user leases the cargo tank for less than 30 days.

b) For DOT Specification cargo tanks that were manufactured prior to September 1, 1995, that were not constructed to ASME Section VIII, Division 1 (Non Code Pressure Vessels), but wishes to certify the cargo tank to a DOT Specification Cargo Tank, the following shall be complied with:

1) The owner shall perform the appropriate tests and inspections as required by 49 CFR Part 178 under the direct supervision of a Registered Inspector to determine if the cargo tank conforms to the applicable specification.

2) Both the owner and the Registered Inspector shall certify that the cargo tank fully conforms to the applicable specification.

3) The owner shall maintain the certification as specified in this section.

c) For ASME stamped cargo tanks, the owner must have the manufacturer's certification and the appropriate ASME Manufacturer's Data Report on file.

1) If the owner does not have the manufacturer's certification and the appropriate ASME Manufacturer's Data Report, the following shall be satisfied:

a. If the pressure vessel of the cargo tank is registered with the National Board of Boiler and Pressure Vessel Inspectors (National Board), they shall obtain a copy of the Manufacturer's Data Report from the National Board.

b. If the pressure vessel of the cargo tank is not registered with the National Board, shall copy the cargo tank's identification and ASME Code nameplate information and retain this information in their files.

2) If the nameplate information is copied as identified in c) 1) b., the owner and the Registered Inspector shall certify that the pressure vessel of the cargo tank fully conforms to the DOT specification.

3) The owner shall retain all certification documents in accordance with retention periods specified in this supplement.

### S6.5.3.1 REPORTING REQUIREMENTS BY THE OWNER OR USER OF TESTS AND INSPECTIONS OF DOT SPECIFICATION CARGO TANKS

The owner or user that performs the required test and the Registered Inspector that performs the inspection as specified at frequencies established in NBIC Part 2, Table S6.13, shall prepare a written report in English that satisfies the requirements of NBIC Part 2, S6.13. Each test and inspection facility that fails a cargo tank based on a test or inspection report shall notify the Owner, register the report with the National Board, and provide a copy of the test report indicating the failure to the competent authority.

### S6.5.3.2 DOT MARKING REQUIREMENTS FOR TESTS AND INSPECTIONS OF DOT SPECIFICATION CARGO TANKS

Each cargo tank that has successfully completed the test and inspection contained in NBIC Part 2, S6.13, shall be durably and legibly marked, in English. The markings shall comply with the following:

a) Date (month and year) of the type of test or inspection performed, subject to the following:

1) Date shall be readily identifiable with the applicable test or inspection;

2) Markings shall be 32 mm (1.25 in.) high, near the specification plate or anywhere on the front head of the cargo tank.

b) The type of test or inspection may be abbreviated as follows:

1) "V" for external visual inspection;

2) "I" for internal visual inspection;

3) "P" for pressure test;

4) "L" for lining inspection;

5) "T" for thickness inspection;

6) "K" for leakage test for a cargo tank tested to the requirements of NBIC Part 2, S6.13.9, except for cargo tanks subject to the requirements of NBIC Part 2, S6.13.9 d) 10); or

7) "K-EPA27" for a cargo tank tested to the requirements of NBIC Part 2, S6.13.9 d) 10), that was manufactured after October 1, 2004.

c) For a cargo tank motor vehicle composed of multiple cargo tanks constructed to the same specification, which are tested and inspected at the same time, one set of test and inspection markings may be used to satisfy the requirements of NBIC Part 2, S6.5.3.2.

d) For a cargo tank motor vehicle composed of multiple cargo tanks constructed to different specifications, which are tested and inspected at different intervals, the test and inspection markings shall appear in the order of the cargo tank's corresponding location, from front to rear.

### S6.5.4 OWNER OR USER REQUIRED RECORDS FOR PORTABLE TANKS

a) The owner of each portable tank or their authorized agent shall retain a written record of the date and results of all required inspections and tests, including the ASME Manufacturer's Data Report.

b) The written record, if applicable, shall indicate the name and address of the person that performed the inspection or test. The inspection and test shall comply with the requirements of the portable tank's specification, as provided in 49 CFR, Part 178.

c) The owner shall maintain a copy of the ASME Manufacturer's Data Report. He shall also maintain a certificate(s) that is signed by the manufacturer of the portable tank, and by the authorized design approval agency, as applicable indicating compliance with the applicable portable tank specification.

d) The signed certificate, including the ASME Manufacturer's Data Report, shall be maintained by the owner or their authorized agent during the time that the portable tank is used for service. DOT Specifications 56 and 57 portable tanks are exempt from this requirement.

#### S6.5.4.1 REPORTING OF PERIODIC AND INTERMEDIATE PERIODIC INSPECTION AND TESTS OF DOT SPECIFICATION PORTABLE TANKS

a) The user of portable tanks shall satisfy the requirements for Periodic and Intermediate Periodic Inspection and Tests of portable tanks as specified in Table S6.14 of this supplement and shall maintain the results of these tests as required in NBIC Part 2, S6.5.4.

b) The methods and procedures to be used in the performance of the required Intermediate Periodic and Inspections and Tests are specified in NBIC Part 2, S6.14.

#### S6.5.4.2 MARKING REQUIREMENTS FOR PERIODIC AND INTERMEDIATE INSPECTION AND TESTS FOR IM OR UN PORTABLE TANKS

Each IM or UN portable tank that has successfully completed the required Periodic or Intermediate Inspection and Test shall be durably and legibly marked, in English. The markings shall comply with the following:

a) Date (month and year) of the last pressure test;

b) Identification markings of the approval agency witnessing the test;

c) When required, the date (month and year) of the last visual inspection;

d) Markings shall be placed on or near the metal identification plate; and

e) Markings shall be 3 mm (0.118 in.) high when on the metal identification plate and 12 mm (0.47 in.) high when on the portable tank.

### S6.5.4.3 DOT MARKING REQUIREMENTS FOR PERIODIC AND INTERMEDIATE INSPECTION AND TESTS OF DOT SPECIFICATION 51, 56, 57, OR 60 PORTABLE TANKS

Each DOT Specification 51, 56, 57, or 60 portable tank that has successfully completed the required Periodic or Intermediate Inspection and Test shall be durably and legibly marked, in English. The markings shall comply with the following:

a) Date (month and year) of the most recent test;

b) Markings shall be placed on or near the metal certification plate;

c) Markings shall be accordance with 49 CFR, Part 178.3; and

d) Letters and numerals shall not be less than 3 mm (0.118 in.) high, when on a metal certification plate and 12 mm (0.47 in.) on the portable tank, except that a portable tank manufactured under a previously authorized specification may continue to be marked with smaller markings if originally authorized under that specification (for example, DOT specification 57 portable tanks).

### S6.5.5 OWNER OR USER REQUIRED REPORTS FOR DOT SPECIFICATION 106A AND DOT 110A TON TANKS

a) The owner or user of a DOT Specification ton tank shall retain the certificate of construction (AAR-Form 4-2) and related papers certifying that the manufacturer of the specification tank identified in the documents is in accordance with the applicable specification.

b) The owner or user shall retain the documents throughout the period of ownership of the specification ton tank and for one year thereafter.

c) Upon a change in ownership of the specification ton tank, the owner shall satisfy the requirements of Section 1.3.15 of the ARR Specification.

### S6.5.5.1 REPORTING OF INSPECTION AND TESTS FOR DOT SPECIFICATION 106A AND DOT 110A TON TANKS

a) The owner or user shall inspect and test ton tanks at frequencies specified in NBIC Part 2, Table S6.15.3 and shall perform the inspections and tests in accordance with NBIC Part 2, S6.15.3.

b) The owner or user is required to develop a written record of the results of the pressure test and visual inspection and shall record the information on a suitable data sheet. Completed copies of these reports shall be retained by the owner and by the person performing the pressure test and visual inspection, as long as the ton tank is in service.

c) The required information to be recorded and checked on these data sheets is:

   1) Date of test and inspection;

   2) DOT Specification Number;

   3) Ton tank identification (registered symbol and serial number);

   4) Date of manufacturer and ownership symbol;

5) Type of protective coating (painted, etc.), and statement as to need for refinishing or recoating;

6) Conditions checked, i.e., leakage, corrosion, gouges, dents or digs, broken or damaged chime or protective ring, fire, fire damage, internal condition;

7) Test pressure;

8) Results of tests;

9) Disposition of ton tank (returned to service, returned to manufacturer for repair, or scraped); and

10) Identification of person conducting the retest or inspection.

d) If a Retest Inspection is required, the owner or user shall prepare a written report in accordance with NBIC Part 2, S6.15.3.6, of this supplement.

### S6.5.5.2 DOT MARKING REQUIREMENTS FOR TESTS AND INSPECTION OF DOT SPECIFICATION 106A AND 110A TON TANKS

a) When a ton tank passes the required inspection and test with acceptable results, the tank car facility shall mark the following information on the ton tank:

1) Date of the inspection and test;

2) Due date of the next inspection and test; and

3) The markings on the ton tank shall be in accordance with Appendix C of the ARR Specifications for Tank Cars.

b) When a tank car facility performs multiple inspections and tests at the same time, one date may be used to satisfy the requirements of NBIC Part 2, S6.5.5.2. Additionally, one date may be shown when multiple inspections and tests have the same due date.



## S6.6 CORROSION AND FAILURE MECHANISMS IN TRANSPORT TANKS

An effective inspection and test program requires an understanding of the applicable potential failure mechanisms and the applicable inspection and test methods to ensure the continued structural integrity of a transport tank.

### S6.6.1 SCOPE

This section provides an overview of the causes of deterioration and failure mechanisms in transport tanks. As provided in this overview, some forms of deterioration and failure mechanisms may include stress corrosion cracking, fatigue, and temperature gradients (brittle fracture behavior) applicable to transport tanks during their normal operation.

### S6.6.2 GENERAL

a) This supplement includes a general discussion of mechanisms and effective inspection and test methods. Additionally, some specific guidance is given on how to evaluate the transport tanks for repairs, modifications, and continued service requirements.

b) There are a variety of inservice conditions that may cause deterioration of the materials used in the construction of transport tanks. These inservice conditions should be taken into consideration during any repair activity. Prior to any repair activity, it is important to identify the cause of the deterioration, and to prevent its recurrence.

## S6.6.3 INTERNAL AND/OR EXTERNAL CORROSION

Internal and/or external wastage from corrosion is probably one of the most common causes of deterioration in transport tanks while in operation. All metals and alloys are susceptible to corrosion. Corrosion is deterioration that occurs when a metal reacts with its environment. Corrosion can be classified based on three factors. These factors are:

a) Nature

1) Wet — liquid or moisture present in the transport tank;

2) Dry — high temperatures that may be present in the transport tank;

b) Mechanism — electrochemical or direct chemical reactions; and

c) Appearance — either uniform or localized.

### S6.6.3.1 TYPES OF CORROSION

To implement the proper corrective actions will depend on which factors caused the problems, making it important to diagnose the reason for failure. Early detection of corrosion problems are important to prevent failures and can be achieved by performing regular inspections and encouraging employees to be observant and communicate their observations. The following types of corrosion mechanisms are commonly found in transport tanks:

a) Pitting Corrosion

Pitting corrosion is the formation of holes in an otherwise relatively un-attacked surface. Some of the characteristics of pitting corrosion are:

1) Usually a slow process causing isolated, scattered pitting over a small area that does not substantially weaken the transport tank. It could, however, eventually cause leakage;

2) In some cases, local corrosion pits can be caused by microbiological activity, commonly known as MIC (microbiologically influenced corrosion) attack; or

3) Generally, the area of the steel surrounding a corrosion pit from MIC will exhibit discoloration or a ring as evidence of a thriving bacteria colony.

b) Line Corrosion

This is a condition where pits are connected; or nearly connected to each other in a narrow band or line. Line corrosion frequently occurs in the interior surfaces of a transport tank at the following locations:

1) The liquid-vapor interface in the transport tank; or

2) The bottom of the transport tank.

c) General Corrosion

This is corrosion that covers a considerable area of the vessel surface of the transport tank. When this condition occurs, the owner or user of the transport tanks has to consider if this condition has compromised the continued safe operation of the transport tank. The following should be used in making this determination:

1) Inspect the affected area or areas to ensure that the required minimum thickness of the vessel is within acceptable limits; and

2) If the affected area's or areas' minimum thickness is below tolerance, depending on the degree of deterioration, restore the area or areas to the required thickness by using the weld buildup method or a flush patch.

d) Grooving Corrosion

This type of corrosion is a form of metal deterioration caused by localized corrosion, and may be accelerated by stress concentration. Grooving is generally noticed:

1) Adjacent to welded surfaces; and

2) On flange-mating surfaces.

e) Exfoliation and Selective Leaching

1) Exfoliation is a subsurface corrosion that begins on a clean surface, but spreads below the surface of the metal. This type of corrosion differs from pitting in that the damage to the metal exhibits a laminated appearance, recognized by a flaky and sometimes blistered surface.

2) Selective leaching results in the removal of one of the elements in an alloy material. This corrosion mechanism is detrimental because it yields a porous metal with poor mechanical properties.

f) Galvanic Corrosion

1) Occurs when two dissimilar metals come in contact with each other in the presence of an electrolyte (e.g., film of water containing dissolved oxygen, nitrogen, and carbon dioxide) constituting an electrolytic cell. The difference in galvanic potential between the two dissimilar materials creates a local electrical cell that may cause rapid corrosion of the less- noble metal. This corrosion mechanism becomes more active when there are large differences between the electrode potentials of the two metals.

2) Galvanic corrosion may also exist with relatively minor changes of alloy composition (e.g., between a weld metal and the base metal). Natural (e.g., an oxide coating on aluminum) or a protective coating may inhibit galvanic corrosion, but in most instances the metals or alloys must be selected on the basis of intrinsic resistance to corrosion.

3) In transport tanks, the effects of galvanic corrosion are most noticeable at welds or at flanged and bolted connections that have been exposed to contact with a fluid that is conductive.

g) Erosion/Corrosion

This type of damage mechanism is generally attributed to the movement of a corrodent over a metal surface that increases the rate of attack due to mechanical wear and corrosion. This type of damage mechanism is generally characterized as having an appearance of smooth bottomed shallow pit, and may also exhibit a directional pattern or surface texture related to the path taken by the corrodent. This deterioration would normally occur at locations where the transport tank is filled or emptied.

h) Crevice Corrosion

1) Environmental conditions in a crevice can, with time, become different from those on a nearby clean surface. A more aggressive environment may develop within the crevice and cause local corrosion. Crevice corrosion commonly can be found in:

a. Gasket surfaces;

b. Lap joints; and

c. Bolts and flanges.

2) Crevice corrosion can also be caused by dirt deposits, corrosion products, scratches in paint, etc.

3) To avoid or greatly reduce corrosion, the owner or user of transport tanks, when having a transport tank manufactured, can specify materials and protection methods (such as coating). By implementing proper selection of materials and protection methods, corrosive attack in transport tanks can be predicted and controlled. However, there may be unexpected failures as a result of one or more of the following:

   a. Poor choice of materials used in transport tank repairs or new construction;

   b. Operating conditions different from those anticipated in service;

   c. Defective fabrication;

   d. Improper design;

   e. Inadequate maintenance; and

   f. Defective material.

## S6.6.4 FAILURE MECHANISMS

There are various failure mechanisms that can result in cracks or loss of structural integrity to transport tanks. The more common failure mechanisms described below are fatigue, mechanical, thermal, and corrosion induced brittle fracture and hydrogen embrittlement, as a result of poor handling practices during welded repairs.

a) Fatigue — Stress reversals (such as cyclic loading) in parts of transport tank equipment are common, particularly at points of high secondary stress. These stresses can originate adjacent to locations of weld repairs and from over-the-road vibratory stresses. If stresses are high and reversals frequent, failure of parts may occur because of mechanical fatigue crack propagation. Fatigue failures in transport tanks may also result from exposure to cyclic temperature and pressure changes. Locations where metals having different thermal coefficients of expansion that are joined by welding may be susceptible to thermal fatigue upon exposure to service temperature variations.

   1) In specific cases where the combined effects of exposure to a corrosive environment and cyclic loading occur together in a transport tank, the damage mechanism that can occur is corrosion assisted fatigue or simply corrosion fatigue.

   2) Corrosion fatigue crack propagation typically occurs along a straight direction, with minimal branching. Some sources of fatigue crack initiation are:

      a. At sharp corners;

      b. At openings in the transport tank; and

      c. At structural attachments.

b) Temperature — At subfreezing temperatures, water and some chemicals handled in transport tanks may freeze and cause failure. Carbon and low-alloy steels may be susceptible to brittle fracture, even at ambient temperatures. A number of failures have been attributed to brittle fracture of steels that were exposed to temperatures below their ductile-to-brittle transition temperature (DBTT) during a pressure test or hydrostatic test. However, most brittle fractures have occurred on the first application of a particular stress level (that is, the first hydrostatic test or overload).

   Special attention should be given to low-alloy steels because they are prone to temper embrittlement, which can result in a loss of toughness.

Temper embrittlement is defined as a loss of ductility and notch toughness due to postweld heat treatment or high temperature service, above 370°C (700°F).

c) Hydrogen Embrittlement — A loss of strength and/or ductility in steels caused by atomic hydrogen dissolved in the steel. It is a low-temperature phenomenon, seldom encountered above 95°C (200°F), and most often occurs as a result of hydrogen evolved from aqueous corrosion reactions or hydrogen generated during welding. Weld underbead cracking (also know as delayed cracking and cold cracking) is also a form of hydrogen embrittlement; however, in this case, the hydrogen comes from the welding operation rather than from a corrosion reaction.

   1) Weld underbead cracking is caused by hydrogen dissolved in a hard, high-strength weld heat-affected zone. Use of low-hydrogen welding practices to minimize dissolved hydrogen, and/or use of high-preheat, and/or postweld heat treatment to reduce heat-affected zone hardness, will reduce the likelihood of weld underbead cracking in susceptible steel.

   2) Hydrogen embrittlement is reversible as long as no physical damage, e.g., cracking, has occurred in the steel. If the atomic hydrogen is removed from the steel before any damage occurs, for example by heating for a short time in the absence of hydrogen between 150°C (300°F) and 205°C (400°F), normal mechanical properties will be restored.

   3) Welding procedures, repair methods, and inspection procedures must include careful consideration of potential failure in corrosive environments, including the various forms of hydrogen embrittlement.

d) Stress Corrosion Cracking (SCC) — Cracking of a metal caused by the combined action of stress and a corrosive environment. SCC only occurs with specific combinations of metal and environment. The stress required may be either applied or residual. Examples of stress corrosion cracking include chloride stress corrosion cracking of stainless steels in hot, aqueous chloride solutions; caustic cracking of carbon steel in hot sodium hydroxide solutions, and ammonia stress corrosion cracking of brass in ammonia solutions (season cracking).

   1) Corrosivity alone is not a good indicator of the likelihood of a particular environment to cause SCC in a particular metal. Solutions that are highly corrosive to a material almost never promote SCC.

   2) The principal variables affecting SCC are tensile stress, service temperature, solution chemistry, duration of exposure, and metal properties. Removing any one of these parameters sufficiently can reduce or eliminate the possibility of SCC occurring in service.



## S6.7 CLASSIFICATION BOUNDARIES

Transport tanks are classified as Class 1, Class 2, and Class 3. The classification is established by the applicable Modal Appendix of ASME Section XII. Also contained in the Modal Appendix is the type of Inspector, i.e., Authorized Inspector, Qualified Inspector, and Certified Individual, that is permitted to perform the applicable fabrication inspection of the transport tank, i.e., cargo tank, tank car, portable tank, and ton tank. The classification of the transport tank, except for continued service inspections, determines the code of construction requirements for repairs or modifications.

## S6.8 PRESSURE, TEMPERATURE, AND CAPACITY REQUIREMENTS FOR TRANSPORT TANKS

a) ASME Section XII has established pressure, temperature, and maximum thickness requirements for transport tanks as follows:

   1) Pressure: full vacuum to 208 bar (full vacuum to 3,000 psia);

   2) Temperature: -269°C to 343°C (-452°F to 650°F); and

3) Maximum material thickness: 38 mm (1-1/2 in.).

b) Transport tanks manufactured prior to the adoption of ASME Section XII by the Competent Authority were manufactured in accordance with ASME Section VIII, Div. 1. Transport tanks manufactured to this Code were required to be stamped with the “U” Code Symbol Stamp in accordance with Section VIII, Div. 1, if the design pressure of the transport tank was 241 kPa (35 psi) (depending on material being transported) and greater. If the design pressure was less than 241 kPa (35 psi) (depending on the media being transported), the transport tank was constructed in accordance with Section VIII, Div. 1, but not stamped with the “U” Code Symbol Stamp.

c) For these transport tanks, the requirements established in NBIC Part 2, for continued service inspection, repairs, or modifications shall apply, unless specifically exempted by the DOT.

## S6.9 REFERENCES TO OTHER CODES AND STANDARDS

Other existing inspection codes, standards, and practices pertaining to the continued service inspection, i.e., CFR 49, Parts 100 through 185, ASME Section XII, etc., of transport tanks can provide useful information and references relative to the inspection techniques listed in this Appendix. Additionally, supplementary guidelines for assisting in the evaluation of inspection results and findings are also available. Some acceptable requirements and guidelines are as follows:

a) American Society of Mechanical Engineers — *ASME Boiler and Pressure Vessel Code*, Section VIII, Div. 1 (*Rules for Construction of Pressure Vessels*).

b) American Society of Mechanical Engineers:

1) ASME Section V (*Nondestructive Examination*).

2) ASME Section IX (*Welding and Brazing Qualifications*).

c) Code of Federal Regulations, Title 49, Parts 100 through 185, *Transportation*.

d) American Petroleum Institute — API 579, *Fitness for Service*.

e) ADR 2003, *European Agreement Concerning the International Carriage of Dangerous Goods by Road*. (Published by the UN Economic Commission for Europe, Information Service, Palais des Nations, CH-1211 Geneve, Suisse.)

f) CGA 6-4.1, *Cleaning Equipment for Oxygen Service*.

g) CGA S-1.2, *Pressure Relief Device Standard*, Part 2: *Cargo and Portable Tanks for Compressed Gases*. (Published by the Compressed Gas Association, Inc. [CGA], 4221 Walney Road, Chantilly, VA 20151.)

h) IMDG Code 2002, *International Maritime Dangerous Goods Code* (including Amendment 31-02. (Published by the International Maritime Organization [IMO], 4 Albert Embankment, London, SE1 7SR England.)

i) RID 2003, *Carriage of Dangerous Goods*. (Published by the Intergovernmental Organization for International Carriage by Rail [OTIF], Gyphenhubeliweg 30, CH-3006 Bern, Switzerland.)

j) *United Nations Recommendations on the Transport of Dangerous Goods – Modal Regulations.* (Published by the United Nations Publications, 2 UN Plaza, New York, New York 10017.)

k) SSPC Publication #91-12, *Coating and Lining Inspection Manual*. (Published by Steel Structures Painting Council, 4400 Fifth Avenue, Pittsburgh, PA 15212-2683.)

## S6.10 CONCLUSION

a) During any continued service inspections or tests of transport tanks, performed by the Registered Inspector, the actual operating and maintenance requirements as specified in this Supplement shall be satisfied. The Registered Inspector shall determine, based on the applicable requirements of the *Code of Federal Regulations*, Title 49, Parts 100 through 185, and NBIC Part 2, Supplement 6, whether the transport tank can continue to be safely operated.

b) Defects or deficiencies in the condition, operation, and maintenance requirements of the transport tank, including piping, valves, fittings, etc., shall be discussed with the owner or user of the transport tank at the time of inspection. Defects or deficiencies shall be corrected using the appropriate methods prior to returning the transport tank to service.

## S6.11 PERSONNEL SAFETY AND INSPECTION ACTIVITIES

a) Proper inspection of transport tanks may require pre-inspection planning. This planning should include development of an inspection plan that will satisfy the applicable technical requirements of this Part, the *Code of Federal Regulations*, Title 49, Parts 100 through 185, Transportation, and appropriate safety considerations. The inspection plan should also include the applicable failure and deterioration mechanisms, and inspection methods and the requirements of the applicable Competent Authority.

b) This supplement describes pre-inspection and post-inspection activities applicable to all transport tanks. Specific inspection requirements for transport tanks are identified in NBIC Part 2, S6.13 for Cargo Tanks, S6.14 for Portable Tanks, NBIC Part 2, S6.15 for Ton Tanks.

c) Personnel safety is the joint responsibility of the owner or user and the Registered Inspector. All applicable safety regulations shall be followed. This includes, if applicable, all governmental rules and regulations. owner's or user's personnel safety programs and/or safety programs by the Inspector's employer or similar regulations such as confined space requirements also apply.



## S6.12 TRANSPORT TANK ENTRY REQUIREMENTS

a) No transport tank shall be entered until it has been properly prepared for inspection. The owner or user and the Inspector shall determine that the transport tank may be entered safely. This shall include:

   1) Potential hazards associated with the entry into the transport tank have been identified by the owner or user and are brought to the attention of the Inspector, along with acceptable means or methods for mitigating each of these hazards;

   2) Coordination of entry into the transport tank by the Inspector and the owner or user representative(s) working in or near the transport tanks;

   3) If personal protective equipment is required to enter the transport tank, the necessary equipment is available, and the Inspector is properly trained in its use; and

   4) An effective energy isolation program is in place and in effect that will prevent the unexpected release of energy or media to enter the transport tanks.

b) The Inspector shall be satisfied that a safe atmosphere exists before entering the transport tank. The oxygen content of breathable atmosphere shall be between 19.5% and 23.5%.

c) The Inspector shall not be permitted to enter an area if toxic, flammable, or inert gases or vapors are present and above acceptable limits without proper personal protective equipment. Protective equipment may include, among other items, protective outer clothing, gloves, eye protection, foot protection, and/or respirators.

d) The Inspector shall have proper training governing the selection and use of any personal protective clothing and equipment necessary, particularly related to respiratory protection if the testing of the atmosphere of the transport tank reveals any hazards. This requirement is to ensure that the inspection may be performed safely.

### S6.12.1 PRE-INSPECTION ACTIVITIES

a) Prior to conducting the inspection, a review of the history of the transport tank and a general assessment of current conditions shall be performed. This shall include a review of information, such as:

1) Date of the last inspection;

2) Current Inspection Certificate;

3) ASME Code Name Plate and/or Specification;

4) If applicable, National Board registration number;

5) Serial number of identification marking of the transport tank;

6) Operating conditions and normal contents of the transport tank;

7) Previous inspection report or inspection certificates;

8) Records of wall thickness checks, especially where corrosion is a consideration; and

9) Observations of the condition of the complete transport tank, including, piping, fitting, valves, etc.

b) The following activities should be performed as required to support the inspection:

1) Verify the pressure gages, thermometers, and indicating devices are in proper calibration;

2) Ensure that all overpressure protection devices are in proper operation, and that they are operating as designed; and

3) Ensure that all structural attachments are free of defects and are operating as designed.

### S6.12.2 PREPARATION FOR INTERNAL INSPECTION

The owner or user has the responsibility to prepare a transport tank for internal inspection. Requirements for safety including occupational safety and health regulations (federal, state, local, or other), the owner's or user's own safety program, and the safety programs of the Inspector's employer are applicable for inspections. The transport tank shall be prepared in the following manner or as deemed necessary by the Inspector.

a) When a transport tank is connected to a common header with other transport tanks or in a system where liquids or gases are present, the transport tank shall be isolated by closing, locking, and/or tagging stop valves in accordance with the owner's or user's procedures.

b) When toxic or flammable materials are involved, additional safety precautions should require removing pipe sections or blanking pipelines before entering the transport tank. The means of isolating the transport tank shall be acceptable to the Inspector and in compliance with applicable occupational safety and health regulations.

c) The transport tank shall be allowed to cool or warm to ambient temperature at a rate to avoid damage to the transport tank.

d) The transport tank shall be drained of all liquid and shall be purged of any toxic or flammable gases or other contaminants that were contained in the transport tank. Mechanical ventilation using a fresh air blower or fan shall be started after the purging operation and maintained until all pockets of “dead air” that may contain toxic or flammable or inert gases are reduced to acceptable limits. During the air purging and ventilation of the transport tank involved with flammable gases, the concentration of the vapor in air should pass through the flammable range before a safe atmosphere is obtained. All necessary precautions shall be taken to eliminate the possibility of explosion or fire.

e) Manhole, if applicable, and handhole plates, washout plugs, inspection plugs, and any other item requested by the Inspector shall be removed.

f) The Inspector shall not enter a transport tank until all safety precautions have been taken. The temperature of the transport tank shall be such that the inspection personnel will not be exposed to excessive heat or cold. The transport tank should be cleaned as necessary.

g) A qualified person (attendant) shall remain outside the transport tank at the point of entry while the Inspector is inside and shall monitor activities inside and outside and communicate with the Inspector as necessary. The attendant shall have means of summoning rescue assistance, if needed, and to facilitate rescue procedures for those inside the transport tank without personally entering the transport tank.

**Note**: If a transport tank has not been properly prepared for an internal inspection, the Inspector shall decline to make the inspection.

### S6.12.3 POST-INSPECTION ACTIVITIES

a) Any defects or deficiencies in the condition, operation, and maintenance practices of the transport tank and auxiliary equipment shall be reported to the owner or user, including recommendations for correction.

b) Documentation of inspections shall contain pertinent data such as a description of the transport tank, classification (Class 1, 2, or 3), the transport tank identification number, inspection intervals, date of inspection, type of inspection, or type of test performed, and any other information required by the Competent Authority. The Inspector shall sign, date, and note any deficiencies, comments, or recommendations on the inspection report. The Inspector should retain and distribute copies of the inspection report as required.

## S6.13 INSPECTION AND TESTS OF CARGO TANKS

All cargo tanks shall be examined and tested at frequencies specified in NBIC Part 2, Table S6.13. The examination and tests shall provide for a visual external, visual internal, leakage test, pressure test, thickness test, and lining test. It should be noted that the information in NBIC Part 2, Table S6.13 is a summary of United States Code of Federal Regulations, Title 49, Part 180. The user shall compare the requirements provided with Part 180 to ensure full compliance.

**TABLE S6.13**
PERIODIC INSPECTIONS AND TESTS

| Test or Inspection (cargo tank specification, configuration, and service) | Date by which first test must be completed (see Note 1) | Interval period after first test |
|---|---|---|
| **External Visual Inspection** | | |
| All cargo tanks designed to be loaded by vacuum with full opening rear heads | September 1, 1991 | 6 Months |
| All other cargo tanks | September 1, 1991 | 1 Year |
| **Internal Visual Inspection** | | |
| All insulated cargo tanks, except MC 330, MC 331, & MC 338 (see Note 4) | September 1, 1991 | 1 Year |
| All cargo tanks transporting lading corrosive to the tank | September 1, 1991 | 1 Year |
| All other cargo tanks, except MC 338 | September 1, 1995 | 5 Years |
| **Lining Inspection** | | |
| All lined cargo tanks transporting lading corrosive to the tank | September 1, 1991 | 1 Year |
| **Leakage Test** | | |
| MC 330 and MC 331 cargo tanks in chlorine service | September 1, 1991 | 2 Years |
| All other cargo tanks, except MC 338 | September 1, 1991 | 1 Year |
| **Pressure Test** | | |
| Hydrostatic or Pneumatic (see Notes 2 and 3) | — | — |
| All cargo tanks which are insulated with no manhole or insulated and lined, except MC 338 | September 1, 1991 | 1 Year |
| All cargo tanks designed to be loaded by vacuum with full opening heads | September 1, 1992 | 2 Years |
| MC 330 and MC 331 cargo tanks in chlorine service | September 1, 1992 | 2 Years |
| All other cargo tanks | September 1, 1995 | 5 Years |
| **Thickness Test** | | |
| All unlined cargo tanks transporting material corrosive to the tank, except MC 338 | September 1, 1992 | 2 Years |

**Note 1:**

If a cargo tank is subject to an applicable inspection or test requirement under the regulations in effect on December 30, 1990, and the due date (as specified by a requirement in effect on December 30, 1990) for completing the required test occurs before the compliance date listed in the Table, the earlier date applies.

**Note 2:**

Pressure testing is not required for MC 300 and MC 331 cargo tanks in dedicated sodium metal service.

**Note 3:**

Pressure testing is not required for uninsulated lined cargo tanks with a design pressure of MAWP 103 kPa (15 psi) or less, which receive an external visual inspection and lining inspection at least once each year.

**Note 4:**

Insulated cargo tanks equipped with manholes or inspection openings may receive either an internal visual inspection in conjunction with the external visual inspection or a hydrostatic or pneumatic test of the cargo tank.

## S6.13.1 VISUAL EXTERNAL INSPECTION

a) Visual inspections are required of the complete cargo tank as required in NBIC Part 2, Table S6.13. The visual inspection shall include the heads, shell, nozzle connections, support attachments, all welded seams (longitudinal and circumferential), nozzle attachment welds, support, piping, appurtenances, structural attachments, and any attachment welds for possible defects. The visual inspection shall include a thorough examination for scratches that affect the pressure-retaining capabilities of the cargo tank, dents, leaks, distortions, corroded or abraded areas, and any other condition that would affect the safe operation of the cargo tank. If the cargo tank is able to be externally inspected, this must be noted in the inspection report of the cargo tank.

b) If the cargo tank is insulated and equipped with an internal lining, the following inspections shall be performed:

1) Insulated cargo tanks — If the insulation on the cargo tank precludes a complete and thorough external visual inspection, the cargo tank shall be subjected to an internal visual inspection, if equipped with a manhole or inspection openings. This inspection shall include all internal surfaces, including welds, nozzle attachments, and, if equipped, baffles, internal stiffeners, surge protection devices for defects, corrosion, and missing or loose attachment;

2) Lined or coated, or those designed to preclude an internal visual inspection — If the cargo tank is externally lined, coated, or of a design that would prevent a complete and thorough external visual examination, the internal areas of the cargo tank that are not obstructed by the lining or coating shall be internally inspected;

3) Lined or coated, or those so designed to preclude access to the internal surfaces — The cargo tank shall be subjected to a hydrostatic or pneumatic test in accordance with NBIC Part 2, S6.13.6;

4) All corroded or abraded areas of a cargo tank wall must be thickness tested in accordance with the following procedures:

a. Measurements must be made using a device capable of accurately measuring thickness within ± 0.051 mm (± 0.002 of an inch);

b. Any individual performing thickness testing must be trained in the proper use of the thickness testing device in accordance with the testing device manufacturer’s instructions; and

c. The minimum thickness requirements for the heads, shell baffle, and bulkhead, when used as tank reinforcement, shall meet the minimum thickness requirements for inservice requirements for cargo tank specifications MC 300, MC 303, MC 304, MC 306, MC 307, MC 310, MC 311 transport tanks, and MC 312 cargo tanks constructed of steel, steel alloys, aluminum, and aluminum alloys are based on 90% of the minimum manufactured thickness. Table S6.13.1-a, provides minimum inservice minimum thicknesses for steel and steel alloys. Table S6.13.1-b provides minimum thicknesses for aluminum and aluminum alloys.

**TABLE S6.13.1-a**

INSERVICE MINIMUM THICKNESSES FOR STEEL AND STEEL ALLOYS

| Minimum manufactured thickness (US "Manufacturers' Standard Gage for Steel Sheets" or inches) | Nominal decimal equivalent, mm (inches) | Inservice minimum reference, mm (inches) |
|---|---|---|
| 19 gage | 1.06 (0.0418) | 0.97 (0.038) |
| 18 gage | 1.21 (0.0478) | 1.09 (0.043) |
| 17 gage | 1.37 (0.0538) | 1.22 (0.048) |
| 16 gage | 1.52 (0.0598) | 1.37 (0.054) |
| 15 gage | 1.71 (0.0673) | 1.55 (0.061) |
| 14 gage | 1.90 (0.0747) | 1.70 (0.067) |
| 13 gage | 2.28 (0.0897) | 2.06 (0.081) |
| 12 gage | 2.66 (0.1046) | 2.39 (0.094) |
| 11 gage | 3.04 (0.1196) | 2.74 (0.108) |
| 10 gage | 3.42 (0.1345) | 3.07 (0.121) |
| 9 gage | 3.80 (0.1495) | 3.43 (0.135) |
| 8 gage | 4.18 (0.1644) | 3.76 (0.148) |
| 7 gage | 4.55 (0.1793) | 4.09 (0.161) |
| 3/16 inch | 4.76 (0.1875) | 4.29 (0.169) |
| 1/4 inch | 6.35 (0.2500) | 5.72 (0.225) |
| 5/16 inch | 7.94 (0.3125) | 7.14 (0.281) |
| 3/8 inch | 9.53 (0.3750) | 8.59 (0.338) |

**TABLE S6.13.1-b**
INSERVICE MINIMUM THICKNESSES FOR ALUMINUM AND ALUMINUM ALLOYS

| Minimum manufactured thickness, mm (inches) | Inservice minimum thickness, mm (inches) |
|---|---|
| 1.98 (0.078) | 1.78 (0.070) |
| 2.21 (0.087) | 1.98 (0.078) |
| 2.44 (0.096) | 2.18 (0.086) |
| 2.77 (0.109) | 2.49 (0.098) |
| 3.30 (0.130) | 2.97 (0.117) |
| 3.58 (0.141) | 3.23 (0.127) |
| 3.84 (0.151) | 3.45 (0.136) |
| 4.37 (0.172) | 3.94 (0.155) |
| 4.39 (0.173) | 3.96 (0.156) |
| 4.93 (0.194) | 4.44 (0.175) |
| 5.49 (0.216) | 4.93 (0.194) |
| 6.02 (0.237) | 5.41 (0.213) |
| 6.86 (0.270) | 6.17 (0.243) |
| 9.14 (0.360) | 8.23 (0.324) |
| 11.40 (0.450) | 10.30 (0.405) |
| 13.70 (0.540) | 12.30 (0.486) |



## S6.13.2 INSPECTION OF PIPING, VALVES, AND MANHOLES

The cargo tank piping, valves, and gaskets must be carefully inspected for corroded areas and the piping system and valve attachment welds or threads must be inspected for corrosion, leakage, or any other defects that might render the cargo tank unsafe for transportation service. This examination shall include:

a) All devices for securing manhole covers must be in satisfactory working condition, and the area must not show any evidence of leakage at either the manhole cover or the manhole gasket;

   1) When inspecting gaskets on any full opening of the cargo tank, the inspector should visually examine the gasket for defects to include cracks and/or splits that may prevent the gasket material from sealing properly;

   2) If the gasket shows any evidence of cuts or cracks that are likely to cause failure, the gasket shall be replaced;

b) All emergency devices and valves including self-closing stop valves, excess flow valves, and remote closure devices must be free of corrosion, distortion, erosion, and any external damage that will prevent safe operation of the cargo tank. Remote closure devices and self-closing stop valves must be operated during inspection to demonstrate that the devices are operating as designed;

c) Any missing bolts, nuts, and fusible links or elements shall be replaced. Loose bolts and nuts must be tightened;

d) All re-closing pressure relief valves shall be externally inspected for any corrosion or damage that might prevent the device from operating as designed;

1) All re-closing pressure relief valves on cargo tanks carrying lading corrosive to the pressure relief valve shall be removed from the cargo tank for inspection and testing;

2) Each re-closing pressure relief valve required to be removed and tested as specified in d) 1) above must open at the required test pressure and reseat to a leak-tight condition at 90% of the set-to-discharge pressure or the pressure prescribed for the applicable cargo tank specifications.

### S6.13.3 INSPECTION OF APPURTENANCES AND STRUCTURAL ATTACHMENTS

a) Major appurtenances, as defined in CFR 49, 180.407 (d)(2)(viii), include but are not limited to suspension system attachments, connecting structures, and those elements of the upper coupler (kingpin) assembly that can be inspected without dismantling the upper coupler (kingpin) assembly. Major appurtenances shall be inspected for any corrosion or damage that might prevent safe operations.

b) If the cargo tank transports lading that is corrosive to the cargo tank, the upper coupler (kingpin) assembly must be inspected at least once in a two-year period. The upper coupler (kingpin) shall be removed for inspection of the following:

1) Corroded and abraded areas;

2) Dents;

3) Distortions;

4) Weld failures; and

5) Any other condition that might render the cargo tank unsafe for transportation service.

c) If the cargo tank is constructed of mild-or high-strength low-alloy steel and employs ring stiffeners or other appurtenances that create air cavities adjacent to the ring stiffeners or other appurtenances to the cargo tank's shell and these areas cannot be visually externally inspected, then the following shall be performed:

1) A thickness test on the stiffener rings shall be performed at least once every two years of at least four symmetrically distributed readings to establish an average thickness for the ring stiffener or appurtenance. The thickness requirements are specified in NBIC Part 2, Tables S6.13.1-a or S6.13.1-b, as applicable;

2) If any of the thickness testing readings for the ring stiffeners are less than the average thickness by more than 10%, thickness testing must be performed from inside the transport tank on the area of the tank wall covered by the appurtenance or ring stiffener. If the results of the thickness test of the transport tank fail to conform to the minimum thickness requirements prescribed for the design as manufactured, the tank must be repaired or removed from hazardous material service. The owner of the transport tank can de-rate the tank to transport authorized material and reduced maximum weight of lading, reduce pressure, or a combination thereof under the following conditions:

a. The reduced loadings, based on the cargo tank's design conditions and material thicknesses, are appropriate for the reduced loading conditions. This reduced loading shall be certified by a Design Certifying Engineer, and a revised manufacturer's certificate shall be issued reflecting these reduced loading conditions;

b. The cargo tank motor vehicle's manufacturer's nameplate shall be revised to reflect the reduced limits;

c. If a. and b. above cannot be satisfied, the owner of the cargo tank should not return the cargo tank to hazardous material service. The owner shall remove, or obliterate, or in a secure manner cover the tank's specification plate; and

d. The Inspector shall record the results of the thickness test on the cargo tank's inspection report.

### S6.13.4 VISUAL INTERNAL INSPECTION

When performing an internal visual inspection of a cargo tank and the cargo tank is equipped with a manhole or an inspection opening, the Inspector shall examine the internal surfaces for corroded and abraded areas, dents, distortions, defects in welds, and any other conditions that might render the cargo tank unsafe for transportation service. As a minimum the inspection shall include:

a) The internal surfaces of the cargo tank shell and heads, and appurtenances such as baffles, clips, pads, piping or other internals;

b) Linings or coatings installed to prevent corrosion to the cargo tank wall shall be inspected in accordance with NBIC Part 2, S6.13.5 and Table S6.13.4;

c) When baffle assemblies prevent access required to perform the inspection of the interior surfaces of the cargo tanks or other interior appurtenances, either the entire baffle assembly or part thereof shall be detached to allow access or, other alternative means of inspection such as the use of boroscopes or cameras must be utilized;

d) For cargo tanks equipped with baffle assemblies, the baffle panels and the means of their attachment to the cargo tank wall shall be inspected for: weld defects, cracks, corrosion, deterioration at point of attachment, loose bolting, distortion or any other condition that might affect the structural integrity of the baffle assembly:

   1) Baffle panels that cannot be inspected, as installed, shall be detached or removed for inspection;

   2) Cracked or corroded baffle clips shall be replaced with material whose properties are equivalent to the material used for the cargo tank wall or material approved by a Design Certifying Engineer;

   3) For baffle clips welded directly to the cargo tank wall on tanks constructed of quenched and tempered steel, the clip shall be examined for cracks using surface Non Destructive Examination (NDE) methods such as PT and MT. The attachment weld to the cargo tank wall shall be examined for cracks using the Wet Fluorescent Magnetic Particle method. NDE must be in accordance with Section V of the ASME Code;

   4) Damaged or worn baffle panels shall be repaired or replaced. Particular attention must be given to bolt holes that are enlarged from original shape or size. Bolting that is worn shall be replaced;

e) If the cargo tank is not equipped with a manhole or inspection opening, or is welded closed and the cargo tank has not transported a lading that is corrosive to the cargo tank wall, it shall be subjected to a pressure test as provided in NBIC Part 2, Tables S6.13.4 and S6.13.6.

**TABLE S6.13.4**
PERIODIC INSPECTIONS AND TESTS

| Test or Inspection (cargo tank specification, configuration, and service) | Test and Inspection Interval After Original Certification Date |
|---|---|
| **External Visual Inspection** | |
| All cargo tanks designed to be loaded by vacuum with full opening rear heads | 6 Months |
| All other cargo tanks | 1 Year |
| **Internal Visual Inspection** | |
| All insulated cargo tanks, except MC 330, MC 331, & MC 338 | 1 Year |
| All cargo tanks transporting lading corrosive to the tank | 1 Year |
| All other cargo tanks, except MC 338 | 5 Years |
| **Lining Inspection** | |
| All lined cargo tanks transporting lading corrosive to the cargo tank | 1 Year |
| **Leakage Test** | |
| MC 330 and MC 331 cargo tanks in chlorine service | 2 Years |
| All other cargo tanks, except MC 338 | 1 Year |
| **Pressure Test (Note 1: sodium metal; Note 2: MAWP < 15 psig)** | |
| All cargo tanks which are insulated with no manhole or insulated and lined, except MC 338 | 1 Year |
| All cargo tanks designed to be loaded by full vacuum with full opening in the rear head of the cargo tank | 2 Years |
| MC 330 and MC 331 cargo tanks in chlorine service | 2 Years |
| All other cargo tanks | 5 Years |
| **Thickness Test** | |
| All unlined cargo tanks in corrosive service, except MC 338 | 2 Years |

**Note 1:**

Pressure testing is not required for MC 300 and MC 331 cargo tanks in dedicated sodium metal service.

**Note 2:**

Pressure testing is not required for uninsulated lined cargo tanks with a design pressure of MAWP 103 kPa (15 psi) or less, which receive an external visual inspection and lining inspection at least once each year.

## S6.13.5 LINING INSPECTIONS

Cargo tank linings include rubber linings and linings other than rubber (elastomeric materials) that are used to protect the tank from corrosion or other harmful effects of the lading material being transported. The inspection requirements are:

a) Rubber linings must be inspected for holes by using a high-frequency spark tester, as described in this section. If holes are found, they must be repaired using equipment and procedures prescribed by the lining manufacturer or lining installer;

b) Linings other than rubber (elastomeric materials) must be inspected and tested in accordance with procedures using equipment and procedures prescribed by the lining manufacturer or lining installers; and

c) If degraded or defective areas of the cargo tank lining are discovered, the lining in these areas shall be removed and the thickness of the cargo tank wall area under the lining defect shall be tested in accordance with the following:

   1) Measurements shall be made using a device capable of accurately measuring thickness to within ± 0.051 mm (± 0.002 of an inch);

   2) The individuals performing the thickness test must be trained in the proper use of the thickness testing device in accordance with the manufacturer's instructions; and

   3) The minimum inservice thickness requirements for series MC 300 cargo tanks for steel and steel alloy and aluminum and aluminum alloy material is specified in NBIC Part 2, Tables S6.13.1-a and S6.13.1-b.

## S6.13.6 PRESSURE TESTS

Cargo tanks may be tested by either the hydrostatic or pneumatic test method. When performing a pressure test, the test procedure shall include the test method (hydrostatic or pneumatic) used for the cargo tank, and the test shall include all appurtenances, all baffles, bulkheads, and upper coupler (fifth wheel) that comprise the cargo tank and shall be pressure tested at pressures established in NBIC Part 2, Table S6.13.6. The pressure test procedure shall include the following:

a) The pressure test shall be performed in accordance with a test pressure that includes provision for the inspector to perform an internal and external visual inspection of all surfaces of the cargo tank. For MC 338 cargo tanks, and cargo tanks not equipped with a manhole, an internal visual inspection is not required.

   1) The visual external inspection shall be conducted while the cargo tank is under test pressure.

   2) The visual internal inspection shall be conducted after the pressure test is completed.

b) When performing the pressure test all self-closing pressure relief valves, including emergency relief vents, and normal vents shall be removed for inspection and test, except for line safety devices that may be removed or left in place.

   1) Each self-closing pressure relief valve that is an emergency relief vent shall be capable of opening at the required set pressure and seat to a leak-tight condition at 90% of the set-to-discharge pressure, or the pressure prescribed for the applicable cargo tank. It should be noted that self-closing pressure relief valves not tested or failing the pressure test must be repaired or replaced.

   2) Normal vents 6.895 kPa (1 psig) shall be tested according to the testing criteria established by the valve manufacturer.

c) If the cargo tank is not carrying a corrosive lading, all areas that are covered by the upper coupler (fifth wheel) assembly must be inspected for corroded, abraded areas, dents, distortions, defects in welds, and any other condition that might render the tank unsafe for transport service. The upper coupler (fifth wheel) assembly must be removed from the cargo tank for this inspection.

d) If the cargo tank motor vehicle has multiple cargo tanks, each cargo tank shall be tested separately. The adjacent cargo tanks shall be empty and at atmospheric pressure.

e) When performing the hydrostatic or pneumatic test, the following requirements shall be specified in the test procedure:

1) All closures, except the pressure relief device, shall be in place during the test;

2) All required loading and unloading venting devices that are rated less than the test pressure may be removed during the test, or:

a. If the venting devices are not removed, the device shall be rendered inoperative by clamps, plugs, or other equally effective restraining devices;

b. The restraining devices shall not prevent detection of leaks or damage of the venting device and shall be removed immediately after the test.

**TABLE S6.13.6**
PRESSURE TEST REQUIREMENTS

| Cargo Tank Specification | Test Pressure |
|---|---|
| MC 300, MC 301, MC 302, MC 303, MC 305, and MC 306 | 20.7 kPa (3 psig) or design pressure, whichever is greater |
| MC 304 and MC 307 | 275.8 kPa (40 psig) or 1.5 times design pressure, whichever is greater |
| MC 310, MC 311, and MC 312 | 20.7 kPa (3 psig) or 1.5 times design pressure, whichever is greater |
| MC 330 and MC 331 | 1.5 times either MAWP or the re-rated pressure, whichever is applicable |
| MC 338 | 1.25 times either MAWP or the re-rated pressure, whichever is applicable |
| DOT 406 | 34.5 kPa (5 psig) or 1.5 times the MAWP, whichever is greater |
| DOT 407 | 275.8 kPa (40 psig) or 1.5 times the MAWP, whichever is greater |
| DOT 412 | 1.5 times the MAWP |



### S6.13.6.1 HYDROSTATIC OR PNEUMATIC TEST METHOD

a) The owner or user of the cargo tank may apply either the hydrostatic or pneumatic test method to satisfy the requirements of the pressure test specified in NBIC Part 2, Table S6.13.4.

b) If the hydrostatic test method is used, the cargo tank shall be completely filled including, if equipped, its dome with water or other liquids having similar viscosity. During the hydrostatic test, the Inspector shall:

1) Ensure that the cargo tank is completely filled and free of any air pockets. During this operation, the liquid should flow freely out of the cargo tank's test vent;

2) Ensure that the temperature of the test media does not exceed 38°C (100°F);

3) Ensure that the test pressure cannot exceed the test pressures specified in NBIC Part 2, Table S6.13.6;

4) Ascertain that the test pressure shall be maintained for a minimum of 10 minutes; and

5) Visually examine the cargo tank for leakage, bulging or other defects. If any of the preceding occurs, terminate the test, drain the cargo tank, and evaluate the cargo tank's capabilities for repair or replacement of the affected areas.

c) If the owner and/or user elect to use the pneumatic test method, precaution should be employed due to the possibility of failure of the cargo tank under pneumatic test pressure conditions. The test area should be limited to the authorized personnel only and the test personnel shall be experienced in the pneumatic testing method. The pneumatic test pressure for the cargo tank shall be:

1) Gradually increased to one-half the test pressure;

2) After reaching one-half the test pressure, the test pressure shall be increased at a rate of approximately one-tenth of the test pressure until the test pressure is reached. The test pressure shall not exceed the test pressures specified in NBIC Part 2, Table S6.13.6;

3) When the test pressure is reached, the test pressure shall be held for a least 5 minutes, then reduced to the MAWP of the cargo tank;

4) At MAWP the inspector shall examine the cargo tank for any leakage, bulging, or any other defects; and

5) Visually examine the cargo tank for leakage, bulging, or other defects. If any of the preceeding occurs, terminate the test, drain the cargo tank of all air or inert gas, and evaluate the cargo tank's suitability for repairs or replacement of the affected areas.

### S6.13.6.2 PRESSURE TESTING INSULATED CARGO TANKS

a) When pressure testing an insulated cargo tank, the insulations and jacketing are not required to be removed, unless it is not possible to reach the test pressure and maintain a condition of pressure equilibrium after the test pressure is reached, or the vacuum integrity cannot be maintained in the insulation space.

b) For MC 338 cargo tanks that transport refrigerated liquid, flammable gas, or oxygen, if the cargo tank is opened for any reason, the cleanliness of the cargo tank shall be verified prior to closure as required by CFR Title 49, Part 178.338-15.



### S6.13.6.3 PRESSURE TESTING CARGO TANKS CONSTRUCTED OF QUENCHED AND TEMPERED STEELS

When testing MC 330 and MC 331 cargo tanks constructed of quenched and tempered steels, in accordance with ASME Section XII, Modal Appendix 1, and for cargo tanks constructed prior to the adoption of ASME Section XII, Part UHT of ASME Section VIII, Div. 1, or constructed of other quenched and tempered steel, without postweld heat treatment, used for the transportation of anhydrous ammonia or any other hazardous material that are subject to stress corrosion cracking, and the transportation of liquefied petroleum gas, the following is required:

a) The cargo tanks must be subjected to an internal visual inspection of all internal surfaces of the cargo tank using the wet fluorescent magnetic particle examination method immediately prior to performing the required pressure test.

b) The fluorescent magnetic particle examination has to be performed in accordance with ASME Section V.

c) The required pressure test as specified in NBIC Part 2, Table S6.13.4 shall be required.

### S6.13.6.4 PRESSURE TESTING CARGO TANKS EQUIPPED WITH A HEATING SYSTEM

If the cargo tank is equipped with a heating system, employing a medium such as, but not limited to, steam or hot water hydrostatically, pressure is as follows:

a) The cargo tank must be tested at least once every 5 years;

b) The test pressure for the heating system shall be at least to the maximum system design operating pressure;

c) The test pressure shall be maintained for a least 5 minutes; and

d) If the heating system employs flues for heating the lading, the flues must be tested to ensure that the lading cannot leak into the flues or into the atmosphere.

### S6.13.6.5 EXCEPTIONS TO PRESSURE TESTING

a) MC 330 and MC 331 cargo tanks that are in dedicated sodium metal service are not required to be pressure tested.

b) Un-insulated cargo tanks, with a design pressure or MAWP of 103 kPa (15 psig) or less, which can be externally visually inspected and a lining inspection at least once every 5 years, are not required to be pressure tested.

### S6.13.6.6 ACCEPTANCE CRITERIA

a) The acceptance criteria for the hydrostatic or pneumatic pressure test of the heating system is based on the cargo tank's capabilities to successfully pass the pressure test, without showing evidence of permanent distortion or other evidence of weakness that might render the cargo tank unsafe for transportation service.

b) If the cargo tank does not satisfy the requirements for the pressure test of the heating system identified in a) above, the cargo tank cannot be returned to transportation service, unless:

   1) Cargo tanks with a heating system, which does not hold pressure, should remain inservice as an unheated cargo tank, if the heating system remains in place and is structurally sound and no lading may leak into the heating system; and

   2) The specification information for the heating system on the nameplate is changed to indicate that the cargo tank has no working heating system.

### S6.13.6.7 INSPECTION REPORT

a) The Inspector shall prepare a written inspection report that identifies the results of the pressure test and specifies the following:

   1) Manufacturer's serial number of the cargo tank;

   2) Name of the cargo tank manufacturer;

   3) DOT or MC specification number;

   4) MAWP of the cargo tank;

   5) Minimum thickness of the head and shell of the cargo tank;

   6) Identify whether the cargo tank is lined, insulated, or both; and

   7) Identify if the cargo tank is for special service, i.e., transport material corrosive to the cargo tank, dedicated service, etc.

b) The written inspection report shall provide for the following additional information:

   1) The type of test or inspection performed; and

   2) Date of the test or inspection (month and year).

c) Listing of all items tested or inspected, including information about pressure relief valve:

1) If the relief valve is removed, inspected and tested, or replaced;

2) If applicable, the type of device;

3) Set to discharge pressure at which the device will reseat; or

4) If the device was reinstalled, repaired, or replaced.

d) Information regarding the inspection of the upper coupler (fifth wheel) assembly, and when applicable:

1) If the coupler assembly (fifth wheel) was visually inspected in place; or

2) If the coupler assembly (fifth wheel) was removed for examination.

e) Information regarding leakage, and type of pressure test (hydrostatic or pneumatic);

f) The test pressure and holding time during the test;

g) Location of defects found and the method of repair;

h) Minimum thickness of the cargo tank's heads and shells, as specified in NBIC Part 2, Table S6.13.1-a or Table S6.13.1-b, as applicable;

1) Name and address of the person performing the test;

2) Registration number of the facility or person performing the test;

3) Continued qualification statement, such as:

a. "Cargo tank meets the requirements of DOT specification identified in this report."

b. "Cargo tank fails to meet the requirements of the DOT specification identified in this report."

i) DOT registration number of the Registered Inspector, and dated signature of the Registered Inspector and the cargo tank owner.

j) The owner and the motor carrier shall retain a copy of the test and inspection reports until the next test or inspection of the same type is successfully completed. This requirement does not apply to a motor carrier leasing a cargo tank for fewer than 30 days.



## S6.13.7 ADDITIONAL REQUIREMENTS FOR MC 330 AND MC 331 CARGO TANKS

After completion of the pressure test, each motor carrier operating a Specification MC 330 and MC 331 cargo tank in anhydrous ammonia, liquefied petroleum gas, or any other service that is prone to stress corrosion cracking, shall make a written report containing the following information:

a) Carrier's name, address of principal place of business, and telephone number;

b) Complete identification plate data required by Specification MC 330 and MC 331 cargo tanks, including data required by the *ASME Boiler and Pressure Vessel Code*;

c) Carrier's equipment number;

d) Statement indicating whether or not the cargo tank was stress relieved after fabrication;

e) Name and address of the person performing the test and date of the test;

f) Statement of the nature and severity of any defects found. As a minimum, the information shall include:

1) Identification of the location of the defects detected, such as in weld, heat-affected zone, the liquid phase, the vapor phase, or the head to shell seam; or

2) If no defects or damage were discovered, this also shall be reported.

g) Statement indicating the methods employed to make repairs; that made the repairs; and the date the repairs were completed. If the cargo tank was stress relieved after the repairs were completed, whether full or local stress relieving was performed;

h) Statement of the disposition of the cargo tank, such as:

1) "cargo tank scrapped"; or

2) "cargo tank returned to service."

i) Statement as to whether or not the cargo tank is used in anhydrous ammonia service that is subject to stress corrosion cracking. If the cargo tank had been used in anhydrous ammonia service since the last report, the owner has to provide a statement in the report indicating whether each shipment of ammonia was certified by its shipper as containing at least 0.2% water by weight.

j) A copy of the written inspection report must be retained by the carrier at its principal place of business during the period the cargo tank is in the carrier's service and for one year thereafter.

k) Upon written request to, and with the approval of the Field Administrator, Regional Service Center, and Federal Motor Carrier Safety Administration for the region in which a motor carrier has its principal place of business, the carrier may maintain the reports at a regional or terminal office.

## S6.13.8 CERTIFICATES AND REPORTS

a) Each person offering a DOT specification cargo tank for sale or lease must provide the purchaser or lessee with the following:

1) A copy of the cargo tank certificate of compliance;

2) If applicable, a copy of the record of repair, modification, stretching, or rebarrelling; and

3) The most recent inspection and test reports.

b) Copies of the documents and reports identified in a) above must be provided to the lessee if the cargo tank is leased for more than 30 days.

## S6.13.9 LEAKAGE TEST

When leakage testing is required by NBIC Part 2, Table S6.13.4, the test shall include testing the product piping with all valves and accessories in place and operative, except that any venting devices set to discharge at less than the leakage test pressure must be removed or rendered inoperative during the test. The leakage test shall include:

a) All internal or external self-closing stop valves must be tested for leakage;

b) Each cargo tank of a multi-cargo tank motor vehicle must be tested with the adjacent cargo tanks empty and at atmospheric pressure;

c) The leakage test shall be maintained for a minimum of 5 minutes;

d) Cargo tanks in liquefied compressed gas service shall be:

1) Inspected externally for leaks during the leakage test;

2) Suitable safeguards must be provided to protect personnel should a failure occur, as follows:

   a. Cargo tanks may be leakage tested with the hazardous material in the cargo tank during the test;

   b. The leakage test pressure shall not be less than 80% of the MAWP marked on the specification plate, unless the cargo tank has a MAWP of 690 kPa (60 psig) or more, in which case it should be leakage tested at its maximum normal operating pressure provided it is in dedicated service or services;

   c. MC 330 or MC 331 cargo tanks in dedicated liquefied petroleum gas service may be leakage tested at not less than 414 kPa (60 psig);

   d. An operator of a MC 330 or MC 331 cargo tank and a non-specification cargo tank equipped with a meter should check leak tightness of the internal self-closing stop valve by conducting a meter creep test; and

   e. A non-specification cargo tank is a cargo tank that conforms and is marked in conformance with the edition of the ASME Code in effect when the cargo tank was fabricated and should be used for the transportation of liquefied petroleum gas, provided the cargo tank satisfies the following:

      1. The cargo tank has a minimum design pressure no lower than 172 kPa (250 psig);

      2. The cargo tank has a water capacity of 13,250 l (3,500 gallons) or less.

3) The cargo tank has been manufactured in accordance with the ASME Code prior to January 1, 1981. This requirement requires the cargo tank to be stamped with the ASME Code Symbol Stamp and documented on an ASME Manufacturer's Data Report;

4) The cargo tank shall conform to the applicable provisions of NFPA 58, except if NFPA is inconsistent with the requirements of Parts 178 and 180 of Title 49;

5) The cargo tank shall be leakage tested in accordance with NBIC Part 2, Table S6.13.4;

6) MC 330 and MC 331 cargo tanks in dedicated service for anhydrous ammonia may be leakage tested at not less than 414 kPa (60 psig);

7) Non-specification cargo tanks must be leakage tested at pressure of not less than 16.6 kPa (2.4 psig), if the cargo tanks comply with one of the following:

   a. For the transport of petroleum products that have a liquid capacity of 13,250 l (3,500 gal); and

   b. Permanently secured non-bulk tanks to a motor vehicle and protected against leakage or damage in the event of turnover, having a liquid capacity of less than 450 l (119 gal), used for transportation of a flammable liquid petroleum product.

8) The cargo tank is used to transport petroleum distillate fuels that are equipped with vapor collection equipment and should be leakage tested in accordance with the Environmental Protection Agency's "Model 27-Determination of Vapor Tightness of Gasoline Delivery Tank Using Pressure-Vacuum Test," as follows:

   a. The test method and procedures and maximum allowable pressure and vacuum changes are in 40 CFR 63.425(e)(1);

   b. The hydrostatic test alternative, using liquid in Environmental Protection Agency's "Method 27-Determination of Vapor Tightness of Gasoline Delivery Tank Using Pressure-Vacuum Test" should not be used to satisfy the leak testing requirements of this Section. The test shall be conducted using air; and

c. Cargo tanks equipped with vapor collection equipment should be leakage tested in accordance with 8) b. above.

9) Cargo tanks that fail to retain leakage test pressure shall not be returned to service as a specification cargo tank, unless all sources of leakage are properly repaired prior to returning the cargo tank to hazardous material service.

10) It is required that after July 1, 2000, that the Registered Inspector who performs inspections on MC 330 and MC 331 cargo tanks inspect the delivery hose assembly and the piping system of the cargo tank under leakage test pressure utilizing the rejection criteria for cargo tanks unloading liquefied compressed gas. It should be noted that an operator should remove and replace damaged sections or correct defects discovered as provided in NBIC Part 2, S6.13.10. If any of the following is discovered, it is cause for rejection:

a. No operator shall use a delivery hose assembly for liquefied compressed gas if it is determined that any of the following conditions exist:

1. Damage to the hose cover that exposes the reinforcement;

2. If the wire braid reinforcement is kinked or flattened so as to permanently deform the wire braid;

3. Soft spots when the hose is not under pressure, or any loose outer covering on the hose;

4. Damaged, slipping, or excessively worn hose couplings; and

5. Loose or missing bolts or fastenings on the bolted hose coupling assembly.

b. No operator can use a cargo tank with a piping system for unloading liquefied compressed gases if any of the following conditions exist:

1. Any external leaks identifiable without the use of instruments;

2. Bolting that is loose, missing, or severely corroded;

3. Manual stop valves that will not actuate; and

4. Rubber hose flexible connectors with any of the following conditions:

a. Damage to the hose cover that exposes the reinforcement;

b. If the wire braid reinforcement is kinked or flattened so as to permanently deform the wire braid;

c. Soft spots when the hose is under pressure, or any loose outer covering on the hose;

d. Damaged, slipping, or excessively worn hose couplings;

e. Loose or missing bolts or fastenings on the bolted hose coupling assembly;

f. Stainless steel flexible connectors with damaged reinforcement braid;

g. Internal self-closing stop valves that fail to close or that permit leakage through the valve detectable without the use of instruments; or

h. Pipes or joints that are severely corroded.

### S6.13.10 NEW OR REPLACED DELIVERY HOSE ASSEMBLIES

The operator shall repair hose assemblies and place the cargo tank back in service if retested successfully in accordance with the following:

a) The new and/or replaced hose assembly is tested at a minimum of 120% of the hose's MAWP;

b) The operator shall visually examine the delivery hose assembly while it's under pressure;

c) If the test is successful, the operator shall ensure that the delivery hose assembly is permanently marked with the month and year of the test; and

d) It should be noted that after July 1, 2000, the operator shall complete a record documenting the test and inspection, which shall include the following:

   1) The date and signature of the Inspector that performed the inspection;

   2) The owner of the hose assembly;

   3) The hose identification number;

   4) The date of the original delivery of the hose assembly and tests;

   5) Notes of any defects observed;

   6) Any repairs that may have been made; and

   7) Identification in the written report that the delivery hose assembly passed or failed the tests and inspections.



### S6.13.10.1 THICKNESS TESTING

a) Thickness testing of the head and shell of unlined cargo tanks used for the transportation of materials corrosive to the cargo tank shall be measured at least once every two years.

b) Cargo tanks measuring less than the sum of the minimum prescribed thickness in NBIC Part 2, Tables S6.13.1-a or S6.13.1-b, as applicable, plus one-fifth of the original corrosion allowance, shall be tested annually.

### S6.13.10.2 TESTING CRITERIA

The testing criteria that shall be used for these requirements are as follows:

a) The measuring device shall be capable of accurately measuring thickness to within ± .50mm (.002 inch);

b) The individuals performing thickness testing shall be trained in the proper use of the thickness testing device used in accordance with the testing device manufacturer's instructions;

c) Thickness testing shall be performed in the following areas, as a minimum:

   1) Areas of the tank shell and heads, including around any piping that retains lading;

   2) Areas of high shell stress, such as the bottom center of the cargo tank;

   3) Areas near openings;

   4) Areas around weld joints;

5) Areas around shell reinforcements;

6) Areas around appurtenance attachments;

7) Areas near the upper coupler (fifth wheel) assembly attachments;

8) Areas near suspension system attachments and connecting structures;

9) Known thin areas in the tank shell and nominal liquid level lines; and

10) Connecting structures joining multiple cargo tanks of carbon steel in a self-supporting cargo tank motor vehicle.

### S6.13.10.3 THICKNESS REQUIREMENTS

a) The minimum thickness for MC 300, MC 301, MC 302, MC 303, MC 304, MC 305, MC 306, MC 307, MC 310, and MC 312 cargo tanks are determined based on the definition of minimum thickness defined in CFR, Title 49, Part 178.320(a).

b) NBIC Part 2, Tables S6.13.1-a and S6.13.1-b, identify the “Inservice Minimum Thickness” values to determine the minimum thickness for the referenced cargo tank.

c) The tables are divided into three columns. The column headed “Minimum Manufactured Thickness” indicates the minimum values required for new construction of DOT 400 series cargo tanks.

d) The “Inservice Minimum Thicknesses” for cargo tanks specified in (a) above are based on 90% of the manufactured thickness specified in the DOT Specification, rounded off to three places.

## S6.13.11 CARGO TANKS THAT NO LONGER CONFORM TO THE MINIMUM THICKNESS REQUIREMENTS IN NBIC PART 2, TABLES S6.13.1-a AND S6.13.1-b

If a cargo tank does not conform to the minimum thickness requirements in NBIC Part 2, Tables S6.13.1-a and S6.13.1-b, for the design as manufactured, the cargo tank should be used at a reduced maximum weight of lading or reduced MAWP, or combinations thereof, provided the following are met:

a) The cargo tank’s design and thickness are appropriate for the reduced loadings conditions as follows:

1) The cargo tank’s design and thickness for the appropriate reduced loading shall be certified by a Design Certifying Engineer;

2) A revised manufacturer’s certificate shall be issued; and

3) The cargo tank’s motor vehicle’s nameplate shall reflect the revised service limits.

b) It is required if a cargo tank no longer conforms with the minimum thickness requirements prescribed in the specification, that the cargo tank cannot be returned to hazardous material service. The cargo tank’s specification plate shall be removed, obliterated, or covered in a secure manner. The inspector shall require that the cargo tank is calculated to identify the thickness of the material as required in NBIC Part 2, S6.13.10.1 and S6.13.10.2, of this Section.

c) MC cargo tanks constructed prior to October 1, 2003, require the minimum thickness, minus the corrosion allowance as provided on the Manufacturer’s Data Report; and

d) MC cargo tanks constructed after October 1, 2003, require the minimum thickness will be the value indicated on the specification plate of the cargo tank. If no corrosion allowance is indicated on the Manufacturer’s Data Report, then the thickness of the cargo tank shall be the thickness of the material of construction indicated on the Manufacturer’s Data Report, with no corrosion allowance.

### S6.13.11.1 MINIMUM THICKNESS FOR 400-SERIES CARGO TANKS

400 series cargo tanks are required to satisfy the minimum thickness requirements as established in Part 178.320(a) of Title 49 for DOT 406 cargo tanks, Part 178.347.2 of Title 49 for DOT 407 cargo tanks and Part 178.348.2 of Title 49 for DOT 412 cargo tanks.

### S6.13.11.2 DOT 406 CARGO TANKS

a) It is required that all head, shell, bulkhead, and baffle materials used in the construction of DOT 406 cargo tanks satisfy Parts A and B of Section II of the *ASME Boiler and Pressure Vessel Code*,except that the following materials are authorized for cargo tanks constructed in accordance with *ASME Boiler and Pressure Vessel Code* that are not stamped with the "U" Code Symbol Stamp must be constructed out of ASTM materials permitted in Part 178.345-2 of Title 49. These materials are as follows:

   1) ASTM A 569;

   2) ASTM A 570;

   3) ASTM A 572;

   4) ASTM A 607;

   5) ASTM A 622;

   6) ASTM A 656; and

   7) ASTM A 715.

b) Aluminum alloys suitable for fusion welding and conforming with the O, H 32, or H 34 temper of one of the following ASTM Specifications may be used for cargo tanks constructed in accordance with the *ASME Boiler and Pressure Vessel Code*:

   1) ASTM B 209, Alloy 5052;

   2) ASTM B 209, Alloy 5086;

   3) ASTM B 209, Alloy 5154;

   4) ASTM B 209, Alloy 5254;

   5) ASTM B 209, Alloy 5454; and

   6) ASTM B 209, Alloy 5652.

c) All heads, bulkheads, and baffles must be of O temper (annealed) or stronger temper. All shell material shall be of H 32, or H 34 temper, except that the lower ultimate strength temper should be used if the minimum shell thicknesses in the tables are increased in proportion to the lesser ultimate strength.

d) NBIC Part 2, Table S6.13.11.2-a, specifies the minimum thickness requirements for heads or bulkheads and baffles when used as tank reinforcement that is based on the volume capacity in liters per mm (gallons per inch) of length for MC 406 cargo tanks constructed out of Mild Steel (MS), High-Strength Low -Alloy Steel (HSLA), Austenitic Stainless Steel (SS), or Aluminum (AL).

e) NBIC Part 2, Table S6.13.11.2-b specifies the minimum thickness requirements for shell based on the cargo tank motor vehicle rated capacity in gallons when the cargo tank is constructed out of Mild Steel (MS), High-Strength Low-Alloy Steel (HSLA), Austenitic Stainless Steel (SS), or Aluminum (AL). The thickness requirements in these tables are specified in decimal of a mm (inch) after forming.

**TABLE S6.13.11.2-a**
MINIMUM THICKNESS FOR HEADS

| Materials | Volume capacity in liter per mm of length (gallons per inch of length) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 14 (0.21) or less | | | Over 14 to 23 (0.21 to 0.36) | | | Over 23 (0.36) | | |
| | MS | HSLA SS | AL | MS | HSLA SS | AL | MS | HSLA SS | AL |
| Thickness, mm (in.) | 2.54 (.100) | 2.54 (.100) | 4.06 (0.160) | 2.92 (0.115) | 3.94 (.155) | 4.39 (0.173) | 3.28 (.129) | 3.28 (.129) | 4.75 (0.187) |

**TABLE S6.13.11.2-b**
MINIMUM THICKNESS FOR SHELLS, IN. (MM)

| Cargo tank motor vehicle rated capacity in liters (gallons) | MS | SS/HSLA | AL |
|---|---|---|---|
| More than 0 to at least 4,500 (0 to 17,000) | 2.54 (0.100) | 2.54 (0.100) | 3.84 (0.151) |
| More than 4,500 to at least 8,000 (17,000 to 30,300) | 2.92 (0.115) | 2.54 (0.100) | 4.06 (0.160) |
| More than 8,000 to at least 14,000 (30,300 to 53,000) | 3.28 (0.129) | 3.28 (0.129) | 4.39 (0.173) |
| More than 14,000 (53,000) | 3.63 (0.143) | 3.63 (0.143) | 4.75 (0.187) |
| Note: The maximum distance between bulkhead, baffles, or ring stiffeners shall not exceed 1,525 mm (60 inches) | | | |

## S6.13.11.3 DOT 407 CARGO TANKS

a) It is required that the type of materials used for DOT 407 cargo tanks, depending on the type of media being transferred be either Mild Steel (MS), High-Strength Low-Alloy Steel (HSLA), Austenitic Stainless Steel (SS), or Aluminum.

b) The minimum required thicknesses of materials specified in NBIC Part 2, Table S6.13.11.3-a, for DOT 407 cargo tanks, when the minimum thickness requirements are based on the volume capacity in liters per sq mm (gallons per square inch) for the cargo tank's heads, or bulkheads and baffles, when these items are used for reinforcement purposes. All thicknesses are expressed in decimals of a mm (inch) after forming.

c) The minimum required thicknesses of materials are specified in NBIC Part 2, Table S6.13.11.3-b, for DOT 407 cargo tanks, when the minimum thickness requirements are based on the volume capacity in liters per sq. mm (gallons per square inch) for the cargo tank shell. All thicknesses are expressed in decimals of a mm (inch) after forming.

**TABLE S6.13.11.3-a**
MINIMUM THICKNESS FOR HEADS (DOT 407), MM (IN.)

| Volume capacity sq. mm (in gal./sq. in. l/) | 10 (0.122) or less | Over 10 to 14 (0.122 to 0.171) | Over 14 to 18 (0.171 to 0.22) | Over 18 to 22 (0.22 to 0.268) | Over 22 to 26 (0.268 to 0.317) | Over 26 to 30 (0.317 to 0.365) | Over 30 (0.365) |
|---|---|---|---|---|---|---|---|
| Thickness (MS) | 2.54 (0.100) | 2.54 (0.100) | 2.92 (0.115) | 3.28 (0.129) | 3.28 (0.129) | 3.63 (0.143) | 3.96 (0.156) |
| Thickness (HSLA) | 2.54 (0.100) | 2.54 (0.100) | 2.92 (0.115) | 3.28 (0.129) | 3.28 (0.129) | 3.63 (0.143) | 3.96 (0.156) |
| Thickness (SS) | 2.54 (0.100) | 2.54 (0.100) | 2.92 (0.115) | 3.28 (0.129) | 3.28 (0.129) | 3.63 (0.143) | 3.96 (0.156) |
| Thickness (A) | 4.06 (0.160) | 4.06 (0.160) | 4.39 (0.173) | 4.75 (0.187) | 4.92 (0.194) | 5.49 (0.216) | 6.02 (0.237) |

**TABLE S6.13.11.3-b**
MINIMUM THICKNESS FOR SHELLS (DOT 407), MM (IN.)

| Volume capacity in gal./sq. in. (l/sq. mm) | 10 (0.122) or less | Over 10 to 14 (0.122 to 0.171) | Over 14 to 18 (0.171 to 0.22) | Over 18 to 22 (0.22 to 0.268) | Over 22 to 26 (0.268 to 0.317) | Over 26 to 30 (0.317 to 0.365) | Over 30 (0.365) |
|---|---|---|---|---|---|---|---|
| Thickness (MS) | 2.54 (0.100) | 2.54 (0.100) | 2.92 (0.115) | 3.28 (0.129) | 3.28 (0.129) | 3.63 (0.143) | 3.96 (0.156) |
| Thickness (HSLA) | 2.54 (0.100) | 2.54 (0.100) | 2.92 (0.115) | 3.28 (0.129) | 3.28 (0.129) | 3.63 (0.143) | 3.96 (0.156) |
| Thickness (SS) | 2.54 (0.100) | 2.54 (0.100) | 2.92 (0.115) | 3.28 (0.129) | 3.28 (0.129) | 3.63 (0.143) | 3.96 (0.156) |
| Thickness (A) | 3.84 (0.151) | 3.84 (0.151) | 4.06 (0.160) | 4.39 (0.173) | 4.92 (0.194) | 5.49 (0.216) | 6.02 (0.237) |



## S6.13.11.4 DOT 412 CARGO TANKS

a) It is required that the type of materials used for DOT cargo tanks, depending on the type of media being transferred be either Mild Steel (MS), High-Strength Low-Alloy Steel (HSLA), Austenitic Stainless Steel (SS), or Aluminum.

b) The minimum required thickness of materials are specified in NBIC Part 2, Table S6.13.11.4-a, for DOT 412 cargo tanks, when the minimum thicknesses requirements are based on the volume capacity in liters per sq mm (gallons per square inch) for cargo tank heads, or bulkheads and baffles, when these items are used for reinforcement purposes. All thicknesses are expressed in decimals of mm (inch) after forming.

c) The minimum required thicknesses of materials are specified in NBIC Part 2, Table S6.13.11.4-b, for DOT 412 cargo tanks, when the minimum thickness requirements are based on the volume capacity in liters per sq mm (gallons per square inch) for the cargo tank's shell. All thicknesses are expressed in decimals of mm (inch) after forming.

**TABLE S6.13.11.4-a**

MINIMUM THICKNESS FOR HEADS (DOT 412)

| Volume Capacity (gallons per inch) | 10 or less | | | | Over 10 to 14 | | | | Over 14 to 18 | | | 18 and over | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lading density at 60°F in lbs/gal. | 10 lbs and less | Over 10 to 13 lbs | Over 13 to 16 lbs | Over 16 lbs | 10 lbs and less | Over 10 to 13 lbs | Over 13 to 16 lbs | Over 16 lbs | 10 lbs and less | Over 10 to 13 lbs | Over 13 to 16 lbs | 10 lbs and less | Over 10 to 13 lbs | Over 13 to 16 lbs |
| Thickness (inch), steel | 0.100 | 0.129 | 0.157 | 0.187 | 0.129 | 0.157 | 0.187 | 0.250 | 0.157 | 0.250 | 0.250 | 0.157 | 0.250 | 0.312 |
| Thickness (inch), aluminum | 0.144 | 0.187 | 0.227 | 0.270 | 0.187 | 0.227 | 0.270 | 0.360 | 0.227 | 0.360 | 0.360 | 0.227 | 0.360 | 0.450 |

**TABLE S6.13.11.4 M-a**

MINIMUM THICKNESS FOR HEADS (DOT 412)

| Volume Capacity (liters per millimeter) | 0.122 l/mm or less | | | | Over 0.122 to 0.21 l/mm | | | | Over 0.21 to 0.22 l/mm | | | 0.22 l/mm and over | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lading density at 15°C in kg/l | 1.2 kg/l and less | Over 1.2 to 1.6 kg/l | Over 1.6 to 1.9 kg/l | Over 1.9 kg/l | 1.2 kg/l and less | Over 1.2 to 1.6 kg/l | Over 1.6 to 1.9 kg/l | Over 1.9 kg/l | 1.2 kg/l and less | Over 1.2 to 1.6 kg/l | Over 1.6 to 1.9 kg/l | 1.2 kg/l and less | Over 1.2 to 1.6 kg/l | Over 1.6 to 1.9 kg/l |
| Thickness (mm), steel | 2.54 | 3.28 | 3.99 | 4.75 | 3.28 | 3.99 | 4.75 | 6.35 | 3.99 | 6.35 | 6.35 | 3.99 | 6.35 | 7.92 |
| Thickness (mm), aluminum | 3.66 | 4.75 | 5.77 | 6.86 | 4.75 | 5.77 | 6.86 | 9.14 | 5.77 | 9.14 | 9.14 | 5.77 | 9.14 | 11.4 |

**TABLE S6.13.11.4-b**

MINIMUM THICKNESS FOR SHELLS (DOT 412)

| Volume capacity (gallons per inch) | 10 or less | | | | Over 10 to 14 | | | | Over 14 to 18 | | | 18 and over | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lading density at 60°F in pounds per gallon | 10 lbs and less | Over 10 to 13 lbs | Over 13 to 16 lbs | Over 16 lbs | 10 lbs and less | Over 10 to 13 lbs | Over 13 to 16 lbs | Over 16 lbs | 10 lbs and less | Over 10 to 13 lbs | Over 13 to 16 lbs | 10 lbs and less | Over 10 to 13 lbs | Over 13 to 16 lbs |
| Thickness (inch), steel<br>Distances between heads (and bulkheads, baffles, and ring stiffeners when used as tank reinforcement | | | | | 0.129 | 0.157 | 0.187 | 0.250 | 0.157 | 0.250 | 0.250 | 0.157 | 0.250 | 0.312 |
| 36 in. or less | 0.100 | 0.129 | 0.157 | 0.187 | 0.100 | 0.129 | 0.157 | 0.187 | 0.100 | 0.129 | 0.157 | 0.129 | 0.157 | 0.187 |
| Over 36 in. to 54 in. | 0.100 | 0.129 | 0.157 | 0.187 | 0.100 | 0.129 | 0.157 | 0.187 | 0.129 | 0.157 | 0.187 | 0.157 | 0.250 | 0.250 |
| Over 54 in. to 60 in. | 0.100 | 0.129 | 0.157 | 0.187 | 0.129 | 0.157 | 0.187 | 0.250 | 0.157 | 0.250 | 0.250 | 0.187 | 0.250 | 0.312 |
| Thickness (inch), aluminum<br>Distances between heads (and bulkheads, baffles, and ring stiffeners when used as tank reinforcement | 0.144 | 0.187 | 0.227 | 0.270 | 0.187 | 0.227 | 0.270 | 0.360 | 0.227 | 0.360 | 0.360 | 0.227 | 0.360 | 0.450 |
| 36 in. or less | 0.144 | 0.187 | 0.227 | 0.270 | 0.144 | 0.187 | 0.227 | 0.270 | 0.144 | 0.187 | 0.227 | 0.187 | 0.227 | 0.270 |
| Over 36 in. to 54 in. | 0.144 | 0.187 | 0.227 | 0.270 | 0.144 | 0.187 | 0.227 | 0.270 | 0.187 | 0.227 | 0.270 | 0.157 | 0.360 | 0.360 |
| Over 54 in. to 60 in. | 0.144 | 0.187 | 0.227 | 0.270 | 0.187 | 0.227 | 0.270 | 0.360 | 0.227 | 0.360 | 0.360 | 0.270 | 0.360 | 0.450 |

**TABLE S6.13.11.4 M-b**

MINIMUM THICKNESS FOR SHELLS (DOT 412)

| Volume capacity (liters per millimeter) | 0.122 or less | | | | Over 0.122 to 0.21 | | | | Over 0.21 to 0.22 | | | 0.22 and over | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lading density at 15°F in kilograms per liter | 1.2 kgs and less | Over 1.2 to 1.6 kgs | Over 1.6 to 1.9 kgs | Over 1.9 kgs | 1.2 kgs and less | Over 1.2 to 1.6 kgs | Over 1.6 to 1.9 kgs | Over 1.9 kgs | 1.2 kgs and less | Over 1.2 to 1.6 kgs | Over 1.6 to 1.9 kgs | 1.2 kgs and less | Over 1.2 to 1.6 kgs | Over 1.6 to 1.9 kgs |
| Thickness (mm), steel; Distances between heads (and bulkheads, baffles, and ring stiffeners when used as tank reinforcement | | | | | 3.28 | 3.99 | 4.75 | 6.35 | 3.99 | 6.35 | 6.35 | 3.99 | 6.35 | 7.92 |
| 914 mm or less | 2.54 | 3.28 | 3.99 | 4.75 | 2.54 | 3.28 | 3.94 | 4.75 | 2.54 | 3.28 | 3.99 | 3.28 | 3.99 | 4.75 |
| Over 914 mm to 1,372 mm | 2.54 | 3.28 | 3.99 | 4.75 | 2.54 | 3.28 | 3.94 | 4.75 | 3.28 | 3.99 | 4.75 | 3.99 | 6.35 | 6.35 |
| Over 1,372 mm to 1,524 mm | 2.54 | 3.28 | 3.99 | 4.75 | 3.28 | 3.94 | 4.75 | 6.35 | 3.99 | 6.35 | 6.35 | 4.75 | 6.35 | 7.92 |
| Thickness (mm), aluminum; Distances between heads (and bulkheads, baffles, and ring stiffeners when used as tank reinforcement | 3.66 | 4.75 | 5.77 | 6.86 | 4.75 | 5.77 | 6.86 | 9.14 | 5.77 | 9.14 | 9.14 | 5.77 | 9.14 | 11.4 |
| 914 mm or less | 3.66 | 4.75 | 5.77 | 6.86 | 3.66 | 4.75 | 5.77 | 6.86 | 3.66 | 4.75 | 5.77 | 3.66 | 5.77 | 6.86 |
| Over 914 mm to 1,372 mm | 3.66 | 4.75 | 5.77 | 6.86 | 3.66 | 4.75 | 5.77 | 6.86 | 4.75 | 5.77 | 6.86 | 3.99 | 9.14 | 9.14 |
| Over 1,372 to 1,524 mm | 3.66 | 4.75 | 5.77 | 6.86 | 4.75 | 5.77 | 6.86 | 9.14 | 5.77 | 9.14 | 9.14 | 6.86 | 9.14 | 11.4 |

## S6.14 INSPECTION AND TESTS OF PORTABLE TANKS

a) For hazardous material ladings, all portable tanks shall be inspected and tested at frequencies specified in NBIC Part 2, Table S6.14. The inspection and tests shall include visual inspection of external and internal surfaces, leak test, pressure test, thickness measurements, and lining test. It should be noted that the information in NBIC Part 2, S6.14, is a summary of CFR Title 49, Part 180.601 through Part 180.605. The user is responsible for full compliance with the requirements in CFR Title 49, Part 180.601 through Part 180.605.

b) All portable tanks shall be visually inspected (internally, unless otherwise noted, and externally) for any condition that might render the portable tank unsafe for transportation service. The inspection shall include:

   1) Inspection of the shell for pitting, corrosion or abrasions, dents, distortions or abrasions, defects in welds, or any other conditions, including leakage; and

   2) Inspection of the piping, valves, and gaskets for corroded areas, defects, and other conditions, including leakage that may be unsafe during filling and discharge or transportation.

c) In addition to the required frequencies established in NBIC Part 2, Table S6.14, it is required that portable tanks be inspected and tested when any of the following occurs:

   1) The portable tank has been in an accident and has been damaged to an extent that may adversely affect the portable tank's ability to retain hazardous materials;

   2) The portable tank has been out of hazardous material transportation service for a period of one year or more;

   3) The portable tank has been modified from its original design specification; and

   4) The portable tank is in an unsafe operating condition based on the existence of observed damage, leaks, or missing safety devices, etc.

**TABLE S6.14**
INSPECTION INTERVALS

| Specification | Periodic Inspection and Test[1] | Intermediate Periodic Inspection and Test[2] |
|---|---|---|
| IM or UN Portable Tanks once placed in service | 5 years | 2-1/2 years |
| DOT 51 Portable Tanks | 5 years | — |
| DOT 56 or DOT 57 Portable Tanks (The first periodic inspection and test is required 4 years after being placed into service and each 2-1/2 years thereafter.) | 2-1/2 years | — |
| DOT 60 Portable Tanks (The first periodic inspection and test is required 4 years after being placed into service and then per the schedule to the right.) | For the first 12 years of service.....2 years | After 12 years of service.....yearly |

1 Retesting is not required on a rubber-lined tank, except before relining.

2 For IM and UN Portable Tanks, periodic inspection and test shall include at least an internal and external inspection of the portable tank and fittings, taking into account the hazardous material intended to be transported.

## S6.14.1 PERIODIC INSPECTION AND TEST

Portable tanks shall be tested and inspected in accordance with the frequency set forth in NBIC Part 2, Table S6.14 and the procedures set forth in NBIC Part 2, S6.14.3 through S6.14.6.4.

## S6.14.2 INTERMEDIATE PERIODIC INSPECTION AND TEST

a) Intermediate periodic inspections and testing shall be performed in accordance with NBIC Part 2, Table S6.14. The intermediate periodic inspection and testing shall include:

   1) An external and an internal inspection of the portable tank and its fittings taking into account the hazardous materials being transported;

   2) A leakage test of the transport tank; and

   3) A test for satisfactory operation of all service equipment;

b) When inspecting portable tanks equipped with sheathing and thermal insulation, etc., the insulation need only be removed to the extent required for a reliable appraisal of the condition of the portable tank;

c) For portable tanks intended for the transportation of a single hazardous material, the internal inspection may be waived if the portable tank is subjected to a leakage test that is performed in accordance with NBIC Part 2, S6.14.3 of this section prior to each filling;

d) Portable tanks used for dedicated transportation of refrigerated liquefied gases that are not fitted with inspection openings are exempt from the internal inspection requirements, but shall be externally inspected.

## S6.14.3 INTERNAL AND EXTERNAL INSPECTIONS

All portable tanks that are subject to five-year periodic inspection and testing (pressure test) are required to be inspected, both internally, unless exempt, and externally. The internal and external inspection shall include:

a) Sheathing, thermal insulation, etc. The sheathing and thermal insulation need only be removed to the extent required for reliable appraisal of the condition of the portable tank;

b) Except for DOT Specification 56 and 57 portable tanks, all re-closing pressure relief devices must be removed from the tank and tested separately unless they can be tested while installed on the portable tank;

c) For portable tanks where the shell and equipment have been pressure tested separately after assembly, the portable tank shall be subjected to a leakage test and effectively tested and inspected for corrosion;

d) Portable tanks used for the transportation of refrigerated, liquefied gases are exempt from the internal inspection and the hydrostatic test or other pressure test during the five-year periodic inspection if the portable tank was originally tested to a minimum test pressure of 1.3 times the design pressure using inert gas and provided that;

   1) The portable tank and its appurtenances were constructed to ASME Section XII, or ASME Section VIII, Division 1; the portable tank shall be inspected in accordance with the applicable requirements of this Code;

   2) Portable tanks shall be either hydrostatically or pneumatically tested with the formula 1.5 x design pressure + static head + 101 kPa (14.7 psi), if the tank is designed for external pressure;

   3) The portable tank shall be subjected to either a hydrostatic or pneumatic test at a test pressure of 1.5 x the sum of the design pressure + the static head of lading + 101 kPa (14.7 psi), if subjected to external vacuum. If the portable tank is constructed in accordance with ASME Section XII or Part UHT of ASME Section VIII, Div. 1, the test pressure shall be twice the design pressure; and

   4) A pneumatic test may be used in lieu of a hydrostatic test if the following conditions are met:

      a. The owner or user has taken necessary precautions to ensure the safety of the inspection and test personnel;

      b. The pneumatic test pressure shall be reached gradually by increasing the test pressure to one-half of the test pressure. Once this pressure is reached, the test pressure will be increased in increments of approximately one-tenth of the test pressure until the required test pressure is reached; and

      c. When the test pressure is reached, the test pressure shall be reduced to at least four-fifths of the test pressure and held for a sufficient time to permit inspection of the portable tank.

## S6.14.4 EXCEPTIONAL INSPECTION AND TEST

a) Exceptional inspection and test is necessary when a portable tank shows evidence of damage, corroded areas, or leakage, or other conditions that indicate a deficiency that could affect the integrity of the portable tank.

b) The extent of the exceptional inspection and test shall depend on the amount of deterioration of the portable tank. The exceptional inspection and test shall include the requirements of NBIC Part 2, S6.14.3 of this section.

c) Pressure relief devices do not need to be included in this test unless there is reason to believe the relief device has been affected by damage or deterioration.

### S6.14.5 INTERNAL AND EXTERNAL INSPECTION PROCEDURE

An internal and external inspection, when required, shall be performed by the owner or user. The inspection shall be conducted by the Inspector. This individual shall ensure that the portable tank is safe for continued transportation service. The Inspector shall evaluate the results of the inspection and report the applicable findings. The inspection shall include:

a) Inspection of the shell for pitting, corrosion or abrasions, dents, distortions, defects in welds, or any other conditions, including leakage;

b) Inspection of the piping, valves, and gaskets for corroded areas, defects, and other conditions, including leakage that might make the portable tank unsafe for filling, discharge, or transportation;

c) Ensuring that the tightening devices for manhole covers are operative, and there is no leakage at the manhole cover or gasket;

d) Checking for any missing or loose bolts or nuts on any flanged connections including piping flanges, pressure relief device connections, or blank flanges. If any bolts are loose or missing, these shall be tightened or replaced;

e) Checking all emergency devices and valves to ensure that they are free from corrosion, distortion, and any damage or defects that could prevent the devices from operating as designed;

f) Ensuring all remote closures and self-closing stop valves are operated to demonstrate their proper operation;

g) Ensuring the required markings on the portable tanks are legible and in accordance with the applicable requirements of CFR Title 49, Part 178.3, and Part 180.605; and

h) Ensuring the framework, supports, and the arrangements for lifting the portable tank are in a satisfactory condition.

### S6.14.6 PRESSURE TEST PROCEDURES FOR SPECIFICATION 51, 57, 60, IM OR UN PORTABLE TANKS

This Section provides the requirements for pressure test procedures for Specification 51, 57, 60, IM or UN Portable Tanks as provided in CFR Title 49, Part 180.605(h). Pressure test requirements for Specification 51, 57, 60, IM and UN Portable Tanks are identified in NBIC Part 2, Table S6.14.6 of this Subsection.

**TABLE S6.14.6**
PRESSURE TESTING REQUIREMENTS

| Specification | Leak Test | Hydrostatic | Pneumatic | Test Media | Minimum Test Pressure |
|---|---|---|---|---|---|
| 51 and 56 | — | X | X | Liquid or Air | 14 kPa (2 psi) or at least 1-1/2 times the design pressure, whichever is greater |
| 51 and 56 used to transport refrigerated liquefied gas | X | X | X | Liquid or Air | 90% of the Maximum Allowable Working Pressure |
| 51 and 56 for the transport of all other materials | — | X | X | Liquid or Air | 25% of the Maximum Allowable Working Pressure |
| 57 | X | — | — | — | 21 kPa (3 psi) to the entire tank |
| 60 | — | — | — | Water or other similar liquid | 413 kPa (60 psig) |
| UN nonrefrigerated gases | — | — | — | Water | 130% of Maximum Allowable Working Pressure |
| UN refrigerated gases | — | X | X | Water or Air | 1.3 times design pressure |
| IM refrigerated or nonrefrigerated liquefied gases | — | X | X | Water or Air | 150% of the Maximum Allowable Working Pressure |



### S6.14.6.1 SPECIFICATION 57 PORTABLE TANKS

a) Specification 57 portable tanks shall be leak tested by a minimum sustained air pressure of at least 21 kPa (3 psig) applied to the entire tank.

b) During each air pressure test, the entire surface of all joints, whether welded or threaded, shall be coated with or immersed in a solution of soap and water, heavy oil, or other material suitable for the purpose of detecting leaks.

c) The test pressure shall be held for a minimum of 5 minutes plus any additional time required to examine all portions of the portable tank.

d) During the air test, the pressure relief device may be removed or left in place. If the relief device is left in place during the test, the device's discharge opening shall be plugged.

e) All closure fittings must be in place during the pressure test.

f) If the portable tank is lagged or insulated, the lagging or insulation does not have to be removed if it is possible to maintain the required test pressure at a constant temperature with the portable tank disconnected from the source of pressure.

### S6.14.6.2 SPECIFICATION 51 OR 56 PORTABLE TANKS

a) Specification 51 or 56 portable tanks shall be tested using either air or liquid. The minimum test pressure shall be at least 14 kPa (2 psig) or at least one and one-half times the maximum allowable working pressure (or re-rated pressure) of the portable tank. The greater test pressure shall be used.

b) The leak testing of all refrigerated liquefied gas tanks shall be performed at 90% of the maximum allowable working pressure of the portable tank.

c) Leak testing for all other portable tanks shall be at a test pressure of at least 25% of the maximum allowable working pressure of the portable tank.

d) If the portable tank is hydrostatically tested, the entire surface of the portable tank shall be inspected for leaks. This includes all welded joints and threaded connections. The requirements below shall be followed for hydrostatic testing:

1) The hydrostatic test pressure shall be held for a minimum of 5 minutes plus any additional time required to complete the inspection;

2) The pressure relief device should be removed or left in place during the hydrostatic test. If the relief device is left in place during the test, the device shall be isolated to prevent the relief device from discharging in accordance with the device manufacturer's recommendations;

3) It is required for DOT 51 specification tanks that the relief valve be removed during the pressure test; and

4) All closure fittings shall remain in place during the hydrostatic test.

e) If the portable tank is pressure tested by air, during the test all surfaces of welded joints and thread connections of the portable tank shall be inspected for leaks and the following procedure shall be followed:

1) All welded joints and threaded connections shall be coated with or immersed in a solution of soap and water, or heavy oil or other material suitable for the purpose of detecting leaks;

2) The air test pressure shall be held for a minimum of 5 minutes. This time period should be increased if so required by the Inspector;

3) The pressure relief device should be removed or left in place during the air test. If the relief device is left in place during the test, the device shall be isolated to prevent the pressure relief device from discharging in accordance with the device manufacturer's recommendations;

4) For Specification 51 portable tanks, the relief device shall be removed during the pressure test; and

5) All closure fittings shall remain in place during the air test.

f) If the portable tank is lagged or insulated and the pressure test performed is either hydrostatic or pneumatic, it is not necessary to remove the lagging or insulation for pressure testing provided the decay in test pressure can be measured at a constant temperature while the portable tank is disconnected from the source of pressure.

### S6.14.6.3 SPECIFICATION 60 PORTABLE TANKS

Specification 60 portable tanks shall be tested by completely filling the portable tank with water or other liquid having a similar viscosity. The test procedure shall include:

a) The temperature of the liquid shall not exceed 37.7°C (100°F) during the test;

b) The test pressure applied shall be at least 413 kPa (60 psig);

c) The test pressure shall be maintained for a minimum of 10 minutes. This time period may be increased if required by the Inspector;

d) During the 10-minute time period, the portable tank shall be capable of maintaining the test pressure with no evidence of leakage;

e) All closures shall be left in place while the pressure test is being performed;

f) The pressure gage shall be located at the tip of the vessel during the test; and

g) Re-closing pressure relief devices must be removed from the tank and tested separately unless they can be tested while installed on the portable tank.

### S6.14.6.4 SPECIFICATION IM OR UN PORTABLE TANKS

All Specification IM or UN portable tanks, except for UN portable tanks used for non-refrigerated and refrigerated liquefied gases, and all piping, valves, and accessories, except pressure relief devices, shall be hydrostatically tested with water, or other liquid similar in density and viscosity as follows:

a) All IM portable tanks used for non-refrigerated and refrigerated liquid gases shall be hydrostatically tested with water to a pressure of not less than 150% of the portable tanks maximum allowable working pressure.

b) All UN portable tanks used for the transportation of non-refrigerated liquefied gases shall be hydrostatically tested, with water to a pressure not less than 130% of the portable tanks maximum allowable working pressure.

    1) UN portable tanks used for the transportation of refrigerated gases should be tested either hydrostatically or pneumatically using an inert gas to a pressure of not less than 1.3 times the design pressure of the portable tank.

    2) If the portable tank is subjected to the pneumatic test method, the owner or user shall take necessary precautions for the safety of the inspection and test personnel.

    3) The pneumatic test pressure shall be reached gradually by increasing the test pressure to one-half of the test pressure. Once this pressure is reached, the test pressure will be increased in increments of approximately one-tenth of the test pressure until the required test pressure is reached.

    4) When the test pressure is reached, the pressure shall be reduced to a value equal to four-fifths of the test pressure and held for a sufficient time to permit the inspection for leaks.

c) The minimum test pressure of IM and UN portable tanks is determined on the basis of the hazardous materials that are intended to be transported in the portable tank as required by CFR Title 49, Part 172.101.

d) For liquid, solid, and non-refrigerated gases, the minimum test pressure for a specific hazardous material is provided in the applicable “T” Codes assigned for a particular hazardous material, as specified in CFR Title 49, Part 172.102 Tables. See NBIC Part 2, Table S6.14.6.4.

e) While the portable tank is under test pressure, it shall be inspected for leakage, distortion, or any other condition that might render the portable tank unsafe for service.

f) If a portable tank fails to meet the requirements of the pressure test or if during the pressure test there are any of the following conditions, the portable tank shall be removed from transportation service, unless the portable tank is adequately repaired and, thereafter, a successful pressure test is conducted in accordance with this Section.

    1) Any permanent distortion of the portable tank exceeding that permitted by the applicable specification;

    2) Any leakage; or

    3) Any deficiencies that would render the portable tank unsafe for transportation.

g) The approval agency shall witness the hydrostatic or pneumatic tests.

h) If the portable tank is damaged or a deficiency is discovered that might render the portable tank unsafe, the tank shall be repaired to a satisfactory condition. This test shall be witnessed by the applicable approval agency. As a minimum, the repair procedures shall include:

1) Retesting to the original pressure test requirements.

2) If the hydrostatic or pneumatic test is successful, the witnessing approval agency shall apply its name, identifying mark, or identifying number on the portable tank's nameplate as required in NBIC Part 2, S6.14.7;

i) All thermal cutting or welding on the shell of IM or UN portable tanks shall be done in accordance with this Section. After completion of the thermal cutting or welding operation, a pressure test shall be performed to the requirements of the portable tank's original test requirements.

**TABLE S6.14.6.4**
"T" CODES

| | |
|---|---|
| T1 to T22 | For liquid and solid hazardous materials of Classes 3 through 9 that are transported in portable tanks.1 |
| T23 | Applies to self-reactive substances of Division 4.1 and organic peroxides of Division 5.2. |
| T50 | Applies to liquefied compressed gases. |
| 1 Note: Class numbers of hazardous materials listed in CFR 49, Part 173.2. | |

## S6.14.7 INSPECTION AND TEST MARKINGS FOR IM OR UN PORTABLE TANKS

a) Each IM or UN portable tank shall be durably and legibly marked, in English, with the date (month and year) of the last pressure test.

b) The identifying agency shall witness the test, when required, and the date of the last visual inspection.

c) The markings required on the portable tank's identification plate shall be identified as follows:

1) Placed on or near the metal identification plate;

2) The size of the letters and numerals on the plate shall be no less than 3 mm (0.1 inches) high; and

3) If the letters and numerals are stamped into the portable tank's shell, they shall be at least 12 mm (0.5 inches) high.

## S6.14.8 INSPECTION AND TEST MARKINGS FOR SPECIFICATION DOT 51, 56, 57, OR 60

a) Each Specification DOT 51, 56, 57, or 60 portable tank shall be durably and legibly marked, in English, with the date (month and year) of the most recent periodic test.

b) The markings shall be placed near the metal certification plate and shall be in accordance with the following:

1) Shall be marked on a non-removable component of the portable tank that identifies the specification markings;

2) Located in an unobstructed area with letters and numerals identifying the standard or specification, (e.g., UN 1A1, DOT 4B240ET, etc.);

3) Shall identify the name and address or symbol of the portable tank manufacturer or, where specifically authorized, the symbol of the approval agency certifying compliance with the UN standard;

4) The markings shall be stamped, embossed, burned, printed, or otherwise marked on the portable tank to provide adequate accessibility, permanency, contrast, and legibility, so as to be readily apparent and understood; and

5) The letters and numerals shall be at least 3 mm (0.1 inches) high if stamped on a plate, and shall be at least 12.0 mm (0.5 inches) high when stamped on the portable tank's shell.

### S6.14.9 RECORD RETENTION

The owner of each portable tank or his authorized agent shall retain a written report of the date and results of all required inspections and tests, including the following:

a) If applicable, the ASME Manufacturer's Data Report (U-1 or U1A Forms);

b) The name and address of the person performing the inspection and/or test in accordance with the applicable specification;

c) The Manufacturer's Data Report including a certificate(s) signed by the manufacturer;

d) The authorized agency, as applicable, indicating compliance with the applicable specification of the portable tank; and

e) The records shall be retained in the owner's files or should be retained by the owner's authorized agent during the time that the portable tank is used. These records do not have to be maintained for DOT 56 and DOT 57 Specification tanks.



## S6.15 GENERAL REQUIREMENTS FOR DOT SPECIFICATION 106A AND 110A TANK CARS (TON TANKS)

All Specification DOT 106A and DOT 110A multi-unit ton tanks shall be cylindrical, circular in cross-section and shall have heads of an approved design, with all fittings, i.e., couplings, nozzles, etc., located in the heads of the tank.

### S6.15.1 SPECIAL PROVISIONS FOR TON TANKS

49 CFR, Section 179.300, has specific criteria for ton tanks that shall be met to satisfy DOT Specification 106A and 110A. The limitations are as follows:

a) Ton tanks shall have a water containing capacity of at least 0.68 tonne (1500 pounds), but in no case can the water containing capacity of the ton tank exceed 1.18 tonnes (2600 pounds);

b) Ton tanks shall not be insulated;

c) Thickness of plates for DOT Specifications 106A and 110A ton tanks shall be in accordance with NBIC Part 2, Table S6.15.1-a;

d) The maximum carbon content for carbon steel used in the fabrication of ton tanks shall not exceed 0.31%;

e) Permitted materials can be either an ASME, SA material, or an ASTM Material permitted by NBIC Part 2, Table S6.15.1-b;

f) DOT Specification 106A ton tanks shall only use forged-welded heads, convex to pressure. The forged-welded heads shall be torispherical with an inside radius not greater than the inside diameter of the shell. The heads shall be one piece, hot formed in one heat so as to provide a straight flange at least 100 mm (4 inches) long. The heads must have a snug fit into the shell;

g) DOT Specification 110A ton tanks shall only use fusion-welded heads formed concave to pressure. The fusion-welded heads shall be an ellipsoid of 2:1 ratio and shall be of one piece, hot formed in one heat so as to provide a straight flange at least 38 mm (1-1/2 inches) long;

h) All longitudinal welded joints on DOT Specification 106A and DOT Specification 110A ton tanks shall be a fusion weld. DOT Specification 106A ton tank head-to-shell attachments shall be a forged-welded joint. DOT Specification 110A ton tank head-to-shell attachments shall be a fusion weld;

i) Postweld heat treatment is required after welding for all DOT Specification 106A and Specification 110A ton tanks;

j) DOT Specification 106A and DOT Specification 110A ton tanks shall be of such a design as to afford maximum protection to any fitting or attachment to the head, including loading and unloading valves. The protection housing shall not project beyond the end of the ton tanks and shall be securely fastened to the tank head;

k) If applicable, siphon pipes and their couplings on the inside of the ton tank's head and lugs on the outside of the tank head for attaching valve protection housing shall be fusion welded prior to performing postweld heat treatment;

l) DOT Specification 106A and DOT Specification 110A ton tanks are required to be equipped with one or more approved types of pressure relief devices. The devices shall be made out of metal and the pressure relief devices shall not be subject to rapid deterioration by the lading. The device's inlet fitting to the tank shall be a screw-type fitting and installed or attached directly into the ton tank's head or attached to the head by other approved methods. For thread connections, the following shall apply:

    1) The threaded connections for all openings shall be in compliance with the National Gas Taper Threads (NGT);

    2) Pressure relief devices shall be set for start-to-discharge, and rupture discs shall burst at a pressure not exceeding the pressure identified in NBIC Part 2, Table S6.15.1-a; and

m) Fusible plugs, if used, shall be required to relieve the pressure from the tank at a temperature not exceeding 79°C (175°F) and shall be vapor tight at a temperature not exceeding 54°C (130°F).

**TABLE S6.15.1-a**

THICKNESS OF PLATES AND SAFETY VALVE REQUIREMENTS

| DOT Specification | 106A500-X | 106A800-X | 110A500-W | 110600-W | 110A800-W | 110A1000-W |
|---|---|---|---|---|---|---|
| Minimum required bursting pressure, MPa (psig) | None Specified | None Specified | 8.62 (1,250) | 10.34 (1,500) | 13.8 (2,000) | 17.2 (2,500) |
| Minimum thickness shell, mm (inches), Test Pressure (See CFR 179.300-15), MPa (psig) | 10.3 (13/32) 3.45 (500) | 17.5 (11/16) 5.52 (800) | 8.7 (11/32) 3.45 (500) | 9.5 (3/8) 4.41 (600) | 11.9 (15/32) 5.52 (800) | 15.1 (19/32) 6.89 (1,000) |
| Start-to-discharge, or burst pressure (maximum MPa (psig)) | 2.59 (375) | 4.14 (600) | 2.59 (375) | 3.10 (450) | 4.14 (600) | 4.83 (700) |

**TABLE S6.15.1-b**

ACCEPTABLE MATERIALS WITH ACCEPTABLE TENSILE STRENGTH AND ELONGATION REQUIREMENTS

| Material Specification | Minimum Tensile Strength MPa (psi) in the welded condition. *These values are to be used in the design calculations.* | Minimum Elongation in 50 mm (2 in. ) (percent) in the welded condition. *These values are to be used in the design calculations.* |
|---|---|---|
| ASTM A 240 type 304 | 517 (75,000) | 25 |
| ASTM A 240 type 304L | 483 (70,000) | 25 |
| ASTM A 240 type 316 | 517 (75,000) | 25 |
| ASTM A 240 type 316L | 483 (70,000) | 25 |
| ASTM A 240 type 321 | 517 (75,000) | 25 |
| ASTM A 285 Gr. A | 310 (45,000) | 29 |
| ASTM A 285 Gr. B | 345 (50,000) | 20 |
| ASTM A 285 Gr. C | 380 (55,000) | 20 |
| ASTM A 515 Gr. 65 | 448 (65,000) | 20 |
| ASTM A 515 Gr. 70 | 483 (70,000) | 20 |
| ASTM A 516 Gr. 70 | 483 (70,000) | 20 |



## S6.15.2 VISUAL INSPECTION OF TON TANKS

Without any regard to any other periodic inspection and test requirements, a ton tank shall be visually inspected for evidence of any:

a) Defects in welds;

b) Abrasions;

c) Corrosion;

d) Cracks;

e) Dents;

f) Distortions; or

g) Any other conditions that might make the ton tank unsafe for transportation.

### S6.15.3 INSPECTION AND TESTS OF DOT SPECIFICATION 106A AND DOT SPECIFICATION 110A TON TANKS

Each ton tank shall be retested by subjecting the ton tank to a hydrostatic test in accordance with NBIC Part 2, Table S6.15.3. The hydrostatic test shall include an evaluation of the tank's permanent expansion. As a minimum, the hydrostatic test and the expansion procedure shall include:

a) The hydrostatic test pressure shall be maintained for a minimum of 30 seconds. This time period may be extended as long as necessary to secure complete expansion of the ton tank.

b) The pressure gage used for the hydrostatic test shall be accurate within 1% of the range of the pressure gage. The accuracy of the pressure gage shall be verified prior to performing the hydrostatic test.

c) The expansion test procedure shall include the following requirements:

1) The expansion shall be recorded in cubic centimeters;

2) Permanent volumetric expansion shall not exceed 10% of the total volumetric expansion at the test pressure; and

3) The expansion gage shall be accurate within one percent of the hydrostatic test pressure.

d) The ton tank shall not show any signs of leakage or stress during the hydrostatic and expansion test.

e) The retest may be made at any time during the calendar year the retest falls due.

**TABLE S6.15.3**

TON TANK PERIODIC INSPECTION AND TEST FREQUENCIES

| | Retest Interval, years | | Minimum Retest Pressure, MPa (psig) | | Pressure Relief Valve Pressure, MPa (psig) | |
|---|---|---|---|---|---|---|
| DOT Specification | Tank | Pressure Relief Device | Tank Hydrostatic Expansion | Tank Air Test | Start-to-Discharge | Vapor Tight |
| 106A500 | 5 | 2 | 500 (3.45) | 100 (0.69) | 375 (2.59) | 300 (2.07) |
| 106A500X | 5 | 2 | 500 (3.45) | 100 (0.69) | 375 (2.59) | 300 (2.07) |
| 106A800 | 5 | 2 | 800 (5.52) | 100 (0.69) | 600 (4.14) | 480 (3.31) |
| 106A800X | 5 | 2 | 800 (5.52) | 100 (0.69) | 600 (4.14) | 480 (3.31) |
| 106A800NCI | 5 | 2 | 800 (5.52) | 100 (0.69) | 600 (4.14) | 480 (3.31) |
| 110A500-W | 5 | 2 | 500 (3.45) | 100 (0.69) | 375 (2.59) | 300 (2.07) |
| 110A600-W | 5 | 2 | 600 (4.41) | 100 (0.69) | 500 (3.45) | 360 (2.48) |
| 110A800-W | 5 | 2 | 800 (5.52) | 100 (0.69) | 600 (4.14) | 480 (3.31) |
| 110A1000-W | 5 | 2 | 1,000 (6.89) | 100 (0.69) | 750 (5.17) | 600 (4.41) |

### S6.15.3.1 AIR TESTS

a) All specification DOT 106A and DOT 110A ton tanks, in addition to the hydrostatic test shall be subjected to an air test at frequencies and pressures specified in NBIC Part 2, Table S6.15.3.

b) The air test shall be under positive control to ensure safety to all inspection and test personnel.

c) Any leakage observed will require the ton tank to be repaired and retested prior to placing the ton tank back into service.

### S6.15.3.2 PRESSURE RELIEF DEVICE TESTING

All pressure relief devices shall be retested by air or gas for the start-to-discharge and vapor tightness requirements at frequencies and pressures specified in NBIC Part 2, Table S6.15.3.

### S6.15.3.3 RUPTURE DISCS AND FUSIBLE PLUGS

All rupture discs required by NBIC Part 2, S6.15.1 l) 2), and fusible plugs required by NBIC Part 2, S6.15.1 m), shall be removed from the ton tank and inspected. The inspection shall include but not be limited to the following:

a) All rupture discs shall be inspected for corrosion, leakage, and manufacturer tolerances;

b) All fusible plugs shall be inspected for corrosion, loose, or deteriorated temperature sensitive materials; and

c) Any indication specified in a) and b) above will require the rupture disc or fusible plug to be replaced with devices specified in NBIC Part 2, S6.15.1 l) 2) and S6.15.1) m).

### S6.15.3.4 SUCCESSFUL COMPLETION OF THE PERIODIC RETESTING

If the results of the periodic retest are successful, the ton tank shall be plainly and permanently stamped on one head or chime of each ton tank. The stamping shall include:

a) The month and year of the test followed by a “V”; and

b) Dates of previous tests and all prescribed markings shall not be removed. Previous dates and markings on the ton tank’s head or chime shall be legible.

### S6.15.3.5 EXEMPTIONS TO PERIODIC HYDROSTATIC RETESTING

Ton tanks that satisfy DOT 106A and DOT 110A and are used exclusively for transporting fluorinated hydrocarbons and mixtures thereof, and are free from corroding components related to the ton tank, may be exempted from the periodic hydrostatic retest if:

a) The ton tank is given a complete internal and external visual inspection of all heads, shells, nozzles, couplings, pressure relief devices, i.e. pressure relief valves and rupture discs and fusible plugs for deterioration and leakage.

b) The visual internal and external inspection is performed by qualified personnel, i.e., Registered Inspector, employee of the owner or user, etc.

### S6.15.3.6 RECORD OF RETEST INSPECTION

The owner or the person performing the required pressure test and visual inspection is required to retain a written record of the results as long as the ton tank is in service. The written report shall identify the following:

a) Date of the test and inspection;

b) DOT Specification Number of the ton tank;

c) Ton tank identification: registered symbol and serial number, date of manufacture, and ownership symbol;

d) Type of protective coating, i.e., painting, etc.;

e) Statement as to the need for refinishing or recoating the ton tank;

f) Conditions checked for:

   1) Leakage;

   2) Corrosion;

   3) Gouges;

   4) Dents or dings;

   5) Broken or damaged chimes, or protective rings;

   6) Fire damage;

   7) Internal conditions;

   8) Test pressure; and

   9) The written report shall also identify the results of the test:

      a. Disposition of the tank, i.e., returned to service, returned to the manufacturer for repair, or scrapped; and

      b. Identification of the person performing the retest or inspection.

### S6.15.4 STAMPING REQUIREMENTS OF DOT 106A AND DOT 110A TON TANKS

To identify compliance with CFR 179.300-1, each DOT 106A and DOT 110A ton tank shall be plainly and permanently stamped with letters and figures 10 mm (3/8 in.) high on valve end chime of the ton tank's head. The minimum requirements for the stamping are as follows:

a) DOT Specification Number;

b) Material and cladding material, if any. This information shall be stamped directly below the DOT Specification Number;

c) Owner's or builder's identifying symbol and serial number. This information shall be stamped directly below the material identification stamping. The owner's or builder's symbol shall be registered with the Bureau of Explosions (duplications are not authorized);

d) Inspector's official mark. This information shall be stamped directly below the owner's or builder's symbol;

e) Date of the original ton tank test (month and year). Provisions should be made that subsequent tests may easily be added thereto;

f) Water capacity of the ton tank in kilograms (pounds); and

g) A duplicate of the stamping that satisfies a) through f) should be used if the plate is made of brass and is permanently attached to the ton tank's head.

## S6.16 PRESSURE RELIEF DEVICES

### S6.16.1 SCOPE

This Section provides details for the application, continued service inspection, and repair of pressure relief devices specified for overpressure protection of transport tanks.

Pressure relief devices are provided for all transport tanks to prevent internal pressure from exceeding design values. They may also be provided to prevent excessive internal vacuum. Overpressure protection may be provided by reclosing pressure relief valves, non-reclosing devices such as rupture disks or breaking bar or breaking pin valves, or combinations of pressure relief valves and non-reclosing devices.

### S6.16.2 SAFETY CONSIDERATIONS

When inspections of pressure relief devices are being performed, Inspectors should be aware that tests of these devices involve the discharge of the test fluid, which can result in high-velocity fluid flow, possible high -or low-temperature fluids, and high noise levels. If a test is being performed with the service fluid, it should be a fluid that is safe for discharge and not toxic or hazardous. Due to the nature of fluids being transported, most testing will involve removing the device from the transport tank and testing it on a test stand. (See NBIC Part 2, S6.12.1, Pre-Inspection Activities.)



### S6.16.3 INSTALLATION PROVISIONS

Incorrect installation of a pressure relief device can have a detrimental effect on device performance. The following provisions shall be followed when installing pressure relief devices on transport tanks:

a) Inlet piping shall have an area at least equal to the pressure relief device inlet size with no restrictions which can affect flow through the device;

b) Pressure relief devices shall be installed to be in communication with the vapor space of the tank in its normal transport orientation as near as practicable on the longitudinal center line, and in the center of the tank;

c) If discharge piping is provided, it shall have an area at least equal to the pressure relief device, be as short and straight as possible, and of a length that will not affect the pressure relief device flow performance. It will typically discharge upward, and should be directed away from personnel that may be around the tank at ground level;

d) Provisions for protection of the outlet of pressure relief devices from contamination from the effects of rain, weather, etc., shall be provided. Where rain caps are provided, the fit shall not be tight enough to affect the valve performance;

e) Pressure relief devices may be installed inside a protective housing consisting of mechanical elements designed to protect the valve during roll-over events. These elements shall not obstruct the outlet of the device;

f) If a rupture disk is used in combination with a pressure relief valve, it shall be located inboard of the pressure relief valve;

g) When a rupture disk is used in combination with a pressure relief valve, a device to detect leakage through the rupture disk, or actuation of the rupture disk, shall be provided. These devices detect leakage or actuation by observation of the accumulation of pressure between the disk and the pressure relief valve, and shall consist of a needle valve, try-cock, tell-tale indicator or pressure gage. Where a valve is provided, it shall be closed during normal operation. Leaking disks or disks, which have discharged, shall be replaced as soon as possible; and

h) Block valves shall not be used on either device inlets or outlets.

### S6.16.4 PRESSURE RELIEF DEVICE INSPECTION

For pressure relief valves, inspection shall consist of an External and Internal Visual Inspection and a Pressure Test to determine valve function. For non-reclosing pressure relief devices, inspection shall consist of an external and internal visual inspection as well.

### S6.16.5 SCHEDULE OF INSPECTIONS

Pressure relief devices shall be inspected at the frequency as required by NBIC Part 2, Tables S6.13.4, S6.14, or S6.15.3. For both an External Visual Inspection and a Pressure Test, the frequency of inspection for pressure relief devices shall be the same as the frequency required for inspection of the transport tank itself.

### S6.16.6 EXTERNAL VISUAL INSPECTION OF PRESSURE RELIEF DEVICES

The following items shall be inspected during the External Visual Inspection:

a) Pressure relief device nameplate data shall be reviewed, and the marked device set pressure compared to the transport tank data. The pressure relief device set pressure shall not exceed the tank maximum allowable working pressure (MAWP) except as permitted by the applicable transport tank specification appendix.

b) Where seals are provided to seal external adjustments of pressure relief valves, the seal must be intact and bear the identification of the organization responsible for performing the adjustment. If the valve has been repaired or reset, it must bear a supplemental nameplate identifying the organization responsible for the repair or resetting.

c) Valves that have the set pressure adjustment permanently sealed, by means such as a rivet or roll pin through the adjustment, shall be checked to ensure there has been no tampering with the set pressure adjustment.

d) Check for evidence of leakage through the valve. For a valve installed with a rupture disk at the inlet, the rupture disk leakage detection device shall be checked for signs of leakage through the disk. When possible, this inspection should be performed with normal transport tank operating pressure present.

e) All connecting bolting shall be present and tight.

f) Evidence of rust or corrosion of the pressure relief device shall be investigated.

g) Where drain holes are provided on the side of the valve, check that the drain holes are not plugged.

h) Check that a valve spindle restraint (test gag) has not been left in place after pressure testing of the transport tank; and

i) Check for proper orientation of rupture disk devices. These devices will have a flow direction arrow or other designation such as inlet or vent side to designate the flow direction. Installation of rupture disk devices in the reverse direction can cause a disk to burst at a higher pressure than its marked burst pressure.

## S6.16.7 PRESSURE TESTING OF PRESSURE RELIEF VALVES

A check of pressure relief valve operation shall be performed to ensure the valve is functioning properly. This testing shall be performed at the time of the transport tank pressure test when the tank pressure test will necessitate removal of the pressure relief valve. When the valve is removed for testing, the connection on the transport tank shall be inspected for corrosion or deposits which could block or reduce the connection area.

a) Prior to the test, the inlet and outlet passages of the valve shall be visually inspected for corrosion or deposits of material which could affect valve operation.

b) The test fluid shall be air or other suitable non-hazardous gas.

c) The valve shall be installed on a test stand and a calibrated test gage of suitable range shall be used.

d) Valves shall be tested for the following operational characteristics:

1) Seat Leakage: The test pressure shall be increased to seat leakage test pressure at which there should be no leakage as determined by a bubble test. This pressure will typically be 90% of the stamped set pressure or the pressure prescribed for the applicable transport tank specification. There shall be no audible or visible leakage at the specified seat leakage test pressure;

2) Set Pressure: The set pressure definition used by the valve manufacturer to originally set the valve shall be determined, and shall be used during evaluations of valve performance. For most transport tank valves this will usually be the “start” to “discharge” pressure which is the pressure at which the first audible discharge is detected. The test pressure shall be increased until the set pressure is determined. The valve shall open within the tolerance for set pressure as specified by the applicable transport tank specification;

3) Re-seal pressure: The test pressure shall then be decreased and the pressure at which the valve reseals shall be recorded. The valve shall reseal at or above the pressure specified by the applicable transport tank specification, or above the normal transport tank operating pressure; and

4) It is recommended that the test sequence be repeated several times to ensure repeatable valve performance. Erratic performance may indicate damage to the valve, including damage or deposits on the seating surface.

e) The results of testing shall be documented and be made available to the Inspector.

f) Testing shall be performed by trained individuals from an organization acceptable to the Competent Authority.

## S6.16.8 CORRECTION OF DEFECTS

Any failure of the valve to meet applicable test specifications shall be brought to the attention of the Inspector and owner, and steps shall be taken to correct the defect. If repairs are required they shall be performed by a qualified organization acceptable to the Competent Authority.

When a valve is to be repaired, it shall be completely disassembled, cleaned, all parts inspected, and repaired as necessary. It shall then be tested and all adjustments resealed with a seal identifying the repair organization. Parts replaced shall be from the valve manufacturer or meet the valve manufacturer’s specifications. Where soft goods such as gaskets, o-rings, and other seals are replaced, new parts shall be used.

Repairs shall be identified with a repair nameplate which includes the organization responsible for the repair, date of the repair, and a unique identifier, identifying repair documentation. The goal of the repair is to bring the valve back to a “like new” condition.

A valve found to be defective may be replaced by a new valve or previously repaired valve. Care shall be taken to ensure that the replacement valve meets the same requirements as the valve being replaced.

### S6.16.9 INSPECTION OF RUPTURE DISKS AND NON-RECLOSING DEVICES

Rupture disks and other non-reclosing devices cannot be tested. In lieu of the required pressure test for a pressure relief valve, the disk and disk holder must be removed from the transport tank and the disk inlet and outlet surfaces visually inspected. (This is considered the “Internal Inspection.”) Signs of corrosion, damage, or deposits will require that the rupture disk be replaced.

A program to periodically replace rupture disks is recommended to prevent premature disk opening during normal operation. This can be caused by corrosion or deterioration of the disk or fatigue of the disk material due to cyclic operation of the transport tank and vibration during normal operation. The rupture disk manufacturer may have recommendations for the frequency of disk replacement. Replacement disks shall have the same specifications for burst pressure and coincident temperature as the disk being replaced, unless the service conditions for the transport vessel are being changed. It is recommended that replacement disks be specified by the complete disk description including model number, burst pressure, and coincident temperature, and the lot number from the disk being replaced. Disks and disk holders from different manufacturers shall not be interchanged.

### S6.17 DEFINITIONS

These definitions shall be used in conjunction with those of Section 9 of the NBIC. Where conflicts between the two arise, those listed below shall prevail.

**Approval** — A written authorization, including a competent authority approval from the Associate Administrator or other designated department official, to perform a function for which prior authorization by the Associate Administrator is required.

**Approval Agency** — An organization or a person designated by the DOT to certify packaging as having been designed, manufactured, tested, modified, marked, or maintained in compliance with applicable DOT regulations.

**Approved** — Approval issued or recognized by the department unless otherwise specifically indicated.

**Appurtenance** — Any attachment to a cargo tank that has no lading retention or containment function and provides no structural support to the cargo tank.

**Associate Administrator** — The Associate Administrator for Hazardous Materials Safety, Research, and Special Programs Administration.

**Atmospheric gas** — Air, nitrogen, oxygen, argon, krypton, neon, and xenon.

**Attachments** — Structural members means the suspension sub-frame, accident protection structures, external circumferential reinforcements, support framing, and kingpin sub-frame (upper coupling).

**Attachments, Light Weight** — Welded to a cargo tank wall such as a conduit clip, brake line clip, skirting structure, lamp mounting bracing, or placard holder.

**Authorized Inspector (AI)** — An inspector regularly employed by an ASME-accredited Authorized Inspection Agency (AIA) who has been qualified according to ASME developed criteria, to perform inspections under the rules of any Jurisdiction that has adopted the ASME Code.

**Baffle** — A nonliquid-tight transverse partition device that deflects, checks, or regulates fluid motion in a tank.

**Bar** — 1 BAR = 100 kPa (14.5 psi).

**Bottle** — An inner packaging having a neck of relatively smaller cross-section than the body and an opening capable of holding a closure for retention of the contents.

**Bottom Shell** — That portion of a tank car surface, excluding the head ends of the tank car, that lies within two feet, measured circumferentially, of the bottom longitudinal center line of the tank car tank.

**Bulk Packaging** — A packaging other than the vessel or a barge, including a transport vehicle or freight container, in which hazardous materials are loaded with no intermediate form of containment and which has:

a) A maximum capacity greater than 450 l (119 gallons) as a receptacle for a liquid;

b) A maximum net mass greater than 400 kg (882 pounds) and a maximum capacity greater than 450 l (119 gallons) as a receptacle for a solid; or

c) A water capacity greater than 454 kg (1,000 pounds) as a receptacle for a gas.

**Bulkhead** — A liquid-tight transverse closure at the ends of or between (compartment) cargo tanks.

**Cargo Tank** — A bulk packaging which:

a) Is a tank intended primarily for the carriage of liquids or gases and includes appurtenances, reinforcements, fittings, and closures;

b) Is permanently attached to or forms a part of a motor vehicle, or is not permanently attached to a motor vehicle but which, by reason of its size, construction, or attachment to a motor vehicle is loaded or unloaded without being removed from the motor vehicle; and

c) Is not fabricated under a specification for cylinders, portable tanks, tank cars, or multi-unit tank car tanks.

**Cargo Tank Motor Vehicle** — A motor vehicle with one or more cargo tanks permanently attached to or forming an integral part of the motor vehicle.

**Carrier** — A person engaged in the transportation of passengers or property by:

a) Land or water, as a common, contract, or private carrier; or

b) Civil aircraft.

**Certified Individual** — An individual that is qualified and certified by a manufacturer accredited by ASME to construct Class 3 Section XII Transport Tanks.

**Combination Packaging** — A combination of packaging for transport purposes, consisting of one or more inner packaging secured in a non-bulk outer packaging. It does not include a composite packaging.

**Combustible Liquid** — Any liquid that does not meet the definition of any other hazard class specified in 173.129 of Title 49 and has a flash point above 60.5°C (141.5°F) and below 93°C (100°F).

**Competent Authority** — A national agency responsible under its national law for the control or regulation of a particular aspect of the transportation of hazardous materials. In the United States, the Associate Administrator of the US Department of Transportation is the Competent Authority.

**Composite Packaging** — A packaging consisting of an outer package and an inner receptacle so constructed that the inner receptacle and the outer package are integral. Once assembled, it remains an integrated single unit. It is filled, stored, shipped, and emptied as such.

**Compressed Gas in Solution** — A non-liquefied compressed gas that is dissolved in a solvent.

**Constructed and Certified in Accordance with the ASME Code** — A cargo tank that is constructed and stamped in accordance with the ASME Code and is inspected and certified by an Authorized Inspector, Qualified Inspector, or a Certified Individual.

**Corrosive Material** — A liquid or solid that causes full thickness destruction of human skin at the site of contact within a specified period of time. A liquid that has a severe corrosion rate on steel or aluminum based on the criteria in 173.173(c) (3) of Title 49 is also a corrosive material.

**Cryogenic Liquid** — A refrigerated liquefied gas having a boiling point colder than -90°C (-130°F) at 101.3 kPa (14.7 psia) absolute.

**Design Certification** — That each cargo tank or cargo tank motor vehicle design type, including its required accident damage protection device, must be certified to conform to the specification requirements by a Design Certifying Engineer who is registered with the department. An accident damage protection device is a rear-end protection, overturn protection, or piping protection.

**Design Certifying Engineer** — A person registered with the department in accordance with Subpart F of Part 107 of 49 CFR who has the knowledge and ability to perform stress analysis of pressure vessels and otherwise determine whether a cargo tank design and construction meets the applicable DOT specification. In addition, Design Certifying Engineer means a person who meets, at a minimum, any one of the following:

a) Has an engineering degree and one year of work experience in cargo tank structural or mechanical design;

b) Is currently registered as a professional engineer by the appropriate authority of a state of the United States or a province of Canada; or

c) Has at least three years experience in performing the duties of a Design Certifying Engineer by September 1, 1991, and was registered with the department by December 31, 1995.

**Design Type** — One or more cargo tanks that are made:

a) To the same specification;

b) By the same manufacturer;

c) To the same engineering drawings and calculations, except for minor variations in piping that do not affect the lading retention capabilities of the cargo tank;

d) Of the same materials of constructions;

e) To the same cross-sectional dimensions;

f) To a length varying by no more than 5 percent;

g) With the volume varying by no more than 5 percent (due to the change in length only); and

h) For the purposes of 178.338 of Title 49 only, with the same insulation system.

**DOT or Department** — US Department of Transportation.

**Elevated Temperatures Material** — A material which, when offered for transportation or transported in a bulk packaging:

a) Is in a liquid phase and at a temperature at or above 100°C (212°F);

b) Is in a liquid phase with a flash point at or above 37.8°C (100°F) that is intentionally heated and offered for transportation, or transported at or above the flash point; or

c) Is in a solid phase and at a temperature at or above 240°C (464°F).

**Extreme Dynamic Loadings** — The maximum loading of a cargo tank motor vehicle may experience during its expected life, excluding accident loadings resulting from an accident, such as overturn or collision.

**Flammable Gas** — Any material that is a gas at 20°C (68°F) or less and 101.3 kPa (14.7 psia) of pressure [a material that has a boiling point of 20°C (68°F) or less at 101.3 kPa (14.7 psia)] which:

a) Is ignitable at 101.3kPa (14.7 psia) when in a mixture of 13% or less by volume with air; or

b) Has a flammable range at 101.3kPa (14.7 psia) with air of at least 12% regardless of the lower limit. Except for aerosols, the limits specified in paragraphs 1) and 2) shall be determined at 101.3kPa (14.7 psia) of pressure and a temperature of 20°C (68°F) in accordance with the ASTM E681-85, *Standard Test Method for Concentration Limits of Flammability of Chemicals*, or other equivalent method approved by the Associate Administrator, Hazardous Material Safety.

**Gas** — A material that has a vapor pressure greater than 300 kPa (43.5 psia) at 50°C (122°F) or is completely gaseous at 20°C (68°F) at a standard pressure of 101.3 kPa (14.7 psia).

**Gross Weight or Gross** — The weight of a packaging plus the weight of its contents.

**Hazardous Class** — The category of hazard assigned to a hazardous material under the definitional criteria of Part 173 of Title 49 and the provisions of the 172.101 Table. A material should meet the defining criteria for more than one hazard class but is assigned to only one hazard class.

**Hazardous Material** — A substance or material that the Secretary of Transportation has determined is capable of posing an unreasonable risk to health, safety, and property when transported in commerce and has been designated as hazardous under section 5103 of Federal Hazardous Law (49 U.S.C. 5103). The term includes hazardous substances, hazardous wastes, marine pollutants, elevated temperature materials, materials designated as hazardous in the Hazardous Material Table (49 CFR 172.101), and materials that meet the defining criteria for hazard classes and divisions of 173 of subchapter C of 171.8 of Title 49.

**Hazardous Zones** — One of four levels of hazard (Hazard Zones A through D) as assigned to gases, as specified in 173.116(a) of Title 49, and one of two levels of hazard (Hazard Zones A and B) assigned to liquids that are poisonous by inhalation as specified in 173.133(a) of Title 49. A hazard zone is based on the LC 50 value for acute inhalation toxicity of gases and vapors.

**High Pressure Liquefied Gas** — A gas with a critical temperature between -50°C (-58°F) and + 65°C (149°F).

**Inner Packaging** — A packaging for which an outer packaging is required for transport. It does not include the inner receptacle of a composite packaging.

**Inner Receptacle** — A receptacle that requires an outer packaging in order to perform its containment function. The inner receptacle should be an inner packaging of a combination packaging or the inner receptacle of a composite packaging.

**Inspection Pressure** — The pressure used to determine leak tightness of the cargo tank when testing with pneumatic or hydrostatic pressure.

**Lading** — The hazardous material contained in the cargo tank.

**Liquefied Compressed Gas** — a gas which, when packaged under pressure for transportation, is partially liquid at temperatures above -50°C (-58°F).

**Liquid** — A material, other than an elevated temperature material, with a melting point or initial melting point of 20°C (68°F) or lower at a standard pressure of 101.3 kPa (14.7 psig). Liquid Phase means a material that meets the definition of liquid when evaluated at the higher of the temperature at which it is offered for transportation or at which it is transported, not at the 37.8°C (100°F) temperature specified in ASTM D 4359-84.

**Low-Pressure Liquefied Gas** — A gas with a critical temperature above + 65°C (149°F).

**Manufacturer** — Any person engaged in the manufacture of a DOT specification cargo tank, cargo tank motor vehicle, or cargo tank equipment that forms part of the cargo tank wall. This term includes attaching a cargo tank to a motor vehicle or to a motor vehicle suspension component that involves welding on a cargo tank wall. A manufacturer must register with the department in accordance Subpart F of Part 107 in Subpart A of 49 CFR.

**Marking** — A descriptive name, identification number, instructions, cautions, weight, specification, or UN marks, or combinations thereof, required by Title 49 on outer packaging or hazardous materials.

**Mode** — Any of the following transportation methods: rail, highway, air, or water.

**Modification** — Any change to the original design and construction of a cargo tank or a cargo tank motor vehicle that affects its structural integrity or lading retention capability including changes to equipment certified as part of an emergency discharge control system. Any modification that involves welding on the cargo tank wall must also meet all requirements for “Repair” as defined in this section. Excluded from this category are the following:

a) A change to motor vehicle equipment such as lights, truck, or tractor power train components, steering, and brake systems, suspension parts, and changes to appurtenances, such as fender attachments, lighting brackets, ladder brackets; and

b) Replacement of components such as valves, vents, and fittings with a component of a similar design and of the same size.

**Motor Vehicle** — A vehicle, machine, tractor, trailer, or semi-trailer, or any combination thereof, propelled or drawn by mechanical power and used upon the highways in the transportation of passengers or property. It does not include a vehicle operated exclusively on a rail or rails or a trolley bus operated by electric power derived from a fixed overhead wire, furnishing local passenger transportation similar to street-railway service.

**Multi-Specification Cargo Tank Motor Vehicle** — A cargo tank with two or more cargo tanks fabricated to more than one cargo tank specification.

**Non-Liquefied Compressed Gas** — When packaged under pressure for transportation is entirely gaseous at -50°C (-58°F) with a critical temperature less than or equal to -50°C (-58°F).

**Normal Operating Loading** — A cargo tank motor vehicle equipped with two or more cargo tanks fabricated to more than one cargo tank specification.

**Operator** — A person who controls the use of aircraft, vessel, or vehicle.

**Outer Packaging** — The outermost enclosure of a composite or combination packaging together with any absorbent material, cushioning, and any other components necessary to contain and protect inner receptacles or inner packaging.

**Owner** — The person who owns a cargo tank motor vehicle used for the transportation of hazardous materials, or that person’s authorized agent.

**Packaging** — A receptacle and any other components or materials necessary for the receptacle to perform its containment function in conformance with the minimum packing requirements of Title 49.

**Packing Group** — A grouping according to the degree of danger present by hazardous materials. Packing Group I indicates great danger; Packing Group II indicates medium danger; Packing Group III indicates minor danger.

**Person** — An individual, firm, co-partnership, corporation, company, association, or joint-stock (including any trustee, receiver, assignee, or similar representative); or any government or Indian tribe (or an agency or instrumentality of any government or Indian tribe) that transports hazardous material to further a commercial enterprise or offers a hazardous material for transportation in commerce.

**Poisonous Gas** — A material that is a gas at 20°C (68°F) or less and a pressure of 101.3 kPa (14.7 psia) a material that has a boiling point of 20°C (68°F) or less at 101.3 kPa (14.7 psia) and which:

a) Is known to be so toxic to humans as to pose a hazard to health during transportation; or

b) In the absence of adequate data on human toxicity, is presumed to be toxic to humans because when tested on laboratory animals it has an LC50.

**Poisonous Material** — A material, other than a gas, which is known to be so toxic to humans as to afford a hazard to health during transportation, or which in the absence of adequate data on human toxicity.

**Portable Tanks** — A bulk packaging (except cylinders having a water capacity of 454 kg (1,000 lb) or less) designated primarily to be loaded onto, or on, or temporarily attached to, a transport vehicle or ship and equipped with skids, mountings, or accessories to facilitate handling of the tank by mechanical means. It does not include a cargo tank, tank car, multi-unit tank car tanks, or trailers carrying 3AX, 3AAX, or 3T cylinders.

**psi** — Pounds per square inch.

**psia** — Pounds per square inch absolute.

**psig** — Pounds per square inch gage.

**Qualified Inspector** — An Inspector regularly employed by an ASME Qualified Inspection Organization (QIO) who has been qualified to ASME developed criteria by a written examination, to perform inspections under the rules of any jurisdiction that has adopted the ASME Code. The QI shall not be in the employ of the manufacturer. See ASME XII, TG-410.

**Rail Car** — A car designed to carry freight or nonpassenger personnel by rail, and includes a box car, flat car, gondola car, hopper car, tank car, and occupied caboose.

**Rebarrelling** — Replacing more than 50% of the combined shell and head material of a cargo tank.

**Receptacle** — A containment vessel for receiving and holding materials, including any means of closing.

**Registered Inspector (RI)** — A person registered with the department in accordance with Subpart F of Part 107 of 49 CFR who has the knowledge and ability to determine whether a cargo tank conforms with the applicable DOT specification. In addition, Registered Inspector means a person who meets, at a minimum, any one of the following:

a) Has an engineering degree and one year of work experience;

b) Has an associate degree in engineering and two years of work experience;

c) Has a high school diploma or General Equivalency Diploma and three years work experience; or

d) Has at least three years experience performing the duties of a Registered Inspector by September 1, 1991, and was registered with the DOT by December 31, 1995.

**Repair** — Any welding on a cargo tank wall done to return a cargo tank or a cargo tank motor vehicle to its original design and construction specification, or to a condition prescribed for a later equivalent specification in effect at the time of the repair. Excluded from this category are the following:

a) A change to motor vehicle equipment such as lights, truck, or tractor power train components. Steering and brake systems, suspension parts, and changes to appurtenances, such as fender attachments, lighting brackets, ladder brackets;

b) Replacement of components such as valves, vents, and fittings with a component of a similar design and of the same size; and

c) Replacement of an appurtenance by welding to a mounting pad.

**Replacement of a Barrel** — To replace the existing tank on a motor vehicle chassis with an unused (new) tank.

**SCF (standard cubic foot)** — One cubic foot of gas measured at 16°C (60°F) and 10 kPa (14.7 psi).

**Single Packaging** — A nonbulk packaging other than a combination packaging.

**Solid** — A material that is not a gas or liquid.

**Solution** — Any homogenous liquid mixture of two or more chemical compounds or elements that will not undergo any segregation under conditions normal to transportation.

**Specification Packaging** — A packaging conforming to one of the specifications or standards for packaging in Part 178 or Part 179 of Title 49.

**Strong Outside Container** — The outermost enclosure that provides protection against the unintentional release of its contents under conditions normally incident to transportation.

**Tanks** — A container, consisting of a shell and heads that form the pressure vessel having opening designed to accept pressure tight fittings or closure, excluding any appurtenances, reinforcements, fittings, or closures.

**Test Pressure** — The pressure to which a tank is subjected to determine structural integrity.

**Top Shell** — The tank car surface, excluding the head ends and bottom shell of the tank car.

**Transport Vehicle** — A cargo-car-carrying vehicle such as an automobile, van, tractor, truck, semi trailer, tank car, or rail car used for the transportation of cargo by any mode. Each cargo-carrying body (trailer, rail car, etc.) is a separate transport vehicle.

**UFC** — Uniform Freight Classification.

**UN** — United Nations.

**UN Portable Tank** — An intermodal tank having a capacity of more than 450 l (119 gal.). It includes a shell fitted with service equipment and structural equipment, including stabilizing members external to the shell and skids, mountings, or accessories to facilitate mechanical handling. A UN portable tank must be capable of being filled and discharged without the removal of its structural equipment and must be capable of being lifted when full. Cargo tanks, rail tank car tanks, nonmetallic tanks, nonspecification tanks, bulk bins, and IBC's and packaging made to cylinder specifications are not UN portable tanks.

**UN Recommendation** — The UN Recommendations on the Transport of Dangerous Goods.

**UN Standard Packaging** — A conforming to standards in the UN Recommendations.

**Vessel** — Includes every description of watercraft, used or capable of being used, as a means of transportation on the water.

**Viscous Liquid** — A liquid material that has a measured viscosity in excess of 2,500 centistokes at 25°C (77°F), when determined in accordance with the procedures specified in ASTM Method D 445-72 “Kinematic Viscosity of Transparent and Opaque Liquids (and the Calculation of Dynamic Viscosity),” or ASTM Method D 1200-70 “Viscosity of Paints, Varnishes, and Lacquers by Ford Viscosity Cup.”

## S6.18 TABLES AND FIGURES

a) TABLE S6.13, Periodic Inspections and Tests

b) TABLE S6.13-a, Inservice Minimum Thickness for Steel and Steel Alloys

c) TABLE S6.13-b, Inservice Minimum Thickness for Aluminum and Aluminum Alloys

d) TABLE S6.13.4, Periodic Inspections and Tests

e) TABLE S6.13.6, Pressure Test Requirements

f) TABLE 6.13.11.2-a, Minimum Thickness for Heads

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n) TABLE S6.14, Inspection Intervals

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p) TABLE S6.14.6.4, “T” Codes

q) TABLE S6.15.1-a, Thickness of Plates and Safety Valve Requirements

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s) TABLE S6.15.3, Ton Tank Periodic Inspection and Test Frequencies

# SUPPLEMENT 7
# INSPECTION OF PRESSURE VESSELS IN LIQUEFIED PETROLEUM GAS SERVICE

## S7.1 SCOPE

This supplement provides requirements and guidelines for the inspection of pressure vessels in liquefied petroleum gas (LPG) service.

a) Pressure vessels designed for storing liquefied petroleum gas can be stationary or can be mounted on skids. LPG is generally considered to be non-corrosive to the interior of the pressure vessel. This supplement provides guidelines of a general nature for the owner, user, or jurisdictional authority. There may be occasions where more detailed procedures will be required such as changing from one service to another (e.g., above ground to underground; or pressure vessels that are commercially refurbished).

b) The application of this supplement to underground pressure vessels will only be necessary when evidence of structural damage to the pressure vessel has been observed, leakage has been determined, or the pressure vessel has been dug up, and is to be reinstalled. Special consideration will be given to pressure vessels that are going to be commercially refurbished (see NBIC Part 2, S7.9).

## S7.2 PRE-INSPECTION ACTIVITIES

a) A review of the known history of the pressure vessel should be performed. This should include a review of information, such as:

   1) Operating conditions;

   2) Historical contents of the pressure vessel;

   3) Results of any previous inspection;

   4) Current jurisdictional inspection certificate, if required;

   5) ASME Code symbol stamping or mark of code of construction, if required; and 6) National Board and/or jurisdictional registration number, if required.

b) The pressure vessel shall be sufficiently cleaned to allow for visual inspection. For commercially refurbished pressure vessels see NBIC Part 2, S7.9.

## S7.3 INSERVICE INSPECTION FOR PRESSURE VESSELS IN LP GAS SERVICE

The type of inspection given to pressure vessels should take into consideration the condition of the pressure vessel and the environment in which it operates. The inspection may be external or internal, and use a variety of nondestructive examination methods. Where there is no reason to suspect an unsafe condition or where there are no inspection openings, internal inspections need not be performed. When service conditions change from one service to another, i.e. above ground to underground; or pressure vessels that are commercially refurbished, an internal inspection may be required. The external inspection may be performed when the pressure vessel is pressurized or depressurized, but shall provide the necessary information that the essential sections of the pressure vessel are of a condition to operate.

### S7.3.1 NONDESTRUCTIVE EXAMINATION (NDE)

Listed below are a variety of methods that may be employed to assess the condition of the pressure vessel. These examination methods should be implemented by experienced and qualified individuals. Generally, some form of surface preparation will be required prior to the use of these examination methods: visual,

magnetic particle, liquid penetrant, ultrasonic, radiography, radioscopy, eddy current, metallographic examination, and acoustic emission. When there is doubt as to the extent of a defect or detrimental condition found in a pressure vessel, additional NDE may be required.

## S7.4 EXTERNAL INSPECTION

The pressure vessel shall be inspected for corrosion, distortion, cracking, or other conditions as described in this section. In addition, the following should be reviewed, where applicable:

a) Insulation or Coating

If the insulation or coating is in good condition and there is no reason to suspect an unsafe condition behind it, then it is not necessary to remove the insulation or coating in order to inspect the pressure vessel. However, it may be advisable to remove a small portion of the insulation or coating in order to determine its condition and the condition of the pressure vessel surface. For commercially refurbished pressure vessels see NBIC Part 2, S7.9.

b) Evidence of Leakage

Any leakage of vapor or liquid shall be investigated. Leakage coming from behind insulation or coating, supports, or evidence of past leakage shall be thoroughly investigated by removing any insulation necessary until the source is established.

c) Structural Attachments

The pressure vessel mountings should be checked for adequate allowance for expansion and contraction, such as provided by slotted bolt holes or unobstructed saddle mountings. Attachments of legs, saddles, skirts, or other supports should be examined for distortion or cracks at welds.

d) Pressure Vessel Connections

Components that are exterior to the pressure vessel and are accessible without disassembly shall be inspected as described in this paragraph. Manholes, reinforcing plates, nozzles, couplings, or other connections shall be examined for cracks, deformation, or other defects. Bolts or nuts should be examined for corrosion or defects. Weep holes in reinforcing plates shall remain open to provide visual evidence of leakage as well as to prevent pressure buildup between the pressure vessel and the reinforcing plate. Accessible flange faces should be examined for distortion. It is not intended that flanges or other connections be opened unless there is evidence of corrosion to justify opening the connection.

e) Fire Damage

Pressure vessels shall be carefully inspected for evidence of fire damage. The extent of fire damage determines the repair that is necessary, if any (See NBIC Part 2, S7.7).

## S7.5 INTERNAL INSPECTION

When there is a reason to suspect an unsafe condition, the suspect parts of the pressure vessel shall be inspected and evaluated. The pressure vessel shall be prepared and determined to be gas-free and suitable for human entry prior to internal inspection (See NBIC Part 2, 2.3.4).

## S7.6 LEAKS

Leakage is unacceptable. When leaks are identified, the pressure vessel shall be removed from service until repaired by a qualified repair organization or permanently removed from service.

## S7.7 FIRE DAMAGE

a) Pressure vessels in which bulging exceeds the limits of NBIC Part 2, S7.8.3 or distortion that exceeds the limits of the original code of construction (e.g., ASME Section VIII, Div. 1), shall be removed from service until repaired by a qualified repair organization or permanently removed from service.

b) Common evidence of exposure to fire is:

   1) Charring or burning of the paint or other protective coat;

   2) Burning or scarring of the metal;

   3) Distortion; or

   4) Burning or melting of the valves.

c) A pressure vessel that has been subjected to action of fire shall be removed from service until it has been properly evaluated. The general intent of this requirement is to remove from service pressure vessels which have been subject to action of fire that has changed the metallurgical structure or the strength properties of the steel. Visual examination with emphasis given to the condition of the protective coating can be used to evaluate exposure from a fire. This is normally determined by visual examination as described above with particular emphasis given to the condition of the protective coating. If there is evidence that the protective coating has been burned off any portion of the pressure vessel surface, or if the pressure vessel is burned, warped, or distorted, it is assumed that the pressure vessel has been overheated. If, however, the protective coating is only smudged, discolored, or blistered, and is found by examination to be intact underneath, the pressure vessel shall not be considered affected within the scope of this requirement. Pressure vessels that have been involved in a fire and show no distortion shall be requalified for continued service by retesting using the liquid pressure test procedure applicable at the time of original fabrication.

d) Subject to the acceptance of the Jurisdiction and the Inspector, alternate methods of pressure testing may be used.

## S7.8 ACCEPTANCE CRITERIA

The acceptance criteria for LPG pressure vessels is based on successfully passing inspections without showing conditions beyond the limits shown below.

### S7.8.1 CRACKS

Cracks in the pressure boundary (e.g., heads, shells, welds) are unacceptable. When a crack is identified, the pressure vessel shall be removed from service until the crack is repaired by a qualified repair organization or permanently retired from service. (See NBIC Part 3, Repairs and Alterations).

### S7.8.2 DENTS

a) Shells

   The maximum mean dent diameter in shells shall not exceed 5% of the shell diameter, and the maximum depth of the dent shall not exceed 5% of the mean dent diameter. The mean dent diameter is defined as the average of the maximum dent diameter and the minimum dent diameter. If any portion of the dent is closer to a weld than 5% of the shell diameter, the dent shall be treated as a dent in a weld area, see b) below.

b) Welds

The maximum mean dent diameter on welds (i.e., part of the deformation includes a weld) shall not exceed 10% of the shell diameter. The maximum depth shall not exceed 5% of the mean dent diameter.

c) Head

The maximum mean dent diameter on heads shall not exceed 10% of the shell diameter. The maximum depth shall not exceed 5% of the mean dent diameter. The use of a template may be required to measure dents on heads.

d) When dents are identified which exceed the limits set forth in these paragraphs, the pressure vessel shall be removed from service until the dents are repaired by a qualified repair organization or permanently retired from service.

### S7.8.3 BULGES

a) Shells

If a bulge is suspected, the circumference shall be measured at the suspect location and in several places remote from the suspect location. The variation between measurements shall not exceed 1%.

b) Heads

1) If a bulge is suspected, the radius of curvature shall be measured by the use of templates. At any point the radius of curvature shall not exceed 1.25% of the diameter for the specified shape of the head.

2) When bulges are identified that exceed the limits set forth in these paragraphs, the pressure vessel shall be removed from service until the bulges are repaired by a qualified repair organization or permanently retired from service.



### S7.8.4 CUTS OR GOUGES

When a cut or a gouge exceeds 25% of the thickness of the pressure vessel, the pressure vessel shall be removed from service until it is repaired by a qualified repair organization or permanently removed from service.

### S7.8.5 CORROSION

a) Line and Crevice Corrosion

For line and crevice corrosion, the depth of the corrosion shall not exceed 25% of the original wall thickness.

b) Isolated Pitting

1) Isolated pits may be disregarded provided that:

a. Their depth is not more than 25% the required thickness of the pressure vessel wall;

b. The total area of the pits does not exceed 7 sq. in. (4,500 sq. mm) within any 8 in. (200 mm) diameter circle; and

c. The sum of their dimensions along any straight line within this circle does not exceed 2 in. (50 mm).

c) General Corrosion

For a corroded area of considerable size, the thickness along the most damaged area may be averaged over a length not exceeding 10 in. (250 mm). The thickness at the thinnest point shall not be less than 75% of the required wall thickness, and the average shall not be less than 90% of the required wall thickness. When general corrosion is identified that exceeds the limits set forth in this paragraph, the pressure vessel shall be removed from service until it is repaired by a qualified "R" Stamp holder or permanently removed from service unless an acceptable for service evaluation is performed in accordance with NBIC Part 2, 4.4.

d) When general, localized or pitting corrosion exceeds the specified corrosion/erosion allowance, but meets the requirements of b) and c), consideration should be given to previous inspections. Patterns of corrosion and damage that are expected to occur over the future service life should be used to determine a specific inspection plan. Repairs may be necessary to maintain a safe and satisfactory operating condition.

### S7.8.6 ANHYDROUS AMMONIA SERVICE

Pressure vessels of 3000 gal. (11.4 $m^3$) water capacity or less used to store anhydrous ammonia, except for pressure vessels used in cargo tank vehicle service, shall not be converted to LPG service.

Cargo tank pressure vessels less than 3000 gal. (11.4 $m^3$) water capacity to be converted from ammonia to LPG service shall be wet-fluorescent magnetic particle tested (WFMT) on all internal surfaces (see NBIC Part 2, 2.3.6.4).

Blue coloring of the brass valves is one indication that the pressure vessel has been in anhydrous ammonia service.

## S7.9 ASME LPG PRESSURE VESSELS LESS THAN 2000 GALLONS BEING REFURBISHED BY A COMMERCIAL SOURCE (23)

Commercially refurbished pressure vessels are used pressure vessels that are temporarily taken out of service for repair and or renewal and sent to a company which specializes in this type of work. Because the history of some of these pressure vessels is unknown, special attention shall be given to inspection and repair before returning any of these pressure vessels back to service. ASME LPG pressure vessels less than 2,000 gal. (7,570 l) may be refurbished subject to the following conditions:

a) A complete external inspection shall be completed under the guidelines of this supplement. If any defects are found, as defined in S7.8.1 through S7.8.5, the defect shall be repaired under NBIC Part 3, Repairs and Alterations, by qualified personnel or permanently removed from service;

b) Pressure vessels of this size that have been previously used in anhydrous ammonia service shall not be converted to LPG service. See NBIC Part 2, S7.8.6;

c) The coating on the outside of the pressure vessel shall be removed down to bare metal so that an inspection can be performed under the guidelines of this supplement; and

d) Verify that there is no internal corrosion if the pressure vessel has had its valves removed or is known to have been out of service for an extended period.

e) Removal and re-attachment of the original manufacturer's nameplate shall only be done in accordance with NBIC Part 2, 5.2.4.

## S7.10 REQUIREMENTS FOR CHANGE OF SERVICE FROM ABOVE GROUND TO UNDERGROUND SERVICE

ASME LPG pressure vessels may be altered from above ground (AG) service to underground (UG) service subject to the following conditions.

a) Pressure vessels that have been previously used in anhydrous ammonia service are not permitted to be converted to LPG service.

b) The outside surface of the pressure vessel shall be cleaned to bare metal for an external inspection of the pressure vessel under the guidelines of this supplement. Prior to placing underground, the outside surface of the pressure vessel shall be prepared consistent with the paint manufactures specification and coated with a coating suitable for UG service. Any touch-up coating shall be the same coating material. All corrosion shall be repaired in accordance with the NBIC.

c) Verify that there is no internal corrosion due to valves having been removed while the pressure vessel is out or service.

d) Any unused connections located on the pressure vessel shall be closed by seal welding around a forged plug or removed using a flush patch. If a flush patch is used the material shall be the same material thickness and material grade as the original code of construction.

e) All connections on top of the pressure vessel, except for the liquid withdrawal opening, shall be replaced with a riser pipe with multi-valve suitable for UG LPG service. The valve shall be enclosed in a protective housing and placed underground in accordance with jurisdictional requirements.

f) The liquid withdrawal opening shall be located within the protective housing.

g) The liquid level tube in the multivalve shall be the length required according to jurisdictional requirements.

h) The NBIC nameplate shall be made of stainless steel and continuous welded to the pressure vessel wall. The nameplate shall also have the information from the original nameplate. This shall include the manufactures name, pressure vessel serial number, National Board number, (if registered with the National Board) MAWP, year built, head and shell thickness, be stamped for “UG service”, the “liquid level tube length = inches” and the National Board “R” stamp. The original manufacturer’s nameplate shall remain attached to the pressure vessel. See Part 2, Section 5.2 of this Part and NBIC, Part 3, Section 5.7 for additional stamping requirements.

i) The support legs and lifting lugs may remain in place and shall be welded around the entire periphery to prevent crevices that create a potential area for corrosion. Unused attachments shall be removed and welds ground flush.

j) A connection shall be added for the attachment of an anode for cathodic protection, per NFPA, 58.

k) All welding shall be performed by a holder of a current “R” Certificate of Authorization in accordance with NBIC Part 3.

## SUPPLEMENT 8
## PRESSURE DIFFERENTIAL BETWEEN SAFETY OR SAFETY RELIEF VALVE SETTING AND BOILER OR PRESSURE VESSEL OPERATING PRESSURE

### S8.1 SCOPE

This supplement provides guidelines for determining the pressure differential between the pressure relief valve setting and the boiler or pressure vessel operating pressure. If a pressure relief valve is subjected to pressure at or near its set pressure, it will tend to weep or simmer, and deposits may accumulate in the seat and disk area. Eventually, this can cause the valve to freeze closed and thereafter the valve could fail to open at the set pressure. Unless the source of pressure to the boiler or pressure vessel is interrupted, the pressure could exceed the rupture pressure of the vessel. It is important that the pressure differential between the valve set pressure and the boiler or pressure vessel operating pressure is sufficiently large to prevent the valve from weeping or simmering.

### S8.2 HOT-WATER HEATING BOILERS

For hot-water heating boilers, the recommended pressure differential between the pressure relief valve set pressure and the boiler operating pressure should be at least 10 psi (70 kPa), or 25% of the boiler operating pressure, whichever is greater. Two examples follow:

a) If the pressure relief valve of a hot-water heating boiler is set to open at 30 psi (200 kPa), the boiler operating pressure should not exceed 20 psi (140 kPa).

b) If the pressure relief valve of a hot water heating boiler is set to open at 100 psi (700 kPa), the boiler operating pressure should not exceed 80 psi (550 kPa). Section IV of the ASME Code does not require that pressure relief valves used on hot water heating boilers have a specified blowdown. Therefore, to help ensure that the pressure relief valve will close tightly after opening and when the boiler pressure is reduced to the normal operating pressure, the pressure at which the valve closes should be well above the operating pressure of the boiler.



### S8.3 STEAM HEATING BOILERS

For steam heating boilers, the recommended pressure differential between the pressure relief valve set pressure and boiler operating pressure should be at least 5 psi (35 kPa), i.e., the boiler operating pressure should not exceed 10 psi (70 kPa).

Since some absorption-type refrigeration systems use the steam heating boiler for their operation, the boiler operating pressure may exceed 10 psi (70 kPa). If the boiler operating pressure is greater than 10 psi (70 kPa), it should not exceed 15 psi (100 kPa), minus the blowdown pressure of the pressure relief valve.

This recommendation can be verified by increasing the steam pressure in the boiler until the pressure relief valve pops, then slowly reducing the pressure until it closes, to ensure that this closing pressure is above the operating pressure.

### S8.4 POWER BOILERS

For power boilers (steam), the recommended pressure differentials between the pressure relief valve set pressure and the boiler operating pressure (see NBIC Part 2, Table S8.4).

## TABLE S8.4

(MINIMUM PRESSURE DIFFERENTIAL AS PERCENTAGE OF BOILER DESIGN PRESSURE)

| Boiler Design Pressure | Minimum Pressure Differential |
|---|---|
| over 15 psi to 300 psi (100 KPa to 2.10 MPa): | 10% but not less than 7 psi (50 KPa) |
| over 300 psi to 1000 psi (2.14 MPa to 6.89 MPa): | 7% but not less than 30 psi (200 KPa) |
| over 1000 psi to 2000 psi (6.89 MPa to 13.8 MPa): | 5% but not less than 70 psi (480 KPa) |
| over 2000 psi (13.8 MPa) | per designer's judgment |

**Notes:**

1) Above 2000 psi (13.8 MPa) the pressure differential between operating pressure and the maximum allowable working pressure is a matter for the designer's judgment , taking into consideration such factors as satisfactory operating experience and the intended service conditions.

2) Pressure relief valves in hot water service are more susceptible to damage and subsequent leakage, than pressure relief valves relieving steam. It is recommended that the maximum allowable working pressure of the boiler and pressure relief valve setting for high-temperature hot-water boilers be selected substantially higher than the desired operating pressure, so as to minimize the time the pressure relief valve must lift.

3) For organic fluid vaporizers a pressure differential of 40 psi (280 kPa) is recommended.

## S8.5 PRESSURE VESSELS



Due to the variety of service conditions and the various designs of pressure relief valves, only general guidelines can be given regarding differentials between the set pressure of the valve and the operating pressure of the vessel. Operating difficulty will be minimized by providing an adequate differential for the application. The following is general advisory information on the characteristics of the intended service and of the pressure relief valves that may bear on the proper pressure differential selection for a given application. These considerations should be reviewed early in the system design since they may dictate the maximum allowable working pressure of the system.

To minimize operational problems it is imperative that the user consider not only normal operating conditions of the fluids (liquids or gases), pressures, and temperatures, but also start-up and shutdown conditions, process upsets, anticipated ambient conditions, instrument response time, and pressure surges due to quick-closing valves, etc. When such conditions are not considered, the pressure relief devices may become, in effect, a pressure controller, a duty for which they were not designed. Additional consideration should be given to the hazard and pollution associated with the release of the fluid. Larger differentials may be appropriate for fluids which are toxic, corrosive, or exceptionally valuable.

The blowdown characteristics and capabilities are the first consideration in selecting a compatible valve and operating margin. After a self-actuated release of pressure, the valve must be capable of reclosing above the normal operating pressure. For example: if the valve is set at 100 psi (700 kPa) with a 7% blowdown, it will close at 93 psi (640 kPa). The operating pressure must be maintained below 93 psi (640 kPa) in order to prevent leakage or flow from a partially open valve. Users should exercise caution regarding the blowdown adjustment of large, spring-loaded valves. Test facilities, whether owned by the manufacturer, repair house, or user, may not have sufficient capacity to accurately verify the blowdown setting. The setting cannot be considered accurate unless made in the field on an actual installation.

Pilot operated valves represent a special case from the standpoint of both blowdown and tightness. The pilot portion of some pilot operated valves can be set at blowdowns as short as 2%. This characteristic is not, however, reflected in the operation of the main valve in all cases. The main valve can vary considerably from the pilot depending on the location of the two components in the system. If the pilot is installed remotely from the main valve, significant time and pressure lags can occur, but reseating of the pilot

ensures reseating of the main valve. The pressure drop in connecting piping between the pilot and the main valve must not be excessive, otherwise the operation of the main valve will be adversely affected.

Tightness capability is another factor affecting valve selection, whether spring-loaded or pilot operated. Tightness varies somewhat depending on whether metal or resilient seats are specified and also on such factors as corrosion and temperature. The required tightness and test method should be specified to comply at a pressure not lower than the normal operating pressure of the process. It should be remembered that any degree of tightness obtained should not be considered permanent. Service operation of a valve almost invariably reduces the degree of tightness.

The following minimum pressure differentials are recommended unless the pressure relief valve has been designed or tested in a specific or similar service and a smaller differential has been recommended by the manufacturer:

| Set Pressure | Recommended pressure differential |
|---|---|
| up to 70 psi (480 kPa) | 5 psi (35 kPa) |
| 70 – 1000 psi (480 kPa – 6.89 MPa) | 10% of set pressure |
| Above 1000 psi (6.89 MPa) | 7% of set pressure |

# SUPPLEMENT 9
# REQUIREMENTS FOR CHANGE OF SERVICE

## S9.1 SCOPE

This supplement provides requirements and guidelines to be followed when a change of service or service type is made to a pressure-retaining item.

Whenever there is a change of service, the jurisdiction where the pressure-retaining item is to be operated shall be notified for acceptance. Any specific jurisdictional requirements shall be met.

## S9.2 CLASSIFICATION OF SERVICE CHANGES

### S9.2.1 SERVICE CONTENTS

A change in service contents is considered to be any modification to the commodity or contents that the pressure-retaining item was originally intended to contain when the pressure-retaining item was constructed.

For example, a change:

a) From LP gas service to air receiver service.

b) From lethal to non lethal service.

### S9.2.2 SERVICE TYPE OR CHANGE OF USAGE

A change in service type is considered to be a change of how the pressure-retaining item is being used.

For example, a change:

a) From above ground service to underground service for LP gas tanks.

b) From mobile or transport use to stationary use.

## S9.3 FACTORS TO CONSIDER

Before a change of service is to be made, the owner or user shall consider and evaluate the effects of the new operating conditions or environment on the existing condition and suitability for service of the pressure-retaining item. Various factors will have an impact on the reliability of the pressure-retaining item in its new service environment. Changes can be successfully adopted providing there is an understanding of the effect on the pressure-retaining item. However, there are some cases where changes are detrimental to the existing pressure-retaining item. The owner or user should seek technical guidance of experienced personnel in appropriate areas affected by the change of service (e.g. design, metallurgy, or operations of the pressure retaining item).

The following is a listing of criteria that should be evaluated as appropriate. The criterion is not limited to that listed herein. Other factors may be considered as necessary;

a) Design Consideration:

    1) Thickness of existing vessel material.

    2) Vessel or system flow rate or pressure.

    3) Weight of vessel with new contents.

4) Existing or additional loads imposed on nozzles and highly stressed areas.

5) Change in pressure or temperature, and cycling.

6) Compliance to product or industry standards, such as ANSI K61, API 579, or NFPA 58.

b) Material Consideration:

1) Chemical and mechanical properties of existing material or any new material to be added or replaced to ensure it has the required strength and toughness to withstand the pressure and temperature effects of the new environment.

2) Effects of erosion or corrosion.

3) Time dependent effects on service life - creep or fatigue, or both effects combined.

c) Environment

1) Physical condition of the pressure-retaining item.

2) Overpressure protection needs.

3) Regulatory environment – Verification of compliance to new or existing jurisdictional rules or regulations.

4) Vessel cleanliness – When changing lading fluids or contents consideration should be given to cleaning or decontaminating the vessel as appropriate.

d) Operational History

1) A review of current and past operational logs or records should be made to ensure that no conditions existed where any further use would render the pressure-retaining item hazardous or otherwise unsafe.

2) Records to be obtained and reviewed would include Manufacturer's Data Reports, Repair and Alteration Forms, Inspection reports, etc.

e) Repairs and Alterations Made:

A review of any repairs, alterations, reratings, or reconfigurations that have been performed on the pressure-retaining item, so as to ensure that they will not have a detrimental impact on the intended use.

f) Proposed Rework

1) Any physical work to be performed to restore the material to the existing or intended state or to meet any requirements for the new operating conditions.

2) Repairs and alterations shall be performed in accordance with NBIC Part 3, *Repair and Alterations*.

3) The effects of heat applied as a result of welding or heat treatment on the material or shaped parts.

4) The method and extent of any physical or non destructive examination should be considered.

5) Any physical testing or pressure testing to be performed to determine or verify leak tightness or structural integrity of the pressure-retaining item.

6) The pressure-retaining item shall meet the code requirements for the new environment at the time of change.

g) Documentation

1) Review existing records that are required to satisfy customer, user, or legal requirements.

2) Review the need for any marking, stamping, or labeling required for the intended service.

3) Review the need for developing or revising an inspection plan to ensure safe operation. Refer to Part 2, Section 1.5.2.1, *Inspection Plan*.

## S9.4 SOME EXAMPLES FOR CHANGE OF SERVICE

Table S9.4 lists examples of what constitutes a change in service and some factors to consider. Note: This list is not all inclusive. There may be other service changes not mentioned.

The listing of "Factors to Consider" is also not all inclusive. There may be other elements that can influence the safe and reliable operation of the pressure retaining item.

The owner shall check with the Jurisdiction where the pressure retaining item is to operate in the new environment, and review local building codes, laws, and regulations for additional requirements or prohibitions against a change of service.

### TABLE S9.4

EXAMPLES OF CHANGE OF SERVICE CONDITIONS

| Change | Some Factors to Consider |
|---|---|
| LP Gas to Ammonia | • PWHT of Vessel During Construction Wet-fluorescent magnetic particle testing (WFMT) on all internal surfaces<br>• Internal access of vessel is necessary, may need to install manhole<br>• NFPA 58 should be consulted |
| Ammonia to LP gas | • NFPA 58 should be consulted for restrictions.<br>• Wet-fluorescent magnetic particle testing (WFMT) on all internal surfaces<br>• Internal access of vessel is necessary., may need to install manhole<br>• Also see, NBIC Part 2, 2.3.6.4, S7.8.6, S7.9 |
| LP gas service: from above ground to underground | • Requires alterations (additional nozzles)<br>• Corrosion protection<br>• See NFPA 58 |
| LP gas to air receiver | • Assurance of vessel cleanliness, i.e. removal of mercaptan<br>• Appropriateness and number of inspection and drain openings<br>• Corrosion allowance |
| Boiler Service: steam to hot water | • Nozzles may require modification for water inlet and outlet<br>• Change of Pressure Relief Device |

| Change | Some Factors to Consider |
|---|---|
| Boiler Service: High-Pressure to Low-Pressure | • Controls required by the LP boiler code<br>• Safety Valve Change<br>• Need for larger openings for steam outlets and safety relief valves |
| Sulfur Dioxide Service Sweet to Sour Gas Service | • Concern Over Hydrogen Cracking |
| Inert to Oxidizing or Reducing Atmosphere | • Inspection for Damage mechinisims that may be present from previous service life that is detrimental to the vessel in the new environment<br>• Cleanliness of Hydrocarbons |
| Lethal Service to Non-Lethal | • Design Conditions and suitability for service |
| DOT Railcars of ICC Transport Tanks to Stationary Service | • Prohibited by DOT regulations for permanent service<br>• Temporary stationary service prohibited as per NFPA<br>• Inspection or damage mechanisms that may be present from previous service life that is detrimental to the vessel in the new environment |

## S9.5 DOCUMENTATION OF CHANGE OF SERVICE

Any records, forms, or reports required documenting the change of service event that may be required by contract or the jurisdiction where the pressure retaining item operates shall be completed. Such documentation should be retained by the owner or user for future reference or use as needed.

## SUPPLEMENT 10
## INSPECTION OF STATIONARY HIGH-PRESSURE (3,000-15,000 psi) (21-103 MPa) COMPOSITE PRESSURE VESSELS

### S10.1 SCOPE

This supplement provides specific requirements and guidelines for inspection of high-pressure composite pressure vessels, hereafter referred to as vessels. This supplement is applicable to pressure vessels with a design pressure that exceeds 3,000 psi (21 MPa) but not greater than 15,000 psi (103 MPa), and is applicable to the following four types of pressure vessels:

a) Metallic vessel with a hoop Fiber Reinforced Plastic (FRP) wrap over the cylindrical part of the vessel (both load sharing).

b) Fully wrapped FRP vessel with a non-load sharing metallic liner.

c) Fully wrapped FRP vessel with a non-load sharing non-metallic liner.

d) Fully wrapped FRP vessel with load sharing metallic liner.

This supplement is intended for inspection of ASME Section X, Class III, vessels and ASME Section VIII, Division 3, Composite Reinforced Pressure Vessels (CRPVs). However, it may be used for inspection of similar vessels manufactured to other construction codes with approval of the jurisdiction in which the vessels are installed.



### S10.2 GENERAL

a) High-pressure composite vessels are used for the storage of fluids at pressures up to 15,000 psi (103 MPa). Composite vessels consist of the FRP laminate with load sharing or non-load sharing metallic shells/liners, or nonmetallic liners. The FRP laminate with load sharing metallic liners form the pressure retaining system. The FRP laminate is the pressure-retaining material for composite vessels with non-load sharing metallic and nonmetallic liners. The purpose of the non-load sharing metallic and the nonmetallic liners is to minimize the permeation of fluids through the vessel wall.

b) Fluids stored in vessels are considered to be non corrosive to the materials used for vessel construction. The laminate is susceptible to damage from:

    1) External chemical attack.

    2) External mechanical damage(i.e. abrasion, impact, cuts, dents, etc.).

    3) Structural damage (i.e. over pressurization, distortion, bulging, etc.).

    4) Environmental degradation [i.e. ultraviolet (if there is no pigmented coating or protective layer), ice, etc.].

    5) Fire or excessive heat.

### S10.3 INSPECTOR QUALIFICATIONS

a) The Inspector referenced in this supplement is a National Board Commissioned Inspector complying with the requirements of NB-263, RCI-1 *Rules for Commissioned Inspector*.

b) The inspector shall be familiar with vessel construction and qualified by training and experience as described in NBIC Part 2, S4.5 to conduct such inspections. The inspector shall have a thorough understanding of all required inspections, tests, test apparatus, inspection procedures, and inspection

techniques and equipment applicable to the types of vessels to be inspected. The inspector shall have basic knowledge of the vessel material types and properties. Refer to Part 2, S4.2 and S4.5

## S10.4 INSPECTION FREQUENCY

a) Initial Inspection

The vessel shall be given an external visual examination by the Inspector or the Authority having jurisdiction where the vessel is installed and during the initial filling operation. The examination shall check for any damage during installation prior to initial filling and for any leaks or damage during and at the conclusion of filling.

b) Subsequent Filling Inspections

Before each refilling of the vessel, the manager of the facility shall visually examine the vessel exterior for damage or leaks. Refilling operations shall be suspended if any damage or leaks are detected and the vessel shall be emptied and subsequently inspected by the Inspector to determine if the vessel shall remain in service.

c) Periodic Inspection

Within 30 days of the anniversary of the initial operation of the vessel during each year of its service life, the vessel shall be externally examined by the Inspector or the Authority having jurisdiction where the vessel is installed. Internal inspections shall only be required if any of the conditions of S10.9 a) are met. These examinations are in addition to the periodic acoustic emission examination requirements of S10.5 c).

## S10.5 INSERVICE INSPECTION

a) NBIC Part 2, Section 1, of this part shall apply to inspection of high-pressure vessels, except as modified herein. This supplement covers vessels, and is not intended to cover piping and ductwork, although some of the information in this supplement may be used for the inspection of piping and ductwork.

b) The inspection and testing for exposed load sharing metallic portions of vessels shall be in accordance with NBIC Part 2, Section 2.3.

c) All composite vessels shall have an initial acoustic emission examination per S10.10 at a maximum examination interval of five years which may be more frequent based on the results of any external inspection per S10.8 or internal inspections per S10.9.

All vessels shall be subject to the periodic inspection frequency given in S10.4.

## S10.6 ASSESSMENT OF INSTALLATION

a) The visual examination of the vessel requires that all exposed surfaces of the vessel are examined to identify any degradation, defects, mechanical damage, or environmental damage on the surface of the vessel.

The causes of damage to vessels are:

1) abrasion damage;

2) cut damage;

3) impact damage;

4) structural damage;

5) chemical or environmental exposure damage or degradation; and

6) heat or fire damage.

The types of damage found are:

1) cracks;

2) discolored areas;

3) gouges and impact damage;

4) leaks;

5) fiber exposure;

6) blisters;

7) delaminations;

8) surface degradation; and

9) broken supports.

b) The visual examination of the vessel requires that the identity of the vessel shall be verified. This shall include the construction code (ASME) to which the vessel was constructed, vessel serial number, maximum allowable operating pressure, date of manufacture, vessel manufacturer, date of expiration of the service life of the vessel, and any other pertinent information shown on the vessel or available from vessel documents. The overall condition of the vessel shall be noted.



## S10.7 VISUAL EXAMINATION

a) Acceptable Damage

Acceptable damage or degradation is minor, normally found in service, and considered to be cosmetic. This level of damage or degradation does not reduce the structural integrity of the vessel. This level of damage or degradation should not have any adverse effect on the continued safe use of the vessel. This level of damage or degradation does not require any repair to be performed at the time of in-service inspection. When there is an external, non load bearing, sacrificial layer of filaments on the vessel, any damage or degradation should be limited to this layer. Damage or degradation of the structural wall shall not exceed the limits specified in Tables S10.7-a or S10.7-b.

b) Rejectable Damage (Condemned—Not Repairable)

Rejectable damage or degradation is so severe that structural integrity of the vessel is sufficiently reduced so that the vessel is considered unfit for continued service and shall be condemned and removed from service. No repair is authorized for vessels with rejectable damage or degradation.

c) Acceptance Criteria for Repairable Damage

Certain, specific types of damage can be identified by the external in-service visual examination. Indications of certain types and sizes may not significantly reduce the structural integrity of the vessel and may be acceptable so the vessel can be left in service. Other types and larger sizes of damages may reduce the structural integrity of the vessel and the vessel shall be condemned and removed from service. Tables S10.7-a or S10.7-b are a summary of the acceptance/rejection criteria for the indications that are found by external examination of the vessel.

d) Fitness for Service

1) If a visual examination reveals that a vessel does not meet all criteria of Table S10.7-a or S10.7-b satisfactorily, it shall be taken out of service immediately, and either be condemned or a fitness for service examination be conducted by the original vessel manufacturer or legal successor who must also hold a National Board "R" certificate. When the vessel is taken out of service, its contents shall be immediately safely vented or transferred to another storage vessel per the owner's written safety procedures.

2) If a fitness for service examination is to be conducted, the original vessel manufacturer shall be contacted as soon as possible after the rejectable defects have been found. The manufacturer shall then determine the vessel fitness-for-service by applicable techniques, (e.g., acoustic emission testing, ultrasonic testing, and/or other feasible methods). The manufacturer shall have documentation that the evaluation method(s) used is satisfactory for determining the condition of the vessel. Repairs to the outer protective layer may be made by a "R" certificate holder other than the original manufacturer following the original manufacturer's instructions.

3) Determination of fitness for service is restricted to original manufacturer or legal successor.

**TABLE S10.7-a**

VISUAL ACCEPTANCE/REJECTION CRITERIA FOR COMPOSITE PRESSURE VESSELS (U.S. CUSTOMARY UNITS)

| Type of Degradation or Damage | Description of Degradation or Damage | Acceptable Level of Degradation or Damage | Rejectable Level of Degradation or Damage |
|---|---|---|---|
| Abrasion | Abrasion is damage to the filaments caused by wearing or rubbing of the surface by friction. | Less than 0.050 in. depth in the pressure bearing thickness. | ≥ 0.050 in. depth in the pressure bearing thickness. |
| Cuts | Linear indications flaws caused by an impact with a sharp object. | Less than 0.050 in. depth in the pressure bearing thickness. | ≥ 0.050 in. depth in the pressure bearing thickness. |
| Impact Damage | Damage to the vessel caused by striking the vessel with an object or by being dropped. This may be indicated by discoloration of the composite or broken filaments and/or cracking. | Slight damage that causes a frosted appearance or hairline cracking of the resin in the impact area. | Any permanent deformation of the vessel or damaged filaments. |
| Delamination | Lifting or separation of the filaments due to impact, a cut, or fabrication error. | Minor delamination of the exterior coating less than a depth of 0.050 in. | Any loose filament ends showing on the surface at a depth ≥ 0.050 in. Any bulging due to interior delaminations. |
| Heat or Fire Damage | Discoloration, charring or distortion of the composite due to temperatures beyond the curing temperature of the composite. | Merely soiled by soot or other debris, such that the cylinder can be washed with no residue. | Any evidence of thermal degradation or discoloration or distortion. |

| Type of Degradation or Damage | Description of Degradation or Damage | Acceptable Level of Degradation or Damage | Rejectable Level of Degradation or Damage |
|---|---|---|---|
| Structural Damage – bulging, distortion, depressions | Change in shape of the vessel due to severe impact or dropping. | None | Any visible distortion, bulging, or depression. |
| Chemical attack | Environmental exposure that causes a change in the composite or failure of the filaments. | Any attack that can be cleaned off and that leaves no residue or evidence of permanent damage. | Any permanent discoloration or loss or softening of material under the exterior coat. |
| Cracks | Sharp, linear indications | None | None |
| Scratches/Gouges | Sharp, linear indications caused by mechanical damage. | Less than 0.050 in. depth in the pressure bearing thickness No structural fibers cut or broken. | ≥ 0.050 in. depth in the pressure bearing thickness or structural fibers cut or broken. |
| Soot | A deposit on the composite caused by thermal or environmental exposure. | Soot that washes off and leaves no residue. | Any permanent marking that will not wash off the surface under the exterior coating. |
| Over pressurization | Excessive pressure due to operational malfunction. | Pressure between MAWP and test pressure, with the approval of the manufacturer. | Any report of pressurization beyond the test pressure or any indication of distortion. |
| Corrosion | Degradation of the composite due to exposure to specific corrosive environments. | None visible in excess of manufacturer's specification. | Any surface damage to structural material identified as corrosion beyond the manufacturer's specification. (See Note 2) |
| Dents | A depression in the exterior of the vessel caused by impact or dropping. | < 1/16 in. in depth | Any dents with a depth ≥ 1/16 in. Or with a diameter greater than 2 inches. |
| Reported collision, accident, or fire | Damage to the vessel caused by unanticipated excursion from normally expected operating conditions. | None reported | Any indication or report of impact or heat damage. |
| Environmental Damage or Weathering | Ultraviolet or other environmental attack under the exterior coating.. | None | Any discoloration that can not be washed off. (See Note 2) |
| Damage to a protective or sacrificial layer | Abrasion, cuts, chemical attack, scratches/gouges, corrosion, environmental damage, or crazing that are limited only to the protective or sacrificial layer. | The depth of any damage to the protective or sacrificial layer that does not exceed the thickness of the protective or sacrificial layer plus 0.050 inch. | The depth of any damage to the protective or sacrificial layer that exceeds the thickness of the protective or sacrificial layer plus 0.050 inch. |
| Crazing | Hairline surface cracks only in the composite resin. | Light hairline cracks only in the resin. | Any damage to the filaments. |

**Note 1:**

Only damage beyond the sacrificial or coated layer should be considered, and that any damage to sacrificial or coated layers should be repaired by suitable techniques (i.e. epoxy filler). Refer to Manufacturer's Data Report for sacrificial layer thickness.

**Note 2:**

Washing off UV scale will accelerate attack into lower composite layers. For this reason, if there is superficial UV damage the affected area should be cleaned and painted with a UV tolerant paint. If broken, frayed, or separated fibers to the non sacrificial layer greater than a depth of 0.05 in., are discovered during the cleaning process then the vessel shall be condemned.

## TABLE S10.7-b

VISUAL ACCEPTANCE/REJECTION CRITERIA FOR COMPOSITE PRESSURE VESSELS (SI UNITS)

| Type of Degradation or Damage | Description of Degradation or Damage | Acceptable Level of Degradation or Damage | Rejectable Level of Degradation or Damage |
|---|---|---|---|
| Abrasion | Abrasion is damage to the filaments caused by wearing or rubbing of the surface by friction. | Less than 1.3 mm. depth in the pressure bearing thickness. | ≥ 1.3 mm depth in the pressure bearing thickness. |
| Cuts | Linear indications flaws caused by an impact with a sharp object. | Less than 1.3 mm. depth in the pressure bearing thickness. | ≥ 1.3 mm depth in the pressure bearing thickness. |
| Impact Damage | Damage to the vessel caused by striking the vessel with an object or by being dropped. This may be indicated by discoloration of the composite or broken filaments and/or cracking. | Slight damage that causes a frosted appearance or hairline cracking of the resin in the impact area. | Any permanent deformation of the vessel or damaged filaments. |
| Delamination | Lifting or separation of the filaments due to impact, a cut, or fabrication error. | Minor delamination of the exterior coating less than a depth of 1.3 mm. | Any loose filament ends showing on the surface at a depth ≥ 1.3 mm. Any bulging due to interior delaminations. |
| Heat or Fire Damage | Discoloration, charring or distortion of the composite due to temperatures beyond the curing temperature of the composite. | Merely soiled by soot or other debris, such that the cylinder can be washed with no residue. | Any evidence of thermal degradation or discoloration or distortion. |
| Structural Damage – bulging, distortion, depressions | Change in shape of the vessel due to sever impact or dropping. | None | Any visible distortion, bulging, or depression. |
| Chemical attack | Environmental exposure that causes a change in the composite or failure of the filaments. | Any attack that can be cleaned off and that leaves no residue or evidence of permanent damage. | Any permanent discoloration or loss or softening of material under the exterior coat. |
| Cracks | Sharp, linear indications | None | None |

| Type of Degradation or Damage | Description of Degradation or Damage | Acceptable Level of Degradation or Damage | Rejectable Level of Degradation or Damage |
|---|---|---|---|
| Scratches/Gouges | Sharp, linear indications caused by mechanical damage. | Less than 1.3 mm depth in the pressure bearing thickness No structural fibers cut or broken. | ≥ 1.3 mm depth in the pressure bearing thickness or structural fibers cut or broken. |
| Soot | A deposit on the composite caused by thermal or environmental exposure. | Soot that washes off and leaves no residue. | Any permanent marking that will not wash off the surface under the exterior coating. |
| Over pressurization | Excessive pressure due to operational malfunction. | pressure between MAWP and test pressure, with approval of the manufacturer. | Any report of pressurization beyond the Test Pressure or any indication of distortion. |
| Corrosion | Degradation of the composite due to exposure to specific corrosive environments. | None visible in excess of manufacturer's specification. | Any surface damage to structural material identified as corrosion beyond the manufacturer's specification. |
| Dents | A depression in the exterior of the vessel caused by impact or dropping. | < 1.6 mm depth | Any dents with a depth ≥ 1.6 mm Or with a diameter greater than 51 mm. |
| Reported collision, accident, or fire | Damage to the vessel caused by unanticipated excursion from normally expected operating conditions. | None reported | Any indication or report of impact or heat damage. |
| Environmental Damage or Weathering | Ultraviolet or other environmental attack under the exterior coating. | None | Any discoloration that can not be washed off. (See Note 2) |
| Damage to a protective or sacrificial layer | Abrasion, cuts, chemical attack, scratches/gouges, corrosion, environmental damage, or crazing that are limited only to the protective or sacrificial layer. | The depth of any damage to the protective or sacrificial layer that does not exceed the thickness of the protective or sacrificial layer plus 1.3 mm. | The depth of any damage to the protective or sacrificial layer that exceeds the thickness of the protective or sacrificial layer plus1.3 mm. |
| Crazing | Hairline surface cracks only in the composite resin. | Light hairline cracks only in the resin. | Any damage to the filaments. |

**Note 1:**

Only damage beyond the sacrificial or coated layer should be considered, and that any damage to sacrificial or coated layers should be repaired by suitable techniques (e.g., epoxy filler). Refer to Manufacturer's Data Report for sacrificial layer thickness.

**Note 2:**

Washing off UV scale will accelerate attack into lower composite layers.. For this reason, if there is superficial UV damage the affected area should be cleaned and painted with a UV tolerant paint. If broken, frayed, or separated fibers to the non sacrificial layer greater than a depth of 1.3 mm, are discovered during the cleaning process then the vessel shall be condemned.

## S10.8 EXTERNAL INSPECTION

a) Vessel Service Life

Vessels have been designed and manufactured for a limited lifetime; this is indicated on the vessel marking. This marking shall first be checked to ensure that such vessels are within their designated service lifetime.

b) Identification of External Damage

The external surface shall be inspected for damage to the laminate. Damage is classified into two levels as shown in Table S10.7-a or Table S10.7-b of this supplement. The acceptance/rejection criteria shown in Table S10.7-a or Table S10.7-b of this supplement shall be followed, as a minimum.

The external surface of the vessel is subject to mechanical, thermal, and environmental damage. The external surface of a vessel may show damage from impacts, gouging, abrasion, scratching, temperature excursions, etc. Areas of the surface that are exposed to sunlight may be degraded by ultraviolet light which results in change in the color of the surface and may make the fibers more visible. This discoloration does not indicate a loss in physical properties of the fibers. Overheating may also cause a change in color. The size (area or length and depth) and location of all external damage shall be noted. Vessel support structures and attachments shall be examined for damage such as cracks, deformation, or structural failure.

c) Types of External Damage

1) General

Several types of damage to the exterior of vessels have been identified. Examples of specific type of damage are described below. The acceptance/rejection criteria for each type of damage are described in Table S10.7-a or Table S10.7-b of this supplement.

2) Abrasion Damage

Abrasion damage is caused by grinding or rubbing away of the exterior of the vessel. Minor abrasion damage to the protective outer coating or paint will not reduce the structural integrity of the vessel. Abrasion that results in flat spots on the surface of the vessel may indicate loss of composite fiber overwrap thickness.

3) Damage from Cuts

Cuts or gouges are caused by contact with sharp objects in such a way as to cut into the composite overwrap, reducing its thickness at that point.

4) Impact Damage

Impact damage may appear as hairline cracks in the resin, delamination, or cuts of the composite fiber overwrap.

5) Delamination

Delamination is a separation of layers of fibers of the composite overwrap due to impact or excessive localized loading. It may also appear as a discoloration or a blister beneath the surface of the fiber.

**Note:** This does not apply to layers intentionally separated by the manufacturer.

6) Heat or Fire Damage

Heat or fire damage may be evident by discoloration, charring or burning of the composite fiber overwrap, labels, or paint. If there is any suspicion of damage, the vessel shall be qualified fit for service using an acoustic emission examination.

7) Structural Damage

Structural damage will be evidenced by bulging, distortion, or depressions on the surface of the vessel.

8) Chemical Attack

Some chemicals are known to cause damage to composite materials. Environmental exposure or direct contact with solvents, acids, bases, alcohols, and general corrosives can cause damage to vessels. Long-term contact with water can also contribute to corrosive damage, although may not be a problem by itself. Chemicals can dissolve, corrode, remove, or destroy vessel materials. Chemical attack can result in a significant loss of strength in the composite material. Chemical attack can appear as discoloration and in more extreme cases the composite overwrap can feel soft when touched. If there is any suspicion of damage, the vessel shall be re-qualified using acoustic emission examination.

## S10.9 INTERNAL EXAMINATION

a) Requirements for Internal Visual Examination

Internal visual examination is normally not required. When vessels have been filled only with pure fluids, corrosion of the interior of the liner should not occur. Internal visual examination of the tanks shall only be carried out when:

1) There is evidence that any commodity except a pure fluid has been introduced into the tank. In particular, any evidence that water, moisture, compressor cleaning solvents, or other corrosive agents have been introduced into the vessel shall require an internal visual examination.

2) There is evidence of structural damage to the vessel, such as denting or bulging.

3) The vessel valve is removed for maintenance or other reason. Internal examination in this case is limited to examination of the threads and sealing surface. When an internal visual examination is conducted, the following procedures shall be followed.

b) Identification of Internal Damage

1) Vessels with Metallic Liners

For vessels with metallic liners, the objective of the internal visual examination is primarily to detect the presence of any corrosion or corrosion cracks.

The internal surface of the vessel shall be examined with adequate illumination to identify any degradation or defects present. Any foreign matter or corrosion products shall be removed from the interior of the vessel to facilitate inspection. Any chemical solutions used in the interior of the vessel shall be selected to ensure that they do not adversely affect the liner or composite overwrap materials. After cleaning the vessel shall be thoroughly dried before it is examined.

All interior surfaces of the vessel shall be examined for any color differences, stains, wetness, roughness, or cracks. The location of any degradation shall be noted.

Any vessel showing significant internal corrosion, dents or cracks shall be removed from service.

2) Vessels with Non-metallic Liners or No Liners

Vessels with non-metallic liners may show corrosion on the plastic liner or metal boss ends. Vessels with non-metallic liners or no liners may also show internal degradation in the form of cracks, pitting, exposed laminate, or porosity.

The internal surface of vessels shall be examined with adequate illumination to identify any degradation or defects present. Any foreign matter or corrosion products shall be removed from the interior of the vessel to facilitate examination. Chemical solutions used in the interior of the vessel shall be selected to ensure they do not adversely affect the liner or composite overwrap materials. After cleaning the vessel shall be thoroughly dried before it is examined.

c) The Inspector shall look for cracks, porosity, indentations, exposed fibers, blisters, and any other indication of degradation of the liner and/or laminate. Deterioration of the liner may include softening of the matrix or exposed fibers.

## S10.10 ACOUSTIC EMISSION EXAMINATION

### S10.10.1 USE AND TEST OBJECTIVES

All high-pressure composite pressure vessels shall be subject to an acoustic emission (AE) examination to detect damage that may occur while the vessel is in service. This method may be used in conjunction with the normal filling procedure.

### S10.10.2 AE TECHNICIAN REQUIREMENTS

The acoustic emission technician conducting the examination required per S10.10.1 and in accordance with S10.10 shall be certified per the guidelines of ASNT SNT-TC-1A or CP-189 AE Level II or III. A technician performing this test shall have training in and experience with measuring $C_e$ and $C_f$ in composites and identifying wave modes.

### S10.10.3 TEST PROCEDURE

AE transducers shall be acoustically coupled to the vessel under test and connected to waveform recording equipment. Waveforms shall be recorded and stored on digital media as the vessel is pressurized. All analysis shall be done on the waveforms. The waveforms of interest are the E (Extensional Mode) and F (Flexural Mode) plate waves.

Prior to pressurization, the velocities of the earliest arriving frequency in the E wave and the latest arriving frequency in the F wave shall be measured in the circumferential direction in order to characterize the material and set the sample time (the length of the wave window).

The E and F waves shall be digitized and stored for analysis. The test pressure shall be recorded simultaneously with the AE events. Permanent storage of the waveforms is required for the life of the vessel.

### S10.10.4 EQUIPMENT (23)

a) Testing System

A testing system shall consist of:

1) sensors;

2) preamplifiers;

3) high pass and low pass filters;

4) amplifier;

5) A/D (analog-to-digital) converters;

6) a computer program for the collection of data;

7) computer and monitor for the display of data; and

8) a computer program for analysis of data.

Examination of the waveforms event by event shall always be possible and the waveforms for each event shall correspond precisely with the pressure and time data during the test. The computer program shall be capable of detecting the first arrival channel. This is critical to the acceptance criteria below.

Sensors and recording equipment shall be checked for a current calibration sticker or a current certificate of calibration.

b) Sensor Calibration

Sensors shall have a flat frequency response from 50 kHz to 400 kHz. Deviation from flat response (signal coloration) shall be corrected by using a sensitivity curve obtained with a Michelson interferometer calibration system similar to the apparatus used by NIST (National Institute for Standards and Technology). Sensors shall have a diameter no greater than 0.5 in. (13 mm) for the active part of the sensor face. The aperture effect shall be taken into account. Sensor sensitivity shall be at least 0.1 V/nm.

c) Scaling Fiber Break Energy

The wave energy shall be computed by the formula:

$$u = \int v^2 \, dt/z$$

Where:

u = signal energy (joules)

v = signal amplitude (volts)

t = time (seconds)

z = resistance (ohms)

**FIGURE S10.10.4-a**

ROLLING BALL IMPACT CALIBRATION SETUP

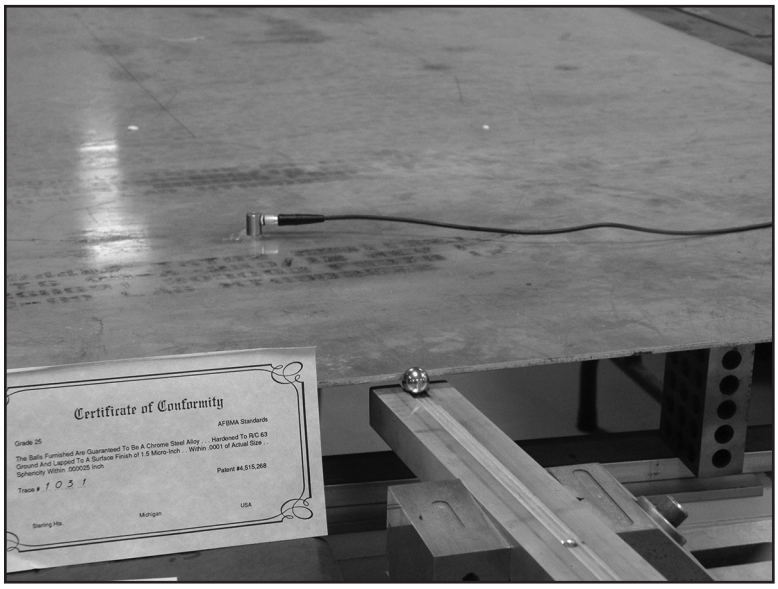
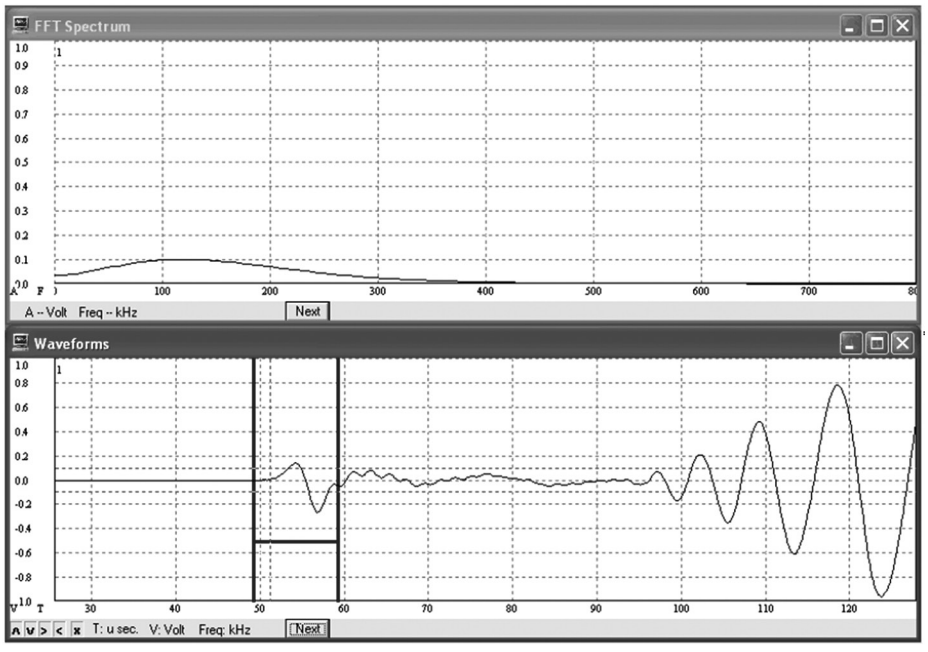



**FIGURE S10.10.4-b**

FRONT END WAVEFORM




which is the formula for computing energy in the AE signal, where V is the voltage in volts (V) and Z is the input impedance in ohms (Ω). A rolling ball impactor shall be used to create an acoustical impulse in an aluminum plate. The measured energy in the wave shall be used to scale the fiber break energy. This scaling is illustrated later on.

The impact setup, an example of which is shown in Figure S10.10.4-a, shall be arranged as follows.

The steel ball shall be ½ inch (13 mm) in diameter. The steel ball is a type typically used in machine shops for measuring taper and is commercially available. The ball shall be made of chrome steel alloy hardened to R/C 63, ground and lapped to a surface finish of 1.5 micro-inch (0.0000381 mm), within 0.0001 inch (0.0025 mm) of actual size and sphericity within 0.000025 inch (0.00064 mm). The plate shall be made of 7075 T6 aluminum, be at least 4 ft x 4 ft (1200 mm X 1200 mm) in size, the larger the better to avoid reflections, be 1/8 inch (3.2 mm) in thickness and be simply supported by steel blocks. The inclined plane shall be aluminum with a machined square groove 3/8 inch (9.5 mm) wide which supports the ball and guides it to the impact point. The top surface of the inclined plane shall be positioned next to the edge of the plate and stationed below the lower edge of the plate such that the ball impacts with equal parts of the ball projecting above and below the plane of the plate. A mechanical release mechanism shall be used to release the ball down the plane.

The ball roll length shall be 12 inch (305 mm) and the inclined plane angle shall be 6 degrees. The impact produces an impulse that propagates to sensors coupled to the surface of the plate 12 inches (305 mm) away from the edge. The sensors shall be coupled to the plate with vacuum grease. The energy of the leading edge of the impulse, known as the wave front shall be measured. The vertical position of the ball impact point shall be adjusted gradually in order to “peak up” the acoustical signal, much as is done in ultrasonic testing where the angle is varied slightly to peak up the response. The center frequency of the first cycle of the E wave shall be confirmed as 125 kHz ± 10 kHz. See Figure S10.10.4-b. The energy value in joules of the first half cycle of the E wave shall be used to scale the fiber break energy in criterion 2, as illustrated there. This shall be an “end to end” calibration meaning that the energy shall be measured using the complete AE instrumentation (sensor, cables, preamplifiers, amplifiers, filters and digitizer) that are to be used in the actual testing situation.

Front end of waveform created by rolling ball impact calibration setup described herein. Fast Fourier transform (FFT) shows center frequency of first cycle is approximately 125kHz. The energy linearity of the complete AE instrumentation (sensor, cables, preamplifiers, amplifiers, filters and digitizer) shall be measured by using different roll lengths of 8, 12 and 16 inches (203, 305, and 406 mm). The start of the E wave shall be from the first cycle of the waveform recognizable as the front end of the E wave to the end of the E wave which shall be taken as 10 microsecond (μs) later. (The time was calculated from the dispersion curves for the specified aluminum plate.) A linear regression shall be applied to the energy data and a goodness of fit $R^2 > 0.9$ shall be obtained.

d) Preamplifiers and Amplifiers - See ASME Section V, Article 11.

e) Filters

A high pass filter of 20 kHz shall be used. A low pass filter shall be applied to prevent digital aliasing that occurs if frequencies higher than the Nyquist frequency (half the sampling rate) are in the signal.

f) A/D

The sampling speed and memory depth (wave window length) are dictated by the test requirements and calculated as follows: Vessel length = L inches (meters). Use $C_E$ = 0.2 in./μs (5080 m/s) and $C_F$ = 0.05 in./μs (1270 m/s), the speeds of the first arriving frequency in the E wave and last arriving frequency in the F wave, respectively, as a guide. The actual dispersion curves for the material shall be used if available.

$L / C_E$ = T1 μs. This is when the first part of the direct E wave will arrive.

$L / C_F$ = T2 μs. This is when the last part of the direct F wave will arrive.

(T2 – T1) x.1.5 is the minimum waveform window time and allows for pretrigger time.

The recording shall be quiescent before front end of the E wave arrives. This is called a “clean front end”. Clean is defined in S10.10.6 b) 2) below.

The sampling rate, or sampling speed, shall be such that aliasing does not occur.

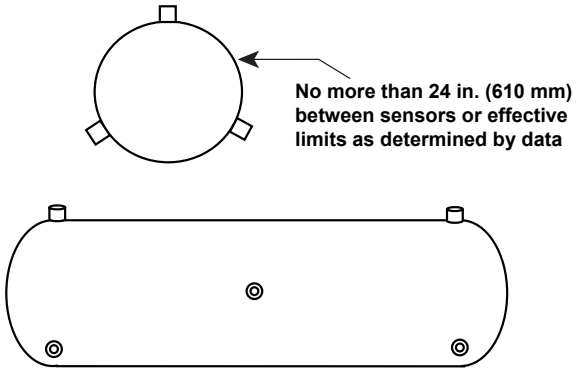
The recording system (consisting of all amplifiers, filters and digitizers beyond the sensor) shall be calibrated by using a 20 cycle long tone burst with 0.1 V amplitude at 100, 200, 300, and 400 kHz. The system shall display an energy of $u = \frac{v^2\,NT}{2Z}$ joules at each frequency, where V=0.1 volts, N = 20, Z is the preamplifier input impedance in ohms (Ω) and T is the period of the cycle in seconds (s).

### S10.10.5 SENSOR PLACEMENT

At least two sensors shall be used in any AE test regardless of vessel size so that electromagnetic interference (EMI) is easily detected by simultaneity of arrival. Sensors shall be placed at equal distances around the circumference of the vessel on the cylindrical portion of the vessel adjacent to the tangent point of the dome such that the distance between sensors does not exceed the greater of 24 in. (610 mm), or the effective sensing distance established by signal measurement. Adjacent rings of sensors shall be offset by ½ a cycle. For example, if the first ring of sensors is placed at 0, 120, and 240 degrees, the second ring of sensors is placed at 60, 180, and 300 degrees. This pattern shall be continued along the vessel length at evenly spaced intervals, such intervals not to exceed the greater of 24 in. (610 mm), or the effective sensing distance established by signal measurement, until the other end of the vessel is reached. See Figure S10.10.4. The diameter referred to is the external diameter of a vessel.

**FIGURE S10.10.5**

SENSOR SPACING AND PATTERN




Maximum distance between sensors in the axial and circumferential directions shall not exceed 24 inches (610 mm) unless it is demonstrated that the essential data can still be obtained using a greater distance and the authority having the jurisdiction concurs.

This spacing allows for capturing the higher frequency components of the acoustic emission impulses and high channel count wave recording systems are readily available.

### S10.10.6 TEST PROCEDURE

Couple sensors to vessel and connect to the testing equipment per ASME Section V Article 11. Connect pressure transducer to the recorder. Conduct sensor performance checks prior to test to verify proper operation and good coupling to the vessel. The E and F waveforms shall be observed by breaking pencil lead at approximately 8 in. (200 mm) and 16 in. (410 mm) from a sensor along the fiber direction. All calibration data shall be recorded.

Recording threshold shall be 60 dB ref 1 μV at the transducer.

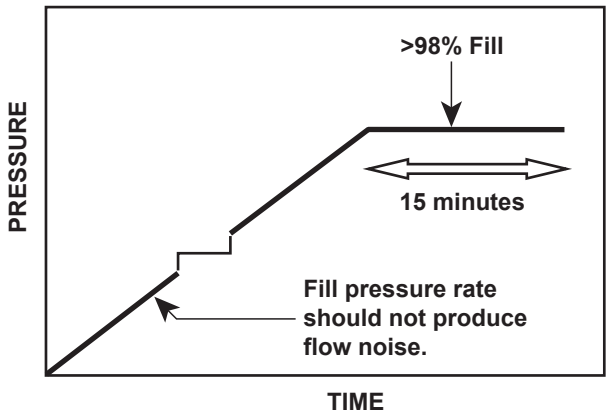
Performance checks shall be carried out by pencil lead breaks (Pentel 0.3 mm, 2H) six inches (150 mm) from each transducer in the axial direction of the cylinder and a break at the center of each group of four sensors.

Pressurize vessel to >98% of normal fill pressure and monitor AE during pressurization and for 15 minutes after fill pressure is reached. See Figure S10.10.5 for a schematic of the pressurization scheme. If at any time during fill the fill rate is too high in that it causes flow noise, decrease fill rate until flow noise disappears. Record events during pressurization and for 15 minutes after fill pressure is reached and save the data. Then conduct a post-test performance check and save data. Test temperature shall be between 50°F (10°C) and 120°F (49°C).

A threshold of 60 dBAE ref 1 μV at the sensor shall be used during all phases of testing.

**FIGURE S10.10.6**

TYPICAL PRESSURIZATION PLAN WHEN FILLING VESSELS




AE shall be monitored for 15 min after operating fill pressure is reached.

## S10.10.7 ACCEPT/REJECT CRITERIA

a) Stability Criterion

Theory of AE Monitoring of high-pressure composite pressure vessels for stability– A stable vessel will exhibit cumulative curves with exponentially decaying curvature. The shape of the cumulative events curve is similar for pressure vessels made of fiberglass, aramid and carbon fiber that exhibit a fiber dominated failure mode. This is essentially a test that demonstrates the composite is not progressing to failure at the hold pressure.

b) Analysis Procedure

Data will include matrix splits, matrix cracks, fiber breaks, and matrix chirps due to fracture surface fretting, and fiber/matrix debonding. Extraneous noise, identified by waveform characteristics, may also be included in the data.

1) Filter data to eliminate any external noise such as electromagnetic interference (EMI), mechanical rubbing, flow noise, etc. Identify noise events by their shape, spectral characteristics, or other information known about the test such as a temporally associated disturbance due to the pressurization system or test fixturing. EMI is characterized by a lack of any mechanical wave propagation characteristics, particularly a lack of dispersion being apparent. EMI can be further identified by simultaneity of arrival on more than one channel. The two criteria shall be considered together to ensure it's not simply an event that happened to be centered between the sensors. Mechanical

rubbing frequencies are usually very low and can be determined by experiment. There should be no flow noise. If the vessel, or a fitting, leaks, this will compromise the data as AE is very sensitive to leaks. Leak noise is characterized by waves that look uniform across the entire length of the waveform window. If a leak occurs during the load hold, the test must be redone. Flow noise is characterized by waves that fill the waveform window.

2) Use only events that have clean front ends and in which first arrival channel can be determined. Clean means having a pre-trigger energy of less than $0.01 \times 10^{-10}$ joules. Energy is computed by the integral of the voltage squared over time.

3) Plot first arrival cumulative events versus time. Plots shall always show the pressure data.

4) Apply exponential fits by channel for pressure hold time and display both data and fit. The values are determined by the fit to $y = A_e^{Bt} + C$..

   The B value is the shape factor of the cumulative curves. C is an intercept and A is a scale factor. The time t shall be equal intervals during the hold with events binned by time interval. Record exponents and goodness of fit ($R^2$). Plot energy decay curves. One third or one fourth of hold time shall be used for event energy binning (cumulative energy). The formula is $y = A_e^{Bt} + C$. .

   The sequence of energy values must monotonically decrease.

   This is similar to using other energy criteria, such as Historic Index. A sequence that is not properly decreasing will be indicated by a low $R^2$ value.

5) Save all plots (all channels) to report document.

6) Record exponents and $R^2$ values.

7) Vessel B Values

   a. Vessel B values shall be tracked and compiled in order to develop a statistically significant database.

   b. B is the critical value that measures the frequency of occurrence of events during pressure hold.

   c. Not every vessel will have the exact same B value.

   d. Data on B values should cluster.

c) The criteria given below apply to each individual sensor on the vessel

1) The stability criteria as described above shall be met. (Also see ASME Section X Mandatory Appendix 8.) Any vessel that does not meet the stability criteria must be removed from service. The criteria are:

   a. Cumulative Event Decay Rate $-0.1 < B < -0.0001$, $R^2 \geq 0.80$

   b. Cumulative Energy Decay Rate $-0.2 < B < -0.001$, $R^2 \geq 0.80$

If these criteria are not met, the vessel does not pass. The vessel may be retested. An AE Level III examiner must review the data from the initial testing and the subsequent loading test before the vessel can be passed. Retest loadings shall follow the original pressurization rates and pressures and use a threshold of 60 dBAE. If the vessel fails the criteria again, the vessel shall not be certified by the Inspector as meeting the provisions of this section.

2) Events that occur at the higher loads during pressurization having significant energy in the frequency band f > 300 kHz are due to fiber bundle, or partial bundle, breaks. These should not be present at operating pressure in a vessel that has been tested to a much higher pressures and is now operated at the much lower service pressure. For fiber bundles to break in the upper twenty percent of load during the test cycle or while holding at operating pressure, the vessel has a severe stress concentration and shall be removed from service.

## S10.10.8 FIBER BREAKAGE CRITERION

a) Analysis Procedure

In order to determine if fiber bundle breakage has occurred during the filling operation the frequency spectra of the direct E and F waves shall be examined and the energies in certain frequency ranges shall be computed as given below.

b) Definitions

Energies (U) in the ranges are defined as:

50 – 400 kHz: $U_0$

100 – 200 kHz: $U_1$

250 – 400 kHz: $U_2$

The criteria for determining if high frequency spectrum events have occurred is given by the following formulas:

$U_0 / (U_{FBB}) \geq 10\%$

$U_2 / (U_1 + U_2) \geq 15\%$

$U_2 / U_0 \geq 10\%$

$U_{FBB}$ is the energy of a fiber bundle break calculated using the average breaking strength from the manufacturer's data or independent test data. The manufacturer's data shall be used if available. The formula that shall be used for calculating average fiber break energy in joules (J) is

$$U_{FB} = \frac{E * A * l * \varepsilon^2}{2}$$

where E is the Young's modulus of the fiber in pascals (Pa), ε is the strain to failure of the fiber, A is area of the fiber in square meters ($m^2$), and l is the ineffective fiber length in meters (m) for the fiber and matrix combination. If the ineffective length is not readily available, four times the fiber diameter shall be used. Set $U_{FBB} = 100 \times U_{FB}$, where $U_{FB}$ has been calculated and scaled by the rolling ball impact energy as in the examples below. If these criteria are met, fiber bundle break damage has occurred during the test and the vessel shall be removed from service.

c) Example of Fiber Break Energy Calculation Suppose d = 7 μm, *E* = 69.6 GPa and ε = 0.01 (average breaking strain) for some carbon fiber. Using $A = \pi d^2/4$ and / = 4d,

$$U_{FB} = \frac{E * A * l * \varepsilon^2}{2}$$

$$U_{FB} = \frac{E69.6 * 10^9\ Pa * \pi * \frac{(7 * 10^{-6}m)^2}{4} * 2.8 * 10^{-5}m * (0.01)^2}{2}$$

$$U_{FB} = 3.75 * 10^{-9} j$$

d) Example of Scaling Calculation

Suppose that the rolling ball impact (RBI) acoustical energy measured by a particular high fidelity AE transducer is $U^{AE}_{RBI}$ = 5 x $10^{-10}$ J and the impact energy $U_{RBI}$ = 1.9 x $10^{-3}$ J (due to gravity). Suppose d = 7 μm, *E* = 69.6 GPa and ε = 0.01 (average breaking strain) for some carbon fiber. Using *A* = πd²/4 and l = 4d, $U_{FB}$ = 3x$10^{-8}$ J. A carbon fiber with a break energy of $U_{FB}$ = 3x$10^{-8}$ J would correspond to a wave energy.

$$U^{AE}_{FB} = U_{FB} \text{ x } U^{AE}_{RBI} / U_{RBI}$$

$$U^{AE}_{FB} = 3\text{x}10^{-8} \text{ J x } 5 \text{ x } 10^{-10} \text{ J / } 1.9 \text{ x } 10^{-3} \text{ J}$$

$$U^{AE}_{FB} = 7.9 \text{ x } 10^{-15} \text{ J.}$$

This is the number that is used to calculate the value of $U_{FBB}$ that is used in the fiber break criterion in the second acceptance criterion and the energy acceptance criterion in the third criterion below.

e) Amplifier Gain Correction

All energies shall be corrected for gain. (20 dB gain increases apparent energy 100 times and 40 dB gain 10,000 times.)

Fiber break waves may look similar to matrix event waves in time space but in frequency space the difference is clear. A fiber break is a very fast source, while a matrix crack evolves much more slowly due to greater than ten to one difference in their tensile moduli. The speed of the fiber break produces the high frequencies, much higher than a matrix crack event can produce. Frequencies higher than 2 MHz have been observed in proximity to a fiber break, however these very high frequencies are attenuated rapidly as the wave propagates. Practically speaking, the observation of frequencies above 300 kHz, combined with certain other characteristics of the frequency spectrum and pressure level, is enough to confirm a fiber break. It should also be noted that it is fiber bundle breaks that are usually detected in structural testing and not the breaking of individual fibers. The energies of individual fiber breaks are very small, about 3x$10^{-8}$ Joules for T-300 carbon fibers for example.

## S10.10.9 FRICTION BETWEEN FRACTURE SURFACES

Friction between fracture surfaces plays a very important role in understanding AE in fatigue testing. It is an indicator of the presence of damage because it is produced by the frictional rubbing between existing and newly created fracture surfaces. Even the presence of fiber bundle breakage can be detected by examining the waveforms produced by frictional acoustic emission or FRAE. Increasing FRAE intensity throughout a pressure cycle means more and more damage has occurred.

Therefore, for a vessel to be acceptable no AE event shall have an energy greater than (F) x $U_{FB}$ at anytime during the test. F is the acoustic emission allowance factor. The smaller the allowance factor, the more

conservative the test. An F = $10^4$ shall be used in this testing. It is the equivalent of three plus fiber tows, each tow consisting of 3,000 fibers, breaking simultaneously near a given transducer.

### S10.10.10 BACKGROUND ENERGY

Background energy of any channel shall not exceed 10 times the quiescent background energy of that channel. After fill pressure is reached, any oscillation in background energy with a factor of two excursions between minima and maxima shows that the vessel is struggling to handle the pressure. Pressure shall be reduced immediately and the vessel removed from service.

## S10.11 DOCUMENT RETENTION

a) The vessel owner shall retain a copy of the Manufacturer's Data Report for the life of the vessel.

b) After satisfactory completion of the periodic in-service inspection, vessels shall be permanently marked or labeled with date of the inspection, signature of the Inspector, and date of the next periodic in-service inspection.

c) The vessel owner shall retain a copy of the in-service inspection report for the life of the vessel.

# PART 2, SUPPLEMENT 11
# INSPECTOR REVIEW GUIDELINES FOR FINITE ELEMENT ANALYSIS (FEA)

## S11.1 SCOPE

This Supplement provides guidelines to be followed when a finite element analysis (FEA) is submitted as part of a quantitative engineering assessment for in-service equipment, or a repair or alteration for a pressure retaining item for review by the Inspector, and the jurisdiction if required. Refer to NBIC Part 2, 4.6.

## S11.2 TERMINOLOGY

a) Finite element analysis (FEA) as applied in engineering is a computational tool for performing engineering analysis. It includes the use of mesh generation techniques for dividing a complex problem into small elements for simulation, as well as the use of software program coded with finite element method algorithms.

b) Quantitative engineering assessment refers to methodologies whereby flaws contained within a pressure retaining item are assessed in order to determine the adequacy of the structure for continued service without failure. The result of the assessment provides guidance on structural integrity, inspection methods and intervals, and shapes decisions to operate, repair, monitor or replace the structure/ pressure retaining item.

## S11.3 CHECKLIST

The following is a checklist of areas to consider and discuss with the FEA practitioner engineer performing the analysis and may be used to familiarize the Inspector with the FEA approach and method as part of validating the FEA report.

### S11.3.1 PRESSURE RETAINING ITEM INFORMATION

a) Vessel type, size, region/section and component(s) under FEA consideration.

b) Materials of construction and materials properties (including those as a function of temperature).

c) Original code of construction.

d) Repair and alteration history.

e) Known extent of degradation and associated damage mechanisms (if available/any).

f) Operating conditions (temperature and heat flux, pressure including vacuum, cyclical service, etc.).

g) Other loads (seismic, earthquake, etc.).

### S11.3.2 SCOPE OF THE FEA

a) The objective of the FEA analysis (to be used to support quantitative engineering analysis, repair, alteration, etc.).

b) The justification for use of FEA rather than rules in the code of construction. Refer to NBIC Part 2 4.6.1.2.

### S11.3.3 FEA SOFTWARE AND MODELLING

a) The software version to be used for the analysis

b) The type of analysis (e.g.,.stress, static, dynamic, elastic, plastic, small or large deformations, heat transfer, etc.).

c) The modelling approach that will be used (e.g., solids, shells, simplification of geometry, mesh generation, solver technique, division into elements and element size, boundary restraints, etc.).

d) The geometries to be modeled (e.g., non-corroded, corroded and future corrosion allowance, bulge, dent, groove, crack, etc.).

## S11.4 REPORT REQUIREMENTS

The following checklist of areas to consider and discuss with the FEA practitioner engineer completing the certified report may be used to define what should be included in the report. An alternate useful reference is the following presentation: Proceedings of the ASME 2014 Pressure Vessels & Piping Conference, PVP2014-28958, Writing and Reviewing FEA Reports Supporting ASME Section VIII, Division 1 and 2 Designs – Practical Considerations and Recommended Good Practice.

### S11.4.1 SECTIONS TO BE INCLUDED IN THE REPORT

a) An introduction and/or executive summary.

b) A description of the model.

c) A presentation of the results.

d) An analysis of the results and conclusions.



### S11.4.2 LISTING OF INFORMATION THAT MAY BE INCLUDED IN THE FEA REPORT

#### S11.4.2.1 ANALYSIS METHOD

a) State the scope of the FEA and the justification for using it; give the program and version.

b) Note whether or not the problem is linear.

c) Give an overview of how the analysis is conducted, for example:

   1) Calculations are done to simplify radiation boundary conditions so that the problem is linear.

   2) Thermal loads are applied to the FEA model and temperatures generated.

   3) Temperatures at select locations are compared to the radiation simplification calculations.

   4) Mechanical loads are added.

   5) Stresses are generated.

   6) Stress classification results are generated.

   7) Results are verified by comparison to something (e.g., BPVVC Section VIII Division 2 Part 5 Design by Analysis).

   8) Results are compared to the construction code.

d) Note if any of the geometry is not included in the stress model.

### S11.4.2.2 STRUCTURAL DESCRIPTION/MESH/STRESS/CLASSIFICATION LINE LOCATIONS

a) Reference the geometry source or show a drawing or sketch with dimensions that relate the model geometry to the actual structure in the FEA analysis.

b) Name all the parts, usually best done with a sketch.

c) Note any symmetry.

d) Give the type of element used for each component.

e) Describe the mesh type (e.g., h, p , 2D, 3D), shape, and order (2nd order or above) and show plots of the mesh.

f) Show the top and bottom of shells or beam orientations and indicate if they are thick or thin elements.

g) Show the cross sections with stress recovery points for beams.

h) Describe any boundary conditions such as supports, restraints, loads, and forces as well as the method of restraining the model to prevent rigid body motion.

i) Describe parts that are connected by node sharing or contact and tell whether the connections are thermal, mechanical, or both.

j) Give the stress classification line locations (usually best done with a sketch).

### S11.4.2.3 MATERIAL PROPERTIES

a) List properties used for every component, references to other sources are not sufficient. They must be explicitly listed. Show the values of any properties modified for the sake of the model. For example, the model density is often modeled.

b) Show calculations for properties that are modified for the sake of the model.

c) Discuss any given artificial properties for the analysis (e.g., the modulus was set to 1000 psi so that the component would not influence the mechanical model. Or, above 1200°F the properties are assumed to be constant).

d) Reference the source for all material properties.

### S11.4.2.4 RESTRAINTS AND LOADS

a) Show all restraints and loads.

b) Discuss the justification for all restraints and loads, and give calculations if they were done to determine the restraints or loads (e.g., end pressure).

c) Discuss any contact regions.

d) Give initial or default temperatures.

### S11.4.2.5 VALIDATION

a) Describe how the model was validated.

b) Describe the accuracy of the model digitization either by use of convergence or to the accuracy of previous successful models.

### S11.4.2.6 RESULTS

For each model the following should be presented:

a) Give temperature plots.

b) Give deformed geometry plots.

c) Give stress classification line results and comparison to code allowable.

d) Relate the results of the model to the defined allowable stresses of the original code of construction.

e) Refer to ASME Section VIII, Division 2, Part 2, 2.3.3.1 (c) (2) Documentation requirements of design-by-analysis calculations in Part 5.

### S11.4.2.7 REFERENCE DOCUMENTS USED

Typical reference documents could include:

a) ASME BPVC II-D;

b) ASME BPVC Section VIII Division 1;

c) ASME BPVC Section VIII Division 2;

d) ASME/API-579;

e) Drawings;

f) User Design Specification (UDS); and

g) ASCE.

# PART 2, SUPPLEMENT 12
# INSPECTION OF LIQUID CARBON DIOXIDE STORAGE VESSELS

## S12.1 SCOPE

This supplement provides guidelines for owners or users for the inspection of Liquid Carbon Dioxide Storage Vessels (LCDSVs), fill boxes, fill lines and pressure relief discharge/vent circuits used for carbonated beverage systems, swimming pool pH control systems and other fill in place systems storing liquid $CO_2$.

## S12.2 GENERAL REQUIREMENTS (ENCLOSED AND UNENCLOSED AREAS)

The inspection should verify that LCDSVs are:

a) not located within 10 feet (3.0 m) of elevators, unprotected platform ledges or other areas where falling would result in dropping distances exceeding half the container height;

b) installed with clearance to satisfactorily allow for filling, operation, maintenance, inspection and replacement of the vessel parts or appurtenances;

c) not located on roofs;

d) adequately supported to prevent the vessel from tipping or falling;

e) not located within 36 in. (0.9 m) of electrical panels; and

f) located outdoors in areas in the vicinity of vehicular traffic are protected with barriers designed to prevent accidental impact by vehicles.

## S12.3 ENCLOSED AREA LCDSV INSTALLATIONS

The inspection should verify that:

a) LCDSV installations that are not periodically removed with remote fill connections:

   1) Are equipped with a gas detection system installed in accordance with paragraph S12.5 of this supplement;

   2) Have signage posted in accordance with paragraph S12.6 of this supplement; and

   3) Are equipped with fill boxes, fill lines and safety relief/vent valve circuits installed in accordance with paragraph S12.4 of this supplement.

b) Portable LCDSV installations with no permanent remote fill connection:

   Warning: LCDSVs shall not be filled indoors or in enclosed areas under any circumstances. Tanks must always be moved to the outside to an unenclosed, free airflow area for filling.

   1) Are equipped with a gas detection system installed in accordance with paragraph S12.5 of this supplement**;**

   2) Have signage posted in accordance with paragraph S12.6 of this supplement.

   3) Have a safety relief/vent valve circuit connected at all times except when the tank is being removed for filling. Connections may be fitted with quick disconnect fittings meeting the requirements of paragraph S12.4 of this supplement.

4) Are provided with a pathway that provides a smooth rolling surface to the outdoor, unenclosed fill area. There should not be any stairs or other than minimal inclines in the pathway.

## S12.4 FILL BOX LOCATION/SAFETY RELIEF/VENT VALVE CIRCUIT TERMINATION

The inspection should verify that fill boxes and/or vent valve terminations are installed above grade, outdoors in an unenclosed, free airflow area, and that the fill connection is located so not to impede means of egress or the operation of sidewalk cellar entrance doors, including during the delivery process and that they are:

a) At least 3 ft. (0.9 m) from any door or operable windows;

b) At least 3 ft. (0.9 m) above grade;

c) Not located within 10 ft. (3.0 m) from side to side at the same level or below, from any air intakes;

d) Not located within 10 ft. (3.0 m) from stair wells that go below grade.

**Note:** Many systems installed prior to 1/1/2014 do not meet the above requirements and the local Jurisdiction should be consulted for guidance.

## S12.5 GAS DETECTION SYSTEMS

A continuous gas detection system shall be provided in the room or area where container systems are filled/used, and in areas where the heavier-than-air gas can accumulate, including below grade, enclosed, or confined space outdoor locations. Small outdoor, at-grade enclosures which are not large enough for a person to enter are not required to have gas detection. Carbon dioxide ($CO_2$) sensors should be provided within 12 in. (305 mm) of the floor in the area where the gas is most likely to accumulate or leaks are most likely to occur, or as specified by the gas detection manufacturer. The system shall be designed to detect and alert at a low and high level alarm.

a) The threshold for activation of a low level alarm shall not exceed a carbon dioxide concentration of 5,000 ppm (9,000 mg/m$^3$) Time Weighted Average (TWA) over 8 hours. When carbon dioxide is detected at the low level alarm, the system shall activate a signal at a normally attended location within the building.

b) The threshold for activation of the high level alarm shall not exceed a carbon dioxide concentration 30,000 ppm (54,000 mg/m$^3$). When carbon dioxide is detected at the high level alarm, the system shall activate an audible alarm at a location approved by the jurisdiction having authority.

The inspection should verify that the gas detection system and audible alarm is operational and tested and documented in accordance with manufacturer's guidelines.

The inspection should verify that audible alarms are placed at the entrance(s) to the room or area where the carbon dioxide storage vessel and/ or fill box is located to notify anyone who might try to enter the area of a potential problem.

## S12.6 SIGNAGE

The inspection should verify that hazard identification signs are posted at the entrance to the building, room, enclosure, or enclosed area where the container is located. The warning sign shall be at least 8 in (200 mm) wide and 6 in. (150 mm) high and indicate:

**FIGURE S12.6**

**CAUTION** - CARBON DIOXIDE GAS

Ventilate the area before entering.
A high carbon dioxide ($Co_2$) gas concentration
in this area can cause asphyxiation.

## S12.7 VALVES, PIPING, TUBING AND FITTINGS

a) Materials – The inspection should verify that the materials selected for valves, piping, tubing, hoses and fittings used in the LCDSV system meet following requirements:

1) Components shall be rated for the operational temperatures and pressures encountered in the applicable circuit of the system.

2) All valves and fittings used on the LCDSV shall be rated for the maximum allowable working pressure(MAWP) stamped on the tank.

3) All piping, hoses and tubing used in the LCDSV system shall be rated for the working pressure of the applicable circuit in the system and have a burst pressure rating of at least four times the MAWP of the piping, hose or tubing.

b) Relief Valves – The inspection should verify that each LCDSV shall have at least one ASME/NB stamped & certified relief valve with a pressure setting at or below the MAWP of the tank. The relief valve shall be suitable for the temperatures and flows experienced during relief valve operation. The minimum relief valve capacity shall be designated by the manufacturer. Additional relief valves that do not require ASME stamps may be added per Compressed Gas Association pamphlet, CGA S-1.3 Pressure Relief Device Standards Part 3, Stationary Storage Containers for Compressed Gases, recommendations. Discharge lines from the relief valves shall be sized in accordance with NBIC Part 2, Tables S12.7-a and S12.7-b.

**Note:** Due to the design of the LCDSV the discharge line may be smaller in diameter than the relief valve outlet size.

**Caution:** Companies and or individuals filling or refilling LCDSV's are responsible for utilizing fill equipment that is acceptable to the manufacturer to prevent over pressurization of the vessel.

c) Isolation Valves – The inspection should verify that each LCDSV has an isolation valve installed on the fill line and tank discharge, or gas supply line in accordance with the following requirements:

1) Isolation valves shall be located on the tank or at an accessible point as near to the storage tank a possible.

2) All valves shall be designed or marked to indicate clearly whether they are open or closed.

3) All valves should be capable of being locked or tagged in the closed position for servicing.

4) Gas supply and liquid $CO_2$ fill valves shall be clearly marked for easy identification.

d) Safety Relief/Vent Lines – The inspection, where possible, should verify the integrity of the pressure relief/vent line from the pressure relief valve to outside vent line discharge fitting. All connections shall be securely fastened to the LCDSV. The minimum size and length of the lines shall be in accordance with NBIC Part 2, Tables S12.7-a and S12.7-b. Fittings or other connections may result in a localized

reduction in diameter have been factored into the lengths given by the NBIC Part 2, Tables S12.7-a and S12.7-b.

**TABLE S12.7-a**

MINIMUM LCDSV SYSTEM RELIEF / VENT LINE REQUIREMENTS (METALLIC)

| Tank Size (Pounds) | Fire Flow Rate Requirements (Pounds per Minute) | Maximum length of 3/8 inch ID Metallic Tube Allowed | Maximum length of 1/2 inch ID Metallic Tube Allowed |
|---|---|---|---|
| Less than 500 | 2.60 maximum | 80 feet | 100 feet |
| 500 - 750 | 3.85 maximum | 55 feet | 100 feet |
| Over 750 – 1,000 | 5.51 maximum | 18 feet | 100 feet |

**TABLE S12.7-b**

MINIMUM LCDSV SYSTEM RELIEF / VENT LINE REQUIREMENTS (PLASTIC/POLYMER)

| Tank Size (Pounds) | Fire Flow Rate Requirements (Pounds per Minute) | Maximum length of 3/8 inch ID plastic/polymer Tube Allowed | Maximum length of 1/2 inch ID plastic/polymer Tube Allowed |
|---|---|---|---|
| Less than 500 | 2.60 maximum | 100 feet | 100 feet |
| 500 - 750 | 3.85 maximum | 100 feet | 100 feet |
| Over 750 – 1,000 | 5.51 maximum | N/A see 1/2 inch | 100 feet |



**TABLE S12.7M-a**

METRIC MINIMUM LCDSV SYSTEM RELIEF / VENT LINE REQUIREMENTS (METALLIC)

| Tank Size (kg) | Fire Flow Rate Requirements (kg per Minute) | Maximum length of 10 mm ID Metallic Tube Allowed | Maximum length of 13 mm ID Metallic Tube Allowed |
|---|---|---|---|
| Less than 227 | 1.18 maximum | 24 feet | 30.5 m |
| 227 - 340 | 1.75 maximum | 17 feet | 30.5 m |
| Over 340 - 454 | 2.5 maximum | 5.5 feet | 30.5 m |

**TABLE S12.7M-b**

METRIC MINIMUM LCDSV SYSTEM RELIEF / VENT LINE REQUIREMENTS (PLASTIC/POLYMER)

| Tank Size (kg) | Fire Flow Rate Requirements (kg per Minute) | Maximum length of 10 mm ID plastic/polymer Tube Allowed | Maximum length of 13 mmID plastic/polymer Tube Allowed |
|---|---|---|---|
| Less than 227 | 1.80 maximum | 30.5 m | 30.5 m |
| 227 - 340 | 1.75 maximum | 30.5 m | 30.5 m |
| Over 340 - 454 | 2.50 maximum | N/A see 13 mm | 30.5 m |

**Note:** Due to the design of the LCDSV, the discharge line may be smaller in diameter than the relief valve outlet size but shall not be smaller than that shown in tables NBIC Part 2, S12.7-a and -b.

# PART 2, SUPPLEMENT 13
# INSPECTION OF BIOMASS FIRED BOILER INSTALLATIONS

## S13.1 SCOPE

a) This supplement provides guidelines for continued inspection of biomass fired boilers and the additional equipment utilized in these installations. In this context Biomass is intended to mean various types of organic fiber wastes, or organic fiber byproducts.

b) Many of the requirements of the earlier sections of Part 2 are common to all boiler installations irrespective of the fuel being fired; therefore this supplement will address the differences that occur when solid fuels, such as biomass, are being used. Thus the primary thrust of this section will be directed toward the inspection of the fuel handling and distribution systems, and the impact these systems may have on the pressure vessel itself.

## S13.2 ASSESSMENT OF INSTALLATION

a) A general assessment of the complete installation shall be undertaken, including observable results of operating and maintenance practices. The assessment includes the general cleanliness of the boiler room, including rafters and beams.

b) The combustion air inlet shall be free of any debris or dust particle build up, and where moveable louvered intakes exist, the actuating mechanisms shall be clean and operate freely. Corrective action is required when non-compliance is noted.

c) The flue gas venting system shall be checked for tightness, with no observable signs of leakage. Corrective action is required if leakage is noted.

d) The intakes of the various fans or blowers shall be free of fuel particle build up or signs of other debris. Corrective action in terms of cleaning is required when discrepancies are noted.

e) The fuel metering equipment and the fuel transportation system shall be free from signs of particulate or dust leakage. Corrective action in terms of cleaning and repair work is required as necessary.

f) Electrical equipment and controls shall be properly protected from the ingress of dust, by ensuring that all cover plates are properly installed and all panel doors are intact, operable and closed.

g) Verify that all guards for rotating equipment (shafts, bearings, drives) are correctly installed and fan inlet screens are in place.

h) On the boiler, generally check for signs of potential problems, including, but not limited to:

   1) Water leaks;

   2) Ash Leaks;

   3) Condition of insulation and lagging;

   4) Casing leaks or cracks;

   5) All safety valves do not have a bypass;

   6) Ensure the inspection plugs are capped;

   7) The drain lines are piped to a safe point of discharge;

8) Missing or misaligned pieces or parts (e.g., twisted, misaligned or bound up buck stays, missing linkage bolting);

9) Condition of support systems;

10) Provision of “Danger” or “Caution” signs;

11) Excess vibration; and

12) Excess noise.

i) Verify that the Owner/User has established function test, inspection, requirements, maintenance and testing of all controls and safety devices in accordance with the manufacturer’s recommendations. Verify that these activities are conducted at assigned intervals in accordance with written procedures, nonconformances which impact continued safe operation of the boiler are corrected and the results are properly documented. These activities shall be at a frequency recommended by the manufacturer, or frequency required by the jurisdiction. Where no frequencies are recommended, or prescribed, the activity should be conducted at least annually.

## S13.3 BOILER ROOM CLEANLINESS

a) While boiler room cleanliness is of primary importance in all boiler rooms it is of particular importance in biomass fired boiler rooms. Biomass can contain fine particulate, which if allowed to leak from the transportation system into the surrounding boiler room, will eventually be drawn into fans, resulting in the possibility of combustion air systems becoming plugged.

b) Boiler rooms containing quantities of fine dusts are susceptible to fire or explosion, again emphasizing the need for high standards of cleanliness.

## S13.4 EMISSION CONTROL REQUIREMENTS

a) Emission control is dependent upon the fuel being fired and the emission requirements prevailing at the location of the boiler installation. As such they are a part of the initial design and installation process, and apart from ensuring that they are kept in top working condition, so that emission requirements are not violated; there is little that can be done from the inspector’s point of view.

b) When Continuous Emissions Monitors (CEM’s) are in use, they should be demonstrated to be functioning properly and have a current calibration sticker.

c) Delta-P pressure gauges which measure the pressure drop across the various elements of the emission control system should all be functioning correctly.

d) There should be no sign of erosion caused by entrained particulate matter, in any part of the breaching, ductwork, stack or the individual emission control elements.

e) On systems in which the emissions control system incorporates a baghouse, appropriate fire detection and suppression systems shall be incorporated and functioning properly.

# PART 2, SECTION 7
# INSPECTION — NBIC POLICY FOR METRICATION

## 7.1 GENERAL

This policy provides guidance for the use of US customary units and metric units. Throughout the NBIC, metric units are identified and placed in parentheses after the US customary units referenced in the text and associated tables. For each repair or alteration performed, selection of units shall be based on the units used in the original code of construction. For example, items constructed using US customary units shall be repaired or altered using US customary units. The same example applies to items constructed using metric units. Whichever units are selected, those units are to be used consistently throughout each repair or alteration. Consistent use of units includes all aspects of work required for repairs or alterations (i.e. materials, design, procedures, testing, documentation, stamping, etc.).

## 7.2 EQUIVALENT RATIONALE

The rationale taken to convert metric units and US customary units involves knowing the difference between a *soft* conversion and a *hard* conversion. A soft conversion is an exact conversion. A hard conversion is simply performing a soft conversion and then rounding off within a range of intended precision. When values specified in the NBIC are intended to be approximate values, a hard conversion is provided. If an exact value is needed to maintain safety or required based on using good engineering judgment, then a soft conversion will be used. In general, approximate accuracy is acceptable for most repairs or alterations performed using the requirements of the NBIC. Therefore, within the NBIC, metric equivalent units are primarily hard conversions.

The following examples are provided for further clarification and understanding of soft conversions versus hard conversions:

**Example 1**: Using 1 in. = 25.4 mm;
12 in. = 304.8 mm (soft conversion)

**Example 2**: Using the above conversion, a hard conversion may be 300 mm or 305 mm depending on the degree of precision needed.

## 7.3 PROCEDURE FOR CONVERSION

The following guidelines shall be used to convert between US customary units and metric units within the text of the NBIC:

a) All US customary units will be converted using a soft conversion;

b) Soft conversion calculations will be reviewed for accuracy;

c) Based on specified value in the NBIC, an appropriate degree of precision shall be identified;

d) Once the degree of precision is decided, rounding up or down may be applied to each soft conversion in order to obtain a hard conversion; and

e) Use of hard conversion units shall be used consistently throughout the NBIC wherever soft conversions are not required.

**Note:**
Care shall be taken to minimize percentage difference between units.

## 7.4 REFERENCING TABLES

The following tables are provided for guidance and convenience when converting between US customary units and metric units. (See NBIC Part 1, 2, 3, 4, Tables 7.4-a through 7.4-j)

**TABLE 7.4-a**
SOFT CONVERSION FACTORS (US X FACTOR = METRIC)

| US Customary | Metric | Factor |
|---|---|---|
| in. | mm | 25.4 |
| ft. | m | 0.3048 |
| $in.^2$ | $mm^2$ | 645.16 |
| $ft.^2$ | $m^2$ | 0.09290304 |
| $in.^3$ | $mm^3$ | 16,387.064 |
| $ft.^3$ | $m^3$ | 0.02831685 |
| US gal. | $m^3$ | 0.003785412 |
| US gal. | liters | 3.785412 |
| psi | MPa | 0.0068948 |
| psi | kPa | 6.894757 |
| ft-lb | J | 1.355818 |
| °F | °C | 5/9 x (°F–32) |
| R | K | 5/9 |
| lbm | kg | 0.4535924 |
| lbf | N | 4.448222 |
| in.-lb | N-mm | 112.98484 |
| ft.-lb | N-m | 1.3558181 |
| ksi√in | MPa√m | 1.0988434 |
| Btu/hr | W | 0.2930711 |
| $lb/ft^3$ | $kg/m^3$ | 16.018463 |
| in.-wc | kPa | 0.249089 |

**Note:**
The actual pressure corresponding to the height of a vertical column of fluid depends on the local gravitational field and the density of the fluid, which in turn depends upon the temperature. This conversion factor is the conventional value adopted by ISO. The conversion assumes a standard gravitational field (gn – 9.80665 N/kg) and a density of water equal to 1,000 $kg/m^3$. 7.4-a through 7.4-j.

Temperature shall be converted to within 1°C as shown in NBIC Part 1, 2, 3, 4, Table 7.4-b.

**TABLE 7.4-b**
TEMPERATURE EQUIVALENTS

| Temperature °F | Temperature °C |
|---|---|
| 60 | 16 |
| 70 | 21 |
| 100 | 38 |
| 120 | 49 |
| 350 | 177 |
| 400 | 204 |
| 450 | 232 |
| 800 | 427 |
| 1,150 | 621 |

Fractions of an inch shall be converted according to NBIC Part 1, 2, 3, Table 7.4-c. Even increments of inches are in even multiples of 25 mm. For example, 40 inches is equivalent to 1,000 mm. Intermediate values may be interpolated rather than converting and rounding to the nearest mm.

**TABLE 7.4-c**
US FRACTIONS/METRIC EQUIVALENTS

| Inches | Millimeters |
|---|---|
| 1/32 | 0.8 |
| 3/64 | 1.2 |
| 1/16 | 1.5 |
| 3/32 | 2.5 |
| 1/8 | 3 |
| 5/32 | 4 |
| 3/16 | 5 |
| 7/32 | 5.5 |
| 1/4 | 6 |
| 5/16 | 8 |
| 3/8 | 10 |
| 7/16 | 11 |
| 1/2 | 13 |
| 9/16 | 14 |
| 5/8 | 16 |
| 11/16 | 17 |
| 3/4 | 19 |
| 7/8 | 22 |
| 1 | 25 |

For nominal pipe sizes, the following relationships were used as shown in NBIC Parts 1, 2 or 3, Table 7.4-d.

**TABLE 7.4-d**
PIPE SIZES/EQUIVALENT

| US Customary Practice | Metric Practice |
|---|---|
| NPS 1/8 | DN 6 |
| NPS 1/4 | DN 8 |
| NPS 3/8 | DN 10 |
| NPS 1/2 | DN 15 |
| NPS 3/4 | DN 20 |
| NPS 1 | DN 25 |
| NPS 1-1/4 | DN 32 |
| NPS 1-1/2 | DN 40 |
| NPS 2 | DN 50 |
| NPS 2-1/2 | DN 65 |
| NPS 3 | DN 80 |
| NPS 3-1/2 | DN 90 |
| NPS 4 | DN 100 |
| NPS 5 | DN125 |
| NPS 6 | DN 150 |
| NPS 8 | DN 200 |
| NPS 10 | DN 250 |
| NPS 12 | DN 300 |
| NPS 14 | DN 350 |
| NPS 16 | DN 400 |
| NPS 18 | DN 450 |
| NPS 20 | DN 500 |
| NPS 22 | DN 550 |
| NPS 24 | DN 600 |
| NPS 26 | DN 650 |
| NPS 28 | DN 700 |
| NPS 30 | DN 750 |
| NPS 32 | DN 800 |
| NPS 34 | DN 850 |
| NPS 36 | DN 900 |
| NPS 38 | DN 950 |
| NPS 40 | DN 1000 |
| NPS 42 | DN 1050 |
| NPS 44 | DN 1100 |
| NPS 46 | DN 1150 |
| NPS 48 | DN 1200 |
| NPS 50 | DN 1250 |
| NPS 52 | DN 1300 |
| NPS 54 | DN 1350 |
| NPS 56 | DN 1400 |
| NPS 58 | DN 1450 |
| NPS 60 | DN 1500 |

Areas in square inches ($in^2$) were converted to square mm ($mm^2$) and areas in square feet ($ft^2$) were converted to square meters ($m^2$). See examples in NBIC Parts 1, 2 or 3, Tables 7.4-e and 7.4-f.

### TABLE 7.4-e

| Area (US Customary) | Area (Metric) |
|---|---|
| 3 $in^2$ | 650 $mm^2$ |
| 6 $in^2$ | 3,900 $mm^2$ |
| 10 $in^2$ | 6,500 $mm^2$ |

### TABLE 7.4-f

| Area (US Customary) | Area (Metric) |
|---|---|
| 5 $ft^2$ | 0.46 $m^2$ |

Volumes in cubic inches ($in.^3$) were converted to cubic mm ($mm^3$) and volumes in cubic feet ($ft^3$) were converted to cubic meters ($m^3$). See examples in NBIC Parts 1, 2 or 3, Tables 7.4-g and 7.4-h.

### TABLE 7.4-g

| Volume (US Customary) | Volume (Metric) |
|---|---|
| 1 $in^3$ | 16,000 $mm^3$ |
| 6 $in^3$ | 96,000 $mm^3$ |
| 10 $in^3$ | 160,000 $mm^3$ |

### TABLE 7.4-h

| Volume (US Customary) | Volume (Metric) |
|---|---|
| 5 $ft^3$ | 0.14 $m^3$ |

Although the pressure should always be in MPa for calculations, there are cases where other units are used in the text. For example, kPa is used for small pressures. Also, rounding was to two significant figures. See examples in Table 7.4-i. (Note that 14.7 psi converts to 101 kPa, while 15 psi converts to 100 kPa. While this may seem at first glance to be an anomaly, it is consistent with the rounding philosophy.)

**TABLE 7.4-i**
PRESSURE/EQUIVALENTS

| Pressure (US Customary) | Pressure (Metric) |
|---|---|
| 0.5 psi | 3 kPa |
| 2 psi | 15 kPa |
| 3 psi | 20 kPa |
| 10 psi | 70 kPa |
| 15 psi | 100 kPa |
| 30 psi | 200 kPa |
| 50 psi | 350 kPa |
| 100 psi | 700 kPa |
| 150 psi | 1.03 MPa |
| 200 psi | 1.38 MPa |
| 250 psi | 1.72 MPa |
| 300 psi | 2.10 MPa |
| 350 psi | 2.40 MPa |
| 400 psi | 2.8 MPa |
| 500 psi | 3.45 MPa |
| 600 psi | 4.14 MPa |
| 1,200 psi | 8.27 MPa |
| 1,500 psi | 10.34 MPa |

**TABLE 7.4-j**

| Strength (US Customary) | Strength (Metric) |
|---|---|
| 95,000 psi | 655 MPa |

Material properties that are expressed in psi or ksi (e.g., allowable stress, yield and tensile strength, elastic modulus) were generally converted to MPa to three significant figures. See example in NBIC Parts 1, 2, 3 or 4, Table 7.4-h.

# PART 2, SECTION 8
# INSPECTION — PREPARATION OF TECHNICAL INQUIRIES TO THE *NATIONAL BOARD INSPECTION CODE* COMMITTEE

(23)

The process for submitting Interpretation, Code Revision, and Code Addition requests has been moved to the Introduction of this book.

# PART 2, SECTION 9
# INSPECTION — GLOSSARY OF TERMS

## 9.1 DEFINITIONS

For the purpose of applying the rules of the NBIC, the following terms and definitions shall be used herein as applicable to each part:

Additional terms and definitions specific to DOT Transport Tanks are defined in NBIC Part 2, Supplement 6.

**Accumulator** — A vessel in which the test medium is stored or accumulated prior to its use for testing.

**Alteration** — A change in the item described on the original Manufacturer's Data Report which affects the pressure containing capability of the pressure-retaining item. (See NBIC Part 3, 3.4.3, *Examples of Alteration*) Nonphysical changes such as an increase in the maximum allowable working pressure (internal or external), increase in design temperature, or a reduction in minimum temperature of a pressure-retaining item shall be considered an alteration.

**ANSI** — The American National Standards Institute.

**Appliance** — A piece of equipment that includes all controls, safety devices, piping, fittings, and vessel(s) within a common frame or enclosure that is listed and labeled by a nationally recognized testing agency for its intended use.

**ASME** — The American Society of Mechanical Engineers.

**ASME Code** — The American Society of Mechanical Engineers Boiler and Pressure Vessel Code published by that Society, including addenda and Code Cases, approved by the associated ASME Board.

**Assembler** — An organization who purchases or receives from a manufacturer the necessary component parts of valves and assembles, adjusts, tests, seals, and ships safety or safety relief valves at a geographical location, and using facilities other than those used by the manufacturer.

**Authorized Inspection Agency (AIA)**

**Inservice**: An Authorized Inspection Agency is either:

a) a Jurisdictional authority as defined in the National Board Constitution; or

b) an entity that is accredited by the National Board meeting NB-369, *Accreditation of Authorized Inspection Agencies Performing Inservice Inspection Activities*; NB-371, *Accreditation of Owner-User Inspection Organizations (OUIO);* or NB-390, *Accreditation of Federal Inspection Agencies (FIA).*

**New Construction**: An Authorized Inspection Agency is one that is accredited by the National Board meeting the qualification and duties of NB-360, *National Board Acceptance of Authorized Inspection Agencies (AIA) Accredited by the American Society of Mechanical Engineers (ASME).*

(23) **Authorized Nuclear Inspection Agency** — An Authorized Inspection Agency meeting the qualification and duties of NB-360, National Board Acceptance of Authorized Inspection Agencies (AIA) Accredited by the American Society of Mechanical Engineers (ASME) and intending to perform nuclear inspection activities and employing Authorized Nuclear Inspectors / Supervisors. The Certificate of Accreditation from ASME must include the performance of inspection activities covering Section III and Section XI of the ASME Boiler and Pressure Vessel Code in accordance with the applicable parts of ASME QAI-1.

**Biomass** — Fuels which result from biological sources requiring a relatively short time for replenishment: Wood and bagasse are typical examples.

**Biomass Fired Boiler** — A boiler which fires biomass as its primary fuel.

**Brazing** — A group of metal joining processes which produce coalescence of materials by heating them to a suitable temperature, and by using a filler metal having a liquidus above 840°F (450°C) and below the solidus of the base materials. The filler metal is distributed between the closely fitted surfaces of the joint by capillary action.

**Boiler** — A boiler is a closed vessel in which water or other liquid is heated, steam or vapor generated, steam or vapor is superheated, or any combination thereof, under pressure for use external to itself, by the direct application of energy from the combustion of fuels or from electricity or solar energy. The term boiler also shall include the apparatus used to generate heat and all controls and safety devices associated with such apparatus or the closed vessel.

**High-Temperature Water Boiler** — A power boiler in which water is heated and operates at a pressure in excess of 160 psig (1.1 MPa) and/or temperature in excess of 250°F (121°C).

**Hot-Water Heating Boiler** — A hot water boiler installed to operate at pressures not exceeding 160 psig (1,100 kPa) and/or temperatures not exceeding 250°F (121°C), at or near the boiler outlet.

**Hot-Water Supply Boiler** — A boiler that furnishes hot water to be used externally to itself at a pressure less than or equal to 160 psig (1,100 kPa gage) or a temperature less than or equal to 250°F (120°C) at or near the boiler outlet.

**Power Boiler** — A boiler in which steam or other vapor is generated at a pressure in excess of 15 psig (100 kPa) for use external to itself. The term power boiler includes fired units for vaporizing liquids other than water, but does not include fired process heaters and systems. (See also High-Temperature Water Boiler).

**Steam Heating Boiler** — A steam boiler installed to operate at pressures not exceeding 15 psig (100 kPa).

**Capacity Certification** — The verification by the National Board that a particular valve design or model has successfully completed all capacity testing as required by the ASME Code.

**Carbons Recycle** — See Flyash Recycle.

**CGA –** Compressed Gas Association

**Changeover Valve** — A three-way stop (or diverter) valve with one inlet port and two outlet ports designed to isolate either one of the two outlet ports from the inlet port, but not both simultaneously during any mode of operation.

**Chimney or Stack** — A device or means for providing the venting or escape of combustion gases from the operating unit.

**Confined Space** — Work locations considered “confined” because their configurations hinder the activities of employees who must enter, work in and exit them. A confined space has limited or restricted means for entry or exit, and it is not designed for continuous employee occupancy. Confined spaces include, but are not limited to, underground vaults, tanks, storage bins, manholes, pits, silos, process vessels, and pipelines. Regulatory Organizations often use the term “permit-required confined space” (permit space) to describe a confined space that has one or more of the following characteristics: contains or has the potential to contain a hazardous atmosphere; contains a material that has the potential to engulf an entrant; has walls that converge inward or floors that slope downward and taper into a smaller area which could trap or asphyxiate an entrant; or contains any other recognized safety or health hazard, such as unguarded machinery, exposed live wires, or heat stress. Confined space entry requirements may differ in many locations and the Inspector is cautioned of the need to comply with local or site- specific confined space entry requirements.

**Conversion**

**Pressure Relief Devices** — The change of a pressure relief valve from one capacity-certified configuration to another by use of manufacturer's instructions.

**Units of Measure** — Changing the numeric value of a parameter from one system of units to another.

**Conveyor System(s)** — A fuel transport system utilized on biomass boilers that drops fuel onto a moving belt, bucket elevator, drag link conveyor, or a screw or auger mechanism. (The speed of the conveyor may be varied to meet fuel demand.)

**Covered Piping Systems (CPS)** — Not to be confused with insulated piping, ASME B31.1 pressure piping systems or other piping systems where safety risks to personnel and equipment may exist during facility operations.

**Cryogenic** — Products stored at or below -238°F (-150°C)

**Demonstration** — A program of making evident by illustration, explanation, and completion of tasks documenting evaluation of an applicant's ability to perform code activities, including the adequacy of the applicant's quality program, and by a review of the implementation of that program at the address of record and/or work location.

**Dense Phase Pneumatic System(s)** — A batch feed transport system used on solid fuel fired boilers for both fuel delivery and/or ash removal. In this system the material to be transported is dropped through a valve in a pressure vessel. When the vessel is filled the valve closes and air at a pressure from 30 to 100 psig (200 to 700 kPa) is admitted and the material leaves the vessel in the form of a "slug". The sequence then repeats.

**Dutchman** — Generally limited to tube or pipe cross-section replacement. The work necessary to remove a compromised section of material and replace the section with material meeting the service requirements and installation procedures acceptable to the Inspector. Also recognized as piecing.

**Emissions** — The discharge of various Federal or State defined air pollutants into the surrounding atmosphere during a given time period.

**Emissions Control System** — An arrangement of devices, usually in series, used to capture various air pollutants and thereby reduce the amount of these materials, or gases, being admitted to the surrounding atmosphere, below Federal or State defined standards.

**Examination** — In process work denoting the act of performing or completing a task of interrogation of compliance. Visual observations, radiography, liquid penetrant, magnetic particle, and ultrasonic methods are recognized examples of examination techniques.

**Existing Material** — The actual material of the pressure retaining item at the location where the repair or alteration is to be performed.

**Exit** — A doorway, hallway, or similar passage that will allow free, normally upright unencumbered egress from an area.

**Field** — A temporary location, under the control of the Certificate Holder, that is used for repairs and/or alterations to pressure-retaining items at an address different from that shown on the Certificate Holder's *Certificate of Authorization.*

**Fluidized Bed** — A process in which a bed of granulated particles are maintained in a mobile suspension by an upward flow of air or gas.

**Fluidized Bed (Bubbling)** — A fluidized bed in which the fluidizing velocity is less than the terminal velocity of individual bed particles where part of the fluidizing gas passes through as bubbles.

**Fluidized Bed (Circulating)** — A fluidized bed in which the fluidizing velocities exceed the terminal velocity of the individual bed particles.

**Flyash** — Suspended ash particles carried in the flue gas.

**Flyash Collector** — A device designed to remove flyash in the dry form from the flue gas.

**Flyash Recycle** — The reintroduction of flyash/unburned carbon from the flyash collector into the combustion zone, in order to complete the combustion of unburned fuel, thereby improving efficiency.

**Forced-Flow Steam Generator** — A steam generator with no fixed steamline and waterline.

**Fuel Transport Fan** — A fan which generates airflow capable of moving fuel particles, in suspension, from a metering device to the combustion zone.

**Fusing** — The coalescence of two plastic members by the combination of controlled heating and the application of pressure approximately normal to the interface between them.

**Grate** — The surface on which fuel is supported and burned and through which air is passed for combustion.

**Hydrostatic Test** — A liquid pressure test which is conducted using water as the test medium.

**Inspection** — A process of review to ensure engineering design, materials, assembly, examination, and testing requirements have been met and are compliant with the code.

**Induced Draft Fan** — A fan exhausting hot gases from the heat absorbing equipment.

**Inspector** — See National Board Commissioned Inspector and National Board Owner-User Commissioned Inspector.

**Interference Fit** — An interference fit, also known as a press fit or friction fit, is a form of fastening between two tight fitting mating parts that produces a joint which is held together by friction after the parts are pushed together. (23)

**Intervening** — Coming between or inserted between, as between the test vessel and the valve being tested.

**Jurisdiction** — A governmental entity with the power, right, or authority to interpret and enforce law, rules, or ordinances pertaining to boilers, pressure vessels, or other pressure-retaining items where the pressure retaining item is installed. It includes National Board member Jurisdictions defined as “Jurisdictional Authorities.” Where there is no National Board Member Jurisdiction, the National Board shall act on behalf of the Jurisdiction.

**Jurisdictional Authority** — A member of the National Board, as defined in the *National Board Constitution*.

**Labeled** — Equipment or materials that comply with nationally or internationally recognized standards and are so labeled. The label of a nationally or internationally recognized testing agency that maintains periodic inspection of production of labeled equipment or materials has been applied. (23)

**Lean Phase Pneumatic System(s)** — A fuel transport system utilized on biomass boilers that drops fuel into a moving airstream, mixes with the air, and travels through a pipe at a velocity in the region of 5,000 ft/min (1,525 m/min). Air pressures are in the region of 25 inches (635 mm) water column.

**Lift Assist Device** — A device used to apply an auxiliary load to a pressure relief valve stem or spindle, used to determine the valve set pressure as an alternative to a full pressure test.

**Listed** — Equipment or materials that are included in a list published by a nationally or internationally recognized testing agency that maintains periodic inspection of production of listed equipment or materials. Listing indicates compliance with nationally or internationally recognized standards. (23)

**Liquid Pressure Test** — A pressure test using water or other incompressible fluid as a test medium.

**Manufacturer's Documentation** — The documentation that includes technical information and certification required by the original code of construction.

**Mechanical Assembly** — The work necessary to establish or restore a pressure retaining boundary, under supplementary materials, whereby pressure-retaining capability is established through a mechanical, chemical, or physical interface, as defined under the rules of the NBIC.

**Mechanical Repair Method** — A method of repair, which restores a pressure retaining boundary to a safe and satisfactory operating condition, where the pressure retaining boundary is established by a method other than welding or brazing, as defined under the rules of the NBIC.

**Metering Device** — A method of controlling the amount of fuel, or air, flowing into the combustion zone.

**"NR" Certificate Holder** — An organization in possession of a valid "NR" *Certificate of Authorization* issued by the National Board.

**National Board** — The National Board of Boiler and Pressure Vessel Inspectors.

**National Board Commissioned Inspector** — An individual who holds a valid and current National Board Commission.

**NBIC** — The *National Board Inspection Code* published by The National Board of Boiler and Pressure Vessel Inspectors.

**Nuclear Items** — Items constructed in accordance with recognized standards to be used in nuclear power plants or fuel processing facilities.

**Original Code of Construction** — Documents promulgated by recognized national standards writing bodies that contain technical requirements for construction of pressure-retaining items or equivalent to which the pressure-retaining item was certified by the original manufacturer.

**Overfire Air** — Air admitted to the furnace above the grate surface /fuel bed. Used to complete the combustion of fine particles, in suspension. Also aids in reducing NOx formation.

**Owner or User** — As referenced in lower case letters means any person, firm, or corporation legally responsible for the safe operation of any pressure-retaining item.

**Owner-User Inspection Organization** — An owner or user of pressure-retaining items that maintains an established inspection program, whose organization and inspection procedures meet the requirements of the National Board rules and are acceptable to the Jurisdiction or Jurisdictional Authority wherein the owner or user is located.

**Owner-User Inspector** — An individual who holds a valid and current National Board Owner-User Commission.

**Piecing** — A repair method used to remove and replace a portion of piping or tubing material with a suitable material and installation procedure.

**Pilot Operated Pressure Relief Valve** — A pressure relief valve in which the disk is held closed by system pressure, and the holding pressure is controlled by a pilot valve actuated by system pressure.

**Plate Heat Exchanger (PHE)** — An assembly of components consisting of heat transfer plates and their supporting frame. The frame provides structural support and pressure containment and may consist of fixed endplates, moveable endplates, an upper carrying bar and lower guide bar which provide plate alignment, and frame compression bolts.

**Pneumatic Test** — A pressure test which uses air or another compressible gas as the test medium.

**Potable Water Heaters** — A corrosion resistant appliance that includes the controls and safety devices to supply potable hot water at pressure not exceeding 160 psig (1,100 kPa) and temperature not in excess of 210°F (99°C).

**Fired Storage Water Heater** — A potable water heater in which water is heated by electricity, the combustion of solid, liquid, or gaseous fuels and stores water within the same appliance.

**Indirect Fired Water Heater** — A potable water heater in which water is heated by an internal coil or heat exchanger that receives its heat from an external source. Indirect fired water heaters provide water directly to the system or store water within the same appliance.

**Circulating Water Heater** — A potable water heater which furnishes water directly to the system or to a separate storage tank. Circulating water heaters may be either natural or forced flow.

**Potable Water Storage Tank** — An unfired pressure vessel used to store potable hot water at temperatures not exceeding 210°F (99°C).

**Practicable** — Capable of being accomplished based on technical consideration of the nature and scope of activities, design, or arrangement**.** (23)

**Pressure Relief Device** — A device designed to prevent pressure or vacuum from exceeding a predetermined value in a pressure vessel by the transfer of fluid during emergency or abnormal conditions.

**Pressure Relief Valve (PRV)** — A pressure relief device designed to actuate on inlet static pressure and reclose after normal conditions have been restored.

**Pressure Relief Valve Shelf Life** — For a pressure relief valve or pilot valve, the length of time for which the device can be stored, after it has been set and tested or repaired, prior to installation, without requiring a retest or reduced service interval.

**Pressure-Retaining Items (PRI)** — Any boiler, pressure vessel, piping, or material used for the containment of pressure, either internal or external. The pressure may be obtained from an external source, or by the application of heat from a direct source, or any combination thereof.

**Pressure roll load** — The terms line load, and nip load are used interchangeably to refer to the interaction between the pressure roll(s) and the Yankee dryer. It is called “nip” load because the pressure roll is rubber-covered and is pressed up against the Yankee with enough force to create a nip (or pinch) that forces the paper into line contact between the rolls and provides some mechanical dewatering. The paper then sticks onto the Yankee surface and follows the Yankee dryer for thermal dewatering by the steam-heated Yankee surface. This “nip load” is called a “line load” because the units are load (force) per length of line contact. The units are pounds per linear inch (PLI) and kilonewtons per meter (kN/m).

**Pressure Test** — A test that is conducted using a fluid (liquid or gas) contained inside a pressure-retaining item.

**Pressure Vessel** — A pressure vessel is a container other than a boiler or piping used for the containment of pressure.

**“R” Certificate Holder** — An organization in possession of a valid “R” *Certificate of Authorization* issued by the National Board.

**Re-ending** — A method used to join original code of construction piping or tubing with replacement piping or tubing material for the purpose of restoring a required dimension, configuration or pressure-retaining capacity.

**Relief Valve** — A pressure relief valve characterized by gradual opening that is generally proportional to the increase in pressure. It is normally used for incompressible fluids.

(23) **Remote Visual Inspection** — The examination of a PRI via a camera affixed to a mobile platform not operated by the Inspector, where the Inspector does not have direct line of sight with the area being examined.

**Repair** — The work necessary to restore pressure-retaining items to a safe and satisfactory operating condition.

**Re-rating (re-rate)** — See alteration. Re-rate does not apply to pressure relief devices.

**Regulatory Authority** — A government agency, such as the United States Nuclear Regulatory Commission, empowered to issue and enforce regulations concerning the design, construction, and operation of nuclear power plants.

**Safe Point of Discharge** — A location that will not cause property damage, equipment damage, or create a health or safety threat to personnel in the event of discharge.

**Safety Relief Valve** — A pressure relief valve characterized by rapid opening or by gradual opening that is generally proportional to the increase in pressure. It can be used for compressible or incompressible fluids.

**Safety Valve** — A pressure relief valve characterized by rapid opening and normally used to relieve compressible fluids.

(23) **Scrapped** — Permanent removal from service by owner's or user's procedures.

**Seal Weld** — Any weld designed primarily to provide a specific degree of tightness against leakage. A seal weld is not intended to provide structural integrity to a pressure retaining item.

**Settings** — Those components and accessories required to provide support for the component during operation and during any related maintenance activity.

**Shop** — A permanent location, the address that is shown on the *Certificate of Authorization*, from which a Certificate Holder controls the repair and/or alteration of pressure-retaining items.

**Suspension Burner** — A combustion system in which the fuel is in the form of relatively small particles, Their buoyancy is maintained in the transport airstream and the fuel/air mixture flow stream, until combustion is completed.

**Testing Laboratory** — National Board accepted laboratory that performs functional and capacity tests of pressure relief devices.

**Thermal Fluid Heater** — A thermal fluid heater is a closed vessel in which a fluid other than water is heated by the direct application of heat from a thermal energy source. Depending on the process heating requirements, the fluid may be vaporized with normal circulation but, more often, the fluid is heated and circulated by a pump.

**Transient** — An occurrence that is maintained only for a short interval as opposed to a steady state condition.

**Underfire Air** — A method of introducing air beneath the grate surface/fuel bed.

**"VR" Certificate Holder** — An organization in possession of a valid "VR" *Certificate of Authorization* issued by the National Board.

**Velocity Distortion** — The pressure decrease that occurs when fluid flows past the opening of a pressure sensing line. This is a distortion of the pressure that would be measured under the same conditions for a non or slowly moving fluid.

**Verify** — To determine that a particular action has been performed in accordance with the requirements either by witnessing the action or reviewing records.

**Volumetric NDE** — A method capable of detecting imperfections that may be located anywhere within the examined volume. Volumetric NDE is limited to radiographic (RT) and ultrasonic (UT) examination methods.

**Water Head** — The pressure adjustment that must be taken into account due to the weight of test media (in this case, water) that is 0.433 psi/ft (10 kPa/m) added (subtracted) from the gage pressure for each foot the gage is below (above) the point at which the pressure is to be measured.

**Welding** — A group of processes which produce a localized coalescence of metallic or nonmetallic materials by heating the materials to the suitable temperature, with or without the application of pressure, and with or without the use of filler material.

**Witness** — To be present at an event and have first-hand knowledge of the action and be able to attest that it occurred.

# PART 2, SECTION 10
# INSPECTION — NBIC APPROVED INTERPRETATIONS

## 10.1 SCOPE

a) This section provides a list of all approved interpretations for previous editions and addenda of the NBIC. A complete list of interpretations including approved interpretations for this edition is provided on the National Board website.

b) Each interpretation references the edition and addenda applicable to the committee response and approval. Use of interpretations, for other than the approved edition and addenda, may not be appropriate for reference.

c) Technical inquiries (also known as "request for interpretation") may be submitted to the NBIC committee to clarify the meaning or intent of existing rules to the NBIC. The requirements for submitting technical inquiries are described in NBIC Parts 1, 2, and 3 (Section 8), Preparation of Technical Inquiries to the NBIC Committee.

(23) **2021 INTERPRETATIONS**

| Interpretation | Edition | Part | Section | Subject |
|---|---|---|---|---|
| 21-16 | 2021 | 3 | 1.3.2 | Jurisdictional requirements not meeting NBIC requirements |
| 21-15 | 2021 | 3 | 5.7.1 | Stamping Requirements for Repairs and Alterations |
| 21-14 | 2021 | 3 | 3.4.3 | Encapsulation of Shells and Heads |
| 21-13 | 2021 | 3 | 3.3.4.8 | Repair of pressure-retaining items without complete removal of defect |
| 21-12 | 2021 | 3 | 3.2.2 b) and e) | Overlaid Replacement Parts |
| 21-11 | 2021 | 3 | 3.3.3 h) | Mechanical Replacement of Shell or Head |
| 21-10 | 2021 | 1 | 1.6.3 | Boiler Room Exit |
| 21-09 | 2021 | 3 | 3.3.2 e) 1) | Routine Repairs |
| 21-08 | 2021 | 3 | 3.3.2 e) | Routine Repair Scope |
| 21-07 | 2021 | 3 | 3.3.3 s) and 3.4.4 d) | Repairs and Alterations of Tube Bundles |
| 21-06 | 2021 | 2 | 2.3.6.2 b) 4) | Air Receiver Tank Manual Drain Valve |
| 21-05 | 2021 | 3 | 3.3.5 and 3.4.5 | ASME Section VIII, Div. 1 Design Personnel Requirements and NBIC Repairs/Alterations |
| 21-04 | 2021 | 3 | 1.3.1 | Repair or Alteration Activity Allowed Prior to Certification |
| 21-03 | 2021 | 3 | 4.2 | NDE Requirements When Repairing Minor Defect on Pressure Vessel with RT4 Marking |
| 21-02 | 2021 | 3 | 1.5.1 and 3.3.3 c) | Subcontracted Weld-Overlay Repair |
| 21-01 | 2021 | 3 | 3.3.6 | Repair and Alterations of Impact Tested Vessels |

## 2019 INTERPRETATIONS (23)

| Interpretation | Edition | Part | Section | Subject |
|---|---|---|---|---|
| 19-26 | 2019 | 1 | S3.1 | Scope of Installation of Liquid Carbon Dioxide Storage Vessel |
| 19-25 | 2019 | 3 | 3.3.3 and 3.4.4 | Examples of Repairs and Alterations |
| 19-24 | 2019 | 3 | 5.7.5 | Stamping Requirements for Small Parts |
| 19-23 | 2019 | 3 | 3.3.2 e) 1 | Mechanical Replacement of Valves, Fittings, Tubes, and/or Pipes |
| 19-23 | 2019 | 3 | 3.3.2 e) 1) | Mechanical replacement of valves, fittings, tubes, and/or pipes |
| 19-22 | 2019 | 3 | 3.3.2 e) | Repair of a Stiffening Ring |
| 19-21 | 2019 | 3 | 1.4.1 | Accreditation Process/Certification of Scope |
| 19-20 | 2019 | 3 | 4.4.1 & 4.4.2 | Liquid Pressure Test Examination Methods Applicable to Alterations |
| 19-19 | 2019 | 3 | 1.3.2 | Authorization of Repair/Alteration Activities |
| 19-18 | 2019 | 3 | 3.3.2 e) | Addition of Non-Load Bearing Attachments |
| 19-17 | 2019 | 3 | 3.3.3 | Scope of Repairs |
| 19-16 | 2019 | 3 | 4.4.2 c) | Alternative Method in lieu of Pressure Testing or Examination |
| 19-15 | 2019 | 3 | 3.4.4 | PV Cycles of operations change as an alteration |
| 19-14 | 2019 | 3 | 3.4.5.1 b) | Alteration of ASME Section VIII Div.2 vessels |
| 19-13 | 2019 | 3 | 4.4.1 e) | Nondestructive Examination |
| 19-12 | 2019 | 3 | 3.3.3 & 3.3.4.3 | Weld build of wasted areas with different material |
| 19-11 | 2019 | 3 | 3.2.2, 3.3.3, & 5.12.4.1 | Mechanical Installation of Replacement Parts in ASME Section VIII Division 3 Pressure Vessels |
| 19-10 | 2019 | 3 | 2.2.6 & S6.9.6 | Continuity of qualified personnel |
| 19-09 | 2019 | 3 | Table 2.3 | Acceptance of latest AWS SWPS for use in the 2019 NBIC |
| 19-08 | 2019 | 3 | 3.3.2 | Routine Repairs for ASME B31.3 Normal Fluid Service and Severe Cyclic piping |
| 19-07 | 2019 | 3 | 5.6 | Form Registration Log |
| 19-06 | 2019 | 3 | 2.2 & 2.2.1 | National Certified Pipe Welding Bureau (NCPWB) welding procedure specifications |
| 19-05 | 2019 | 3 | 1.5.1 d) 1) | Clarification of Part 3, 1.5.1 d) 1) |
| 19-04 | 2019 | 3 | 2.5.3.6 | Welding Method 6 on Grade 92 steel |
| 19-03 | 2019 | 3 | 1.6.6.2 m), 1.6.7.2 m), & 1.6.8.2 m) | ISO/IEC 17025 edition reference in NBIC Part 3, 1.6.6.2, 1.6.7.2, and 1.6.8.2 |
| 19-02 | 2019 | 3 | 3.3.4.3-a | Wastage/Wasted Areas |
| 19-01 | 2019 | 3 | 3.3.2 | “R” Certificate Holder manufacturing parts and subassemblies |

## 2017 INTERPRETATIONS

| Interpretation | Edition | Part | Section | Subject |
|---|---|---|---|---|
| 17-22 | 2017 | 3 | 3.3.2, 3.3.5 | Repair of Section VIII Div. 2 and Div. 3 Pressure Vessels |
| 17-21 | 2017 | 3 | 3.3.2 e) | Determining the Pressure Used for Hydrostatic Test |
| 17-20 | 2017 | 3 | 3 4.4.2 c) | NDE methods in lieu of a hydrostatic test |
| 17-19 | 2017 | All Parts | 8.1 b) | Interpretations issued to earlier NBIC editions |
| 17-18 | 2017 | 3 | 3.2.6 | Reference to Other Codes and Standards |
| 17-17 | 2017 | 3 | 3.3.5, 3.4.5 | Repair and alteration of Section VIII Division 2 items |
| 17-16 | 2017 | 3 | 3.4.1 | Certifying engineer of UDS for re-rating of pressure vessel |
| 17-15 | 2017 | 3 | 2.5.3.2, 2.5.3.3, 2.5.3.4 | Alternative Welding Methods |
| 17-14 | 2017 | 1, 4 | Part 1, 2.9.6 h) and Part 4, 2.2.10 h) | Plugging a Valve Casing Drain |
| 17-13 | 2017 | 3 | 2.5.3 e) | Alternative NDE methods acceptable to the Inspector and the Jurisdiction |
| 17-12 | 2017 | 3 | 3.3.4 | Reducing a pressure vessel's overall shell length |
| 17-11 | 2017 | 3 | 2.5.3.6 e) | Changing of Welding Consumables |
| 17-10 | 2017 | 3 | 3.4.5 | ASME Section VIII, Division 2, Class 1 Vessels. |
| 17-09 | 2017 | 3 | 2.5.2 | Post-Weld Heat Treatment of full penetration groove weld |
| 17-08 | 2017 | 3 | 3.3.5.2.a and 3.4.5.1.a | Repair/Alteration Plans for ASME VIII, Division 2, Class 1 Pressure Vessels |
| 17-07 | 2017 | 3 | 2.5.3 | Omission of PWHT by an R Certificate holder |
| 17-06 | 2017 | 3 | 2.5.3.6 | Part 3, Section 2.5.3.6, Welding Method 6 |
| 17-05 | 2017 | 3 | 3 | Repairs to a Pressure Retaining Part |
| 17-04 | 2017 | 2 | All | Evaluation of existing equipment with minimal documentation |
| 17-03 | 2017 | 3 | 3, Figure 3.3.4.3-b and 3, 3.3.2(e)(5) | Adding Handhole Ring on Pressure Side of Pressure Retaining Item |
| 17-02 | 2017 | 3 | 1.5.1 | Continuity Records Retention |
| 17-01 | 2017 | 3 | All | Application of Term "Practicable" |

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| 15-14 | 2017 | 3 | 1.5.1 | Continuity Records Retention |
| 15-13 | 2015 | 3 | 5.7.2 | Routine Repair Stamping Requirements |
| 15-12 | 2015t | 3 | 3.3.2 | Surface Repair of Corrugating Rolls |
| 15-11 | 2013 | 3 | 3 | Repair/Replacement of Bolting Material |
| 15-10 | 2017 | 3 | All | Application of Term “Practicable” |

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| 15-08 | 2015 | 3 | 5.7 | Alteration to One Side of Shell/Tube Heat Exchanger |
| 15-07 | 2015 | 3 | 3.4.3 | Local Stress from Bracket Loading |
| 15-06 | 2015 | 3 | 3.4.3 | Change in Boiler Heat Input from HRSG |
| 15-05 | 2015 | 3 | 1.3.2 c) | Verification of Installation of Repair Nameplate |
| 15-04 | 2015 | 3 | 3 | Explosive Weld Plugs Tube Repair |
| 15-03 | 2015 | 3 | 3.2.6 | Fillet Welded Patches |
| 15-02 | 2015 | 3 | 5.12.2 | Valve Repair Nameplate Field Labels |
| 15-01 | 2015 | 1 | 3.3.4 | Boiler Clearance Less than Recommended |

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| Interpretation | Edition | Part | Section | Subject |
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| 13-10 | 2013 | 3 | 3 | Use of Backing Strips to Install Flush Patches |
| 13-09 | 2013 | 3 | 4 | Penetrant Examination in Lieu of Hydrostatic Test |
| 13-08 | 2013 | 3 | 1.6.1 | Quality Control System Responsibilities |
| 13-07 | 2013 | 3 | 3.2 | Weld Buildup of Wasted Areas |
| 13-06 | 2013 | 3 | 2.5.2 | Postweld Heat Treatment Requirements |
| 13-05 | 2013 | 1 | 3.8.2.3 | Operating Limit Control Location on Hot Water Supply Boilers |
| 13-04 | 2013 | 3 | 3.3.2 e) | Seal Welding of Inspection Opening Covers |
| 13-03 | 2011 | 3 | 3.3.2 d) 1) | Standard Threaded Fitting Welded through ASME VIII, Div. 1 Vessel |
| 13-02 | 2011 | 3 | 5.7.5 | Stamping Requirements for Alterations |
| 13-01 | 2013 | 3 | 1.8.5 q) | Personnel Qualified IAW ANSI/ASME N45.2.23 |

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| 11-06 | 2011 | 3 | 3.2.5 | Calculations / Start of Work |
| 11-05 | 2011 | 2 | 5.2.2 – 5.2.3 | Replacement of Stamped Data on Corrugator Rolls |
| 11-04 | 2011 | 3 | 1.7 | Application of “VR” Stamp |
| 11-03 | 2011 | 2 | 2.5.8 | Test Frequencies |
| 11-02 | 2011 | 3 | 4.4.2 a) | Liquid Pressure Test Requirements |
| 11-01 | 2011 | 3 | 3.3.2 | Routine Repair Considerations |

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| 07-15 | 2007 | 2008 | 2 | S2.10.6 | Average Pitch |
| 07-14 | 2007 | 2009 | 3 | 3.3.3 | Replacement of Pressure Retaining Parts |
| 07-13 | 2007 | 2009 | All | | The Original Code of Construction |
| 07-12 | 2007 | 2009 | 3 | 3.4.3 | Replacement of Heads with Different Types |
| 07-11 | 2007 | 2010 | 3 | 3.2.2 a) | Replacement Parts |
| 07-10 | 2007 | 2009 | 3 | 3.3.2–3.3.3 | Routine Repairs |
| 07-09 | 2007 | 2008 | 2 | S2.9 b) & S2.11 b) 7) b) | Schedule 80 Pipe in External Piping |
| 07-08 | 2007 | 2009 | 3 | 3.4.3 c) | Handhole Replacement with Flush Patch |
| 07-07 | 2007 | 2009 | 3 | 3.3.4.3 e) & 3.3.2 d) 3) | Weld Buildup of Wasted Area / Routine Repair |
| 07-06 | 2007 | | 3 | | Replacement Parts for Repairs and Alterations |
| 07-05 | 2007 | 2008 | 1 | 2.9.5.1 c) | Change-Over Valve Permitted in ASME Code Case-2254 Use |
| 07-04 | 2007 | | 1 | 4.5.1 a) | Installation of New Rupture Disc in an Existing Holder |
| 07-03 | 2007 | | 3 | 2.5.3 | Use of Alternative Welding Method 2 on P-No 4 and P-No 5A Base Material |
| 07-02 | 2007 | | 3 | 1.6.2, 1.7.5.4, & 1.8.2 | NBIC Manual Requirements for “R”, “VR”, and “NR” Stamp Holders |
| 07-01 | 2004 | 2006 | | RB-8400 & RB-8410 | “Try Testing” of Pressure Relief Valves |

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| 04-22 | 2004 | | RC-1130 | Inspector Verification of NDE Performed |
| 04-21 | 2004 | 2005 | RC-1130 | Inspector Involvement in NDE in Lieu of Pressure Test |
| 04-20 | 2004 | 2005 | RC-2051(d) & RC-3031(b) | Pneumatic Test in Lieu of Liquid Pressure Test |
| 04-19 | 2004 | 2005 | RD-2020 | Repair of Threaded Bolt Holes |
| 04-18 | 2004 | 2005 | RD-3010 | Re-rating Using a Later Edition/Addenda of The Original Code of Construction |
| 04-17 | 2001 | 2003 | RD-2020(c) | Procedures for Repairing Cracks and Crack Classification |

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| 04-15 | 2004 | | RD-2060 | Utilizing a Flush Patch to Gain Access Window in Pressure Retaining Items |
| 04-14 | 2004 | | RC-1000 & RC-3000 | Replacement Safety Valves with Different Capacities and Set Pressures than Boiler Data Report |
| 04-13 | 2004 | | RC-1020, RC-1030, Appendix 4, & RC-3022 | Replacement of a Cast Iron Section |
| 04-12 | 2001 | 2003 | RD-1030, RC-1050(c) | Post Weld Heat Treatment of Parts |
| 04-11 | 2001 | 2003 | RC-1050(c), RC-2050, & RC-2051 | Requirements for Testing Replacement Parts |
| 04-10 | 2004 | | RC-2031 | Flush Patches in Pipes and Tubes NPS 5 or less |
| 04-09 | 2004 | | RC-2031 | Routine Repairs |
| 04-08 | 2004 | | RE-1050 | Fabricated Replacement Critical Parts |
| 04-07 | 2004 | | RE-1050 | Source for Critical Parts |
| 04-06 | 2004 | | RC-1050(c), RC-2050, RC-2051, & RC-1110 | Written Procedure Requirements for Non-Destructive Examinations |
| 04-05 | 2001 | 2003 | RC-1050(c) & RC-2050 | "R" Stamp Holder Installation of Code Manufacturer Supplied Parts |
| 04-04 | 2004 | | RC-3022(b) & (d) | Re-rating of Pressure-Retaining Items for Lethal Service/Removal of Insulation |
| 04-03 | 2004 | | RC-3022(b) & (d) | Re-rating of Pressure-Retaining Items/Removal of Insulation |
| 04-02 | 2004 | | RA-2213 | "VR" Certificate Holder Verification of Manufacturer's Nameplate Capacity |
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| 01-40 | 2001 | 2003 | RC-2051(e), RC-3031(c), RC-2050, & RC-3030(c) | Use of VT when Pressure Test Is Not Practicable |
| 01-39 | 2001 | 2003 | RC-3051 | Inspector Responsibilities for Form R-2 after Witnessing Pressure Test |
| 01-38 | 2001 | 2003 | RD-3022(d) | Design Only "R" Stamp Holders Pressure Testing and Form R-2 |
| 01-37 | 2001 | 2003 | RC-1140 & RC-3040 | Construction Phase & Stamping when Re-rating without Physical Changes |
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| 01-34 | 2001 | 2002 | RD-1060(h)(2) | Butter Layers Using the SMAW Process |
| 01-34 | 2001 | 2002 | RD-1040(i)(6) | Shielding Gas Dewpoint Temperature |
| 01-33 | 2001 | 2002 | UG-45 | Evaluation of Inservice Pressure Vessels and Requirement of UG-45 |
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| 01-24 | 2001 | | RC-1110(a) | NDE of Tack Welds by Welders and Welder Operators |
| 01-23 | 2001 | | RC-2031(a)(1) | Routine Repairs |
| 01-22 | 2001 | | RC-2031 | Routine Repairs |
| 01-21 | 2001 | | Appendix 6, Part B | Alternative Welding Methods in Lieu of Post Weld Heat Treatment |
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| 01-14 | 2001 | | RC-2082(b) | Repair Plan (Sec. VIII, Div. 2) AIA Acceptance |
| 01-13 | 2001 | | RB-4010 | Replacement of Stamped Data |
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| 01-10 | 1998 | 2000 | RD-1000 | Alternative Postweld Heat Treatment Methods |
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| 01-07 | 1998 | 2000 | RA-2030(a) | Owner-User Inspection Organizations |
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| 01-05 | 1998 | 2000 | RA-2330(n) | "NR" Program Audits |
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(S7.9)

**Repair**
(Foreword), (Introduction), (1.3), (1.5.2), (1.5.2.1), (2.2.10.6), (2.2.11), (2.2.12.2), (2.2.12.9), (2.2.3), (2.3.4), (2.3.5.4), (2.3.6.4), (2.3.6.5), (2.3.6.6), (2.3.6.7), (2.4.2), (2.5.2), (2.5.5.2), (2.5.7), (2.5.8), (3.4.8), (3.4.9), (4.3.1), (4.4.1), (4.4.2), (4.4.4), (4.4.5), (4.4.7.2), (4.4.8.4), (4.4.8.7), (4.5.6.2), (4.5.6.4), (5.3.5), (5.3.6), (5.3.7.1), (S1.3), (S1.4.2.2), (S1.4.2.8.1), (S1.4.2.14), (S1.4.2.15), (S1.4.2.17), (S1.4.3.2), (S1.5.4), (S2.1), (S2.3), (S2.4.1), (S2.4.2), (S2.4.3), (S2.8.1), (S2.10.4.2), (S2.10.5), (S2.10.7), (S2.11), (S2.13.2), (S2.14.12), (S2.14.13), (S3.4), (S4.5), (S4.6.2), (S4.9.2), (S5.3.2), (S5.3.2.5), (S5.5), (S6.2), (S6.4), (S6.4.3), (S6.4.5), (S6.4.7.4.1), (S6.4.7.4.2), (S6.5.5.1), (S6.6.2), (S6.6.3.1), (S6.6.4), (S6.7), (S6.8), (S6.13.3), (S6.13.4), (S6.13.5), (S6.13.6), (S6.13.6.1), (S6.13.6.7), (S6.13.7), (S6.13.8), (S6.13.9), (S6.13.10), (S6.14.6.4), (S6.15.3.1), (S6.15.3.6), (S6.16.1), (S6.16.6), (S6.16.8), (S6.17), (S7.4), (S7.6), (S7.7), (S7.8.1), (S7.8.2), (S7.8.3), (S7.8.4), (S7.8.5), (S7.9), (S7.10), (S8.5), (S9.3), (S10.7), (7.1), (7.2), (9.1)

**Repair Organization**
(Introduction), (S6.16.8), (S7.6), (S7.7), (S7.8.1), (S7.8.2), (S7.8.3), (S7.8.4)

**Replacement Stamping**
(5.2), (5.2.2), (5.2.3), (5.3.2)

**Request**
(Foreword), (Introduction), (1.5.3), (2.1), (2.4.3), (4.5.7), (5.2.1), (5.2.3), (S2.6.2), (S6.12.2), (S6.13.7), (Section 8)

**Re-rating**
(S6.4.5), (9.1)

**Resin**
(2.2.12.7), (S3.1), (S4.3), (S4.8.1), (S10.7), (S10.8)

**Responsibility**
(Foreword), (Introduction), (1.4), (1.5.2.1), (4.4.1), (S2.4.1), (S6.11), (S6.12.2)

**Return to Service**
(S1.5.6), (S2.13.4)

**Review**
(Foreword), (Introduction), (1.3), (1.5.2), (1.5.2.1), (2.2.3), (2.2.6), (2.2.10.6), (2.2.11), (2.2.12.6), (2.3.3), (2.3.4), (2.3.5.3), (2.3.5.4), (2.4.2), (2.4.3), (2.5.5.3), (2.5.7), (4.2), (4.4.1), (4.4.3), (4.4.4), (4.4.6), (4.4.7), (4.4.8.2), (5.3.7.1), (S1.4.2.23), (S1.5), (S2.4.1), (S2.6.2), (S2.6.3.4), (S4.6.1), (S5.1), (S5.6), (S6.4.6), (S6.12.1), (S6.16.6), (S7.2), (S7.4), (S8.5), (S9.5), (S10.10.7), (7.3), (8.4), (9.1)

**Revisions**
(Foreword), (Introduction), (Section 8)

**Risk-Based Inspection**
(1.3), (4.5), (4.5.1), (4.5.2), (4.5.3), (4.5.4), (4.5.5), (4.5.6), (4.5.7)

**Rivets**
(3.3.1), (S1.4.2.1), (S1.4.2.5), (S1.4.2.11), (S1.4.2.14), (S1.4.2.20), (S1.4.2.29), (S1.4.2.30), (S1.4.2.34), (S1.5.4), (S2.10.1), (S2.10.2), (S2.10.2.2), (S2.10.2.3), (S2.10.6), (S2.11), (S2.13.2), (S2.15)

**Riveted Joints**
(2.2.8), (4.4.7.2), (S1.4.2.1), (S2.10.6)

**Rupture Discs**
(2.5.7.3), (S6.4.7.5.3), (S6.15.1), (S6.15.3.3), (S6.15.3.5)

## S

**Safe Point of Discharge**
(2.2.12.7), (2.3.6.8), (2.3.6.9), (2.5.4), (S2.8.1), (S6.16.3), (S2.9), (S6.16.3), (9.1)

**Safety**
(Foreword), (Introduction), (1.1), (1.3), (1.4), (1.4.1), (1.5), (1.5.3), (2.2.4), (2.2.5), (2.2.6), (2.2.10.2), (2.2.10.4), (2.2.10.5), (2.2.10.6), (2.2.12.6), (2.2.12.7), (2.2.12.9), (2.3.2), (2.3.4), (2.3.5.2), (2.3.5.4), (2.3.6.2), (2.3.6.4), (2.3.6.5), (2.3.6.6), (2.3.6.7), (2.4.2), (2.5.1), (2.5.8), (4.3.1.3), (4.4.4), (4.5.2), (4.5.3), (4.5.4), (4.5.5), (4.5.6.2), (S1.4.2.26), (S2.3), (S2.4), (S2.4.1), (S2.4.3), (S2.6), (S2.10), (S2.10.3), (S2.10.6), (S2.14.1), (S2.14.7), (S4.9.1), (S4.9.2), (S5.3.1), (S5.3.2), (S6.11), (S6.12.2), (S6.13.7), (S6.14.3), (S6.14.6.4), (S6.15.3.1), (S6.17), (S10.7), (7.2), (9.1)

**Safety Device**
(Introduction), (1.4), (2.2.10.5), (2.2.10.6), (2.2.12.7), (2.3.5.2), (2.3.6.5), (2.4.8), (2.5.1), (2.5.5.1), (S2.4.3), (S2.8), (S2.14.12), (S6.13.6), (S6.14), (9.1)

**Safety/Safety Relief Valve**
(2.2.10.2), (2.2.10.4), (2.2.12.6), (2.3.5.4), (2.3.6.2), (2.3.6.4), (2.3.6.7), (2.5.1), (2.5.5.3), (2.5.7), (2.5.8), (5.2.3), (5.3.3), (5.3.5), (5.3.6), (S1.5.4), (S2.4.3), (S2.6.1), (S2.7.1), (S2.8), (S2.8.1), (S2.8.5), (S2.9), (S2.11), (S2.13.2), (S2.14.12), (S2.14.13), (S5.2.2), (S6.4.6.3), (S6.15.1), (S6.18), (S8.1), (S8.2), (S8.3), (S8.4), (S8.5), (9.1)

**Safety Valve Capacity**
(S1.6), (S2.8.1), (S2.11)

**Scale and Sludge**
(2.2.12.1), (2.2.12.2), (2.2.12.6), (2.2.12.9), (S1.4.2.8.1), (S2.10.4.2)

**Seal Welding**
(2.3.6.4), (S1.4.2.1), (S1.4.2.9), (S1.4.2.10), (S1.4.2.11), (S1.4.2.13), (S1.4.2.15), (S1.4.2.17), (S7.10), (9.1)

**Service Conditions**
(2.2.2), (2.3.2), (2.3.5.4), (2.3.6.1), (2.3.6.5), (2.4.2), (2.4.3), (2.5.8), (4.3.1), (4.4.1), (4.4.7.2), (S6.6.2), (S6.16.9), (S7.3), (S8.4), (S8.5)

**Service Fluid**
(2.5.7), (S3.4), (S6.16.2)

**Settings**
(2.2.10.3), (2.3.3), (S2.7.3.1), (9.1)

**Set Pressure**
(2.2.12.6), (2.3.6.2), (2.3.6.6), (2.5.1), (2.5.2), (2.5.3), (2.5.5.3), (2.5.7), (2.5.8), (4.3.1.2), (4.4.7.2), (S2.7.1), (S2.8.1), (S2.11), (S6.13.6), (S6.16.6), (S6.16.7), (S8.1), (S8.2), (S8.3), (S8.4), (S8.5), (9.1)

**Shop**
(S1.5), (S2.14.12), (S2.14.13), (9.1)

**Siphons (Thermic)**
(2.2.10.4), (2.3.5.1), (S1.4.2.18), (S1.5.4), (S2.8.5), (S2.10.8)

**Sleeve**
(S1.4.2.10), (S1.4.2.22), (S1.5.4)

**Specifications**
(2.2.12.7), (2.3.5.4), (2.3.6.5), (4.4.5), (S2.6.3.4), (S4.5), (S6.4.6.2), (S6.4.7.5.2), (S6.5.3.2), (S6.5.4), (S6.5.5.2), (S6.13.1), (S6.13.2), (S6.13.11.2), (S6.15.1), (S6.16.8), (S6.16.9), (S6.17), (S7.10)

**Stamping**
(Introduction), (1.5.2), (1.7), (1.7.1), (2.3.6.6), (2.5.2), (5.1), (5.2.1), (5.2.2), (5.2.3), (5.3.2), (5.3.3), (S6.5), (S6.5.1), (S6.5.2), (S6.15.3.4), (S6.15.4), (S7.2), (S7.10), (S9.3), (7.1)

**Stays / Staybolts**
(2.2.12.2), (S1.4.1), (S1.4.2.8.1), (S1.4.2.9), (S1.4.2.10), (S1.4.2.11), (S1.4.2.12), (S1.4.2.13), (S1.4.2.18), (S1.5.5), (S1.5.2.2), (S2.10.4), (S2.10.4.1), (S2.10.4.2), (S2.10.6), (S2.11), (S2.13.3), (S2.14.8)

**Stayed Surfaces**
(S1.4.1), (S2.10.4), (S2.10.4.2), (S2.10.6), (S2.15)

**Steam Heating Boilers**
(2.5.7), (2.5.8), (S8.3)

**Stop Valves**
(1.5.3), (2.2.6), (2.11), (S6.4.7.4.4.1), (S6.4.7.4.4.2), (S6.12.2), (S6.13.2), (S6.13.9), (S6.14.5)

**Storage Methods**
(S1.5.1), (S2.13.1)

**Stress Corrosion Cracking (SCC)**
(2.3.6.4), (3.3.2), (3.3.3.5), (3.4.4), (4.4.6), (S5.3.1), (S5.3.2.2), (S5.3.2.7), (S6.6.1), (S6.6.4), (S6.13.6.3), (S6.13.7)

**Structural Attachments**
(2.3.3), (S6.4.7.6.1), (S6.6.4), (S6.12.1), (S6.13.1), (S6.13.3), (S7.4)

**Superheater**
(2.2.12.3), (S1.4.2.16), (S1.5.4), (S1.5.5), (S1.5.6), (S1.6)

**Supports**
(Introduction), (2.2.5), (2.2.10.3), (2.2.12.3), (2.2.12.8), (2.3.3), (2.3.6.1), (2.3.6.2), (2.3.6.3), (2.3.6.4), (2.3.6.7), (2.3.6.9), (2.4.4), (2.4.7), (2.5.4), (4.4.7.2), (S1.4.2.16), (S2.8.1), (S2.11), (S4.4), (S4.8.2), (S6.4.7.6.2), (S6.14.5), (S7.4), (S7.10), (S10.6), (S10.8)

**Surface Preparation**
(3.3.3.4), (4.2), (S2.4.4.1), (S4.10), (S7.3.1)

**Surfaces (FRP)**
(S4.4), (S4.7.2), (S4.8), (S4.8.1), (S4.8.2), (S4.11), (S10.6)

## T

**Telltale Holes**
(2.2.12.2), (S1.4.1), (S1.4.2.9), (S1.4.2.10), (S1.4.2.13)

**Temperature Effects**
(3.4.3), (S9.3)

**Temperature and Pressure Relief Valves**
(2.5.7)

**Tests**
(Introduction), (2.2.10.4), (2.2.10.6), (2.2.11), (2.3.6.6), (2.5.8), (4.3.1), (4.3.1.2), (4.4.5), (5.3.7), (S1.4.3.1), (S2.4.2), (S2.4.4), (S2.6), (S2.6.2), (S2.7.1), (S2.7.3.1), (S2.10.1), (S4.5), (S6.4.6), (S6.4.7), (S6.4.7.3), (S6.4.7.4.1), (S6.5.3), (S6.5.3.1), (S6.5.3.2), (S6.5.4), (S6.5.4.1), (S6.5.4.2), (S6.5.4.3), (S6.5.5.1), (S6.5.5.2), (S6.10), (S6.13), (S6.13.4), (S6.13.6), (S6.13.10), (S6.14), (S6.14.6.4), (S6.14.9), (S6.15.3), (S6.15.3.1), (S6.15.3.4), (S6.15.4), (S6.16.2), (S6.18), (9.1)

**Test Medium**
(2.5.7), (4.3.1), (4.3.1.3), (S2.6), (9.1)

**Test Only**
(4.3.1)

**Testing**
(Foreword), (Introduction), (1.4), (1.4.1), (1.5.2), (2.2.10.4), (2.2.10.6), (2.2.12.9), (2.3.3), (2.3.6.2), (2.3.6.4), (2.3.6.7), (2.4.8.1), (2.5.1), (2.5.3), (2.5.7), (2.5.8), (4.2.4), (4.3), (4.3.1), (4.3.1.1), (4.3.1.2), (4.3.1.3), (4.4.8.1), (4.4.8.5), (S1.4.1), (S1.4.2.9), (S1.4.2.10), (S1.4.2.13), (S2.4.3), (S2.4.4.2), (S2.5.1), (S2.6), (S2.6.1), (S2.6.2), (S2.7.3.1), (S2.7.3.2), (S2.10.4.2), (S2.11), (S2.13.3), (S2.14.12), (S4.6.3), (S5.4), (S5.5), (S5.6), (S6.2), (S6.4.2), (S6.4.6.2), (S6.4.7), (S6.4.7.2), (S6.4.7.4), (S6.4.7.4.4), (S6.4.7.4.4.2), (S6.4.7.5), (S6.4.7.5.1), (S6.4.7.5.2), (S6.12), (S6.13.1), (S6.13.2), (S6.13.3), (S6.13.4), (S6.13.5), (S13.6), (S6.13.6.1), (S6.13.6.2), (S6.13.6.3), (S6.13.6.4), (S6.13.6.5), (S6.13.9), (S6.13.10.1), (S6.13.10.2), (S6.14), (S6.14.2), (S6.14.3), (S6.14.6.2), (S6.15.3.2), (S6.16.2), (S6.16.6), (S6.16.7), (S6.17), (S6.18), (S7.7), (7.1), (8.3), (S9.3), (S10.3), (S10.5), (S10.7), (S10.10.2), (S10.10.3), (S10.10.4), (S10.10.6), (S10.10.7), (S10.10.8), (9.1)

**Thermal Expansion**
(S1.5.6), (S2.13.4), (S3.1)

**Thermal Fluid Heaters**
(2.2.12.7)

**Thermic Siphon**
(2.2.10.4), (2.3.5.1), (S1.4.2.18), (S1.5.4), (S2.8.5), (S2.10.8)

**Thermometer**
(2.2.10.6), (S6.12.1)

**Thinning**
(2.2.12.5), (2.2.12.7), (2.2.12.9), (2.3.6.1), (S1.4.1), (S1.4.2.8.1), (S2.5.2.2), (S2.6.2), (S2.6.3.4), (S2.10.4.2), (S2.11), (S4.8.1), (S5.2.2), (S5.3), (S5.3.1)

**Throttle and Throttle Valves**
(S1.4.2.20), (S1.4.2.21), (S1.5.4), (S2.13.2), (S2.14.2), (S2.14.3), (S2.14.4), (S2.14.7)

**Threaded Connections**
(2.3.4), (2.4.4), (S6.14.6.1), (S6.14.6.2), (S6.15.1)

**Threaded Opening**
(S2.5.2.2), (S2.9), (S2.11), (S2.5.2.2), (S2.9)

**Ton Tanks (DOT)**
(S6.1), (S6.4.6), (S6.4.6.3), (S6.4.7.2), (S6.4.7.3), (S6.4.7.5.3), (S6.4.7.6.3), (S6.5), (S6.5.5.1), (S6.11), (S6.15), (S6.15.1), (S6.15.2), (S6.15.3), (S6.15.3.1), (S6.15.3.5), (S6.15.4)

**Training**
(1.4.1), (4.2), (4.2.3), (4.5.1), (4.5.4), (4.5.5), (4.5.6.4), (S2.3), (S2.4.1), (S6.4.6), (S6.12), (S6.13.6), (S10.3), (S10.10.2)

**Transient**
(4.2.8), (S5.3.2.6), (9.1)

**Transport Tanks (DOT)**
(Introduction), (2.3.6.6), (S6.1) (S6.2)

**Try-Cocks**
(S2.7.1), (S2.8.3), (S2.11), (S2.14.3), (S2.14.7)

**Tubes**
(2.2.8), (2.2.9), (2.2.10.3), (2.2.12.2), (2.2.12.3), (2.2.12.7), (2.2.12.8), (2.2.12.9), (3.4.6), (S1.1) (S1.4.2.17), (S1.4.3.2), (S1.5.4), (S2.5.2.1), (S2.5.2.2), (S2.11), (S2.13.2), (S2.14.6), (S2.14.9)

**Tubesheet**
(1.1), (2.2.12.2), (S1.5.4), (S2.5.2.1), (S2.5.2.2), (S2.11), (S2.13.2)

## U

**Ultrasonic Examination**
(2.2.8), (4.4.7.2), (S2.5.3), (S2.10.4.2), (S10.7)

**Uniform Corrosion**
(3.3.1)

**Unique Identifier**
(S6.16.8)

**Units of Measurement**
(Introduction), (7.1)

**User**
(Foreword), (Introduction), (1.4), (1.4.1), (1.4.2), (1.5.1), (1.5.2), (1.5.2.1), (1.5.3), (1.7), (2.2.6), (2.2.8), (2.2.10.6), (2.2.11), (2.3.5.4), (2.3.6.5), (2.5.8), (4.3.1), (4.3.1.2), (4.4.1), (4.4.3), (4.4.7), (4.4.8.1), (4.4.8.2), (4.5.1), (4.5.7), (5.2.1), (5.2.3), (5.3.3), (S1.3), (S2.1), (S2.2), (S2.3), (S2.4), (S2.4.1), (S2.4.2), (S2.5.2.1), (S2.7.3.1), (S2.8.1), (S6.5.3), (S2.11), (S5.2), (S6.4.7.7), (S6.5.1), (S6.5.2), (S6.5.3.1), (S6.5.4), (S6.5.4.1), (S6.5.5), (S6.5.5.1), (S6.6.3.1), (S6.10), (S6.11), (S6.12), (S6.12.2), (S6.12.3), (S6.13), (S6.13.6.1), (S6.14), (S6.14.3), (S6.14.5), (S6.14.6.4), (S6.15.3.5), (S7.1), (S7.10), (S8.5), (S9.3), (S9.5), (S10.9), (9.1)

## V

**Vacuum Test**
(S6.13.9)

**Vaporizers**
(2.2.12.7)

**Valves**
(Introduction), (1.5.3), (2.2.5), (2.2.6), (2.2.10.2), (2.2.10.3), (2.2.10.5), (2.2.12.7), (2.2.12.8), (2.3.6.4), (2.3.6.6), (2.3.6.7), (2.4.5), (2.5.4), (2.5.5.1), (2.5.5.2), (2.5.6), (2.5.7), (2.5.7.1), (2.5.7.2), (S1.4.2.20), (S1.4.2.26), (S2.4.3), (S2.7.1), (S2.9), (S2.11), (S2.13.4), (S2.14.3), (S2.14.7), (S2.14.10), (S6.4.7.4.4), (S6.4.7.4.4.1), (S6.4.7.4.4.2), (S6.7.4.4.3), (S6.5.3), (S6.10), (S6.12.1), (S6.12.2), (S6.13.2), (S6.13.9), (S6.14), (S6.14.5), (S6.14.6.4), (S6.15.1), (S6.16.3), (S6.16.6), (S6.17), (S7.7), (S7.8.6), (S7.9), (S8.5), (9.1)

**Verification**
(2.3.5.3), (4.4.8.5), (S2.6.1), (S9.3)

**Vibrations**
(2.2.12.5), (2.2.12.8), (2.3.6.1), (2.3.6.2), (2.4.4), (2.4.7), (3.3.2), (4.4.6), (S1.4.2.26), (S1.4.2.27), (S3.4), (S6.16.9)

**Visual Acuity**
(S4.5)

**Visual Examination**
(2.3.6.9), (2.3.6.10), (2.4.5), (4.2.1), (4.4.8.5), (S2.5.2), (S.2.5.2.2), (S2.6.1), (S.3.4), (S6.13.1), (S.7.7), (S10.4), (S10.6), (S10.7), (S10.9)

**Volume**
(2.2.12.5), (2.2.12.9), (2.3.6.7), (4.2.4), (4.2.5), (4.3.1.3), (4.5.6.2), (S1.5.5), (S2.5.3), (S2.10.2.2), (S2.13.3), (S6.13.11.2), (S6.13.11.3), (S6.15.3), (S6.17), (7.4)

**"VR" Stamp**
(S2.11)

## W

**Water Column**
(S2.2.10.2), (S2.2.10.3), (S1.4.2.26), (S1.4.3), (S1.4.3.1), (S1.4.3.2), (S2.4.3), (S2.11), (S2.15)

**Water Gage Connection**
(5.3.4), (S1.4.3)

**Water Gage Glass**
(5.3.2), (S1.4.3)

**Water Heaters**
(2.2.12.5), (2.2.12.6), (2.5.4), (2.5.5.1), (2.5.7), (2.5.8), (S1.5.4), (9.1)

**Waterside Deposits**
(2.2.8), (2.2.9), (2.2.12.2), (S1.4.2.5), (S1.4.2.25)

**Weld Buildup**
(S1.4.2.17), (S6.6.3.1)

**Welder**
(S4.5)

**Welding**
(2.2.12.9), (2.3.6.4), (2.3.6.6), (3.3.2), (3.3.3.4), (3.3.3.5), (3.4.1), (3.4.4), (5.3.4), (S1.4.2.1), (S1.4.2.9), (S1.4.2.11), (S1.4.2.13), (S1.4.2.15), (S1.4.2.17), (S5.3.2), (S5.3.2.6), (S6.6.4), (S6.9), (S6.13.11.2), (S6.14.6.4), (S6.15.1), (S7.10), (S9.3), (8.4)

**Weld Repair**
(2.3.6.4), (S2.11), (S6.6.4)

**Wrapper Sheet**
(S2.11), (S2.15)

## X

## Y

**Yankee Dryers**
(S5.1), (S5.2), (S5.2.1), (S5.2.2), (S5.3), (S5.3.1), (S5.3.2), (S5.3.2.1), (S5.3.2.5), (S5.3.2.6), (S5.4), (S5.5), (S5.6)

## Z

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