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**THE  
NATIONAL  
BOARD**  
OF BOILER AND  
PRESSURE VESSEL  
INSPECTORS

# **NATIONAL BOARD SUBGROUP FRP**

## **MINUTES**

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Meeting of April 15<sup>th</sup>, 2019  
Ft. Lauderdale, FL

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**1. Call to Order**

Subgroup FRP Chair Mr. Bernie Shelley called the meeting to order at 1:55 PM local time.

**2. Introduction of Members and Visitors**

Mr. Shelley asked that all present members and visitors to introduce themselves. It was determined that enough members were present to establish a quorum.

**3. Announcements**

The NBIC Main Committee has requested that a representative of the subgroup be present at any meetings where FRP items are discussed. This can be in person or on the phone. The subgroup’s secretary Mr. Jonathan Ellis will provide contact information to NBIC committee chairs so that they can be informed on FRP items prior to the next NBIC meeting.

Mr. Shelley announced that Mr. Dale Keeler has resigned from the subgroup. He also announced that he will be stepping down as Chair later this year.

Mr. Ellis announced the Mr. Francis Brown’s and Ms. Debra McCauley’s subgroup membership renewal is awaiting subcommittee and Board of Trustees approval.

A vote was then taken by the present members to add John Eihusen, Brian Linnemann, Allen Beckwith, and Bill Holtzlaw as members of the subgroup. This vote passed unanimously. Their membership to the subgroup is subject to subcommittee and Board of Trustees approval.

**4. Adoption of the Agenda**

A motion was made, seconded, and passed to adopt the agenda as presented.

**5. Approval of the Minutes of April 2018 Meeting**

The minutes of the April 2018 meeting in Orlando can be found on the National Board website:  
<https://www.nationalboard.org/Index.aspx?pageID=13&ID=18>

A motion was made, seconded, and approved to approve the minutes form the April 2018 meeting.

**6. Action Items**

<b>Item Number: NB11-1901</b>	<b>NBIC Location: Part 1</b>	<b>No Attachment</b>
<p><b>General Description:</b> Add guidance for the safe installation of high pressure composite pressure vessels operating in close proximity to the public</p> <p><b>Subgroup:</b> FRP</p> <p><b>Task Group:</b> D. Keeler (PM)</p> <p><b>Meeting Action:</b> Mr. Ellis gave a progress report of the item, stating that Mr. Rex Smith of Subcommittee Installation is working on a revision to the previous proposal.</p>		

<b>Item Number: NB15-2202</b>	<b>NBIC Location: Part 1</b>	<b>No Attachment</b>
<p><b>General Description:</b> Add checklist for the safe installation of high pressure composite pressure vessels operating in close proximity to the public</p> <p><b>Subgroup:</b> FRP</p> <p><b>Task Group:</b> D. Keeler (PM)</p> <p><b>Meeting Action:</b> Mr. Ellis informed the subgroup that this item was closed at the subcommittee and Main Committee levels. The group requested that Mr. Ellis ask why the item was closed as the minutes from the previous Subcommittee Installation meeting did not provide a reason.</p>		

<b>Item Number: NB16-1401</b>	<b>NBIC Location: Part 2, S10</b>	<b>Attachment Page 1</b>
<p><b>General Description:</b> Revise and update Supplement 10 on Inspection of CRPVs</p> <p><b>Subgroup:</b> FRP</p> <p><b>Task Group:</b> N. Newhouse (PM), M. Gorman</p> <p><b>Meeting Action:</b> Mr. Ellis informed the group that the item was passed by letter ballot at the subgroup level. The group spent some time discussing potential revisions to the proposal based on comments from the ballot.</p>		

<b>Item Number: NB16-1402</b>	<b>NBIC Location: Part 3</b>	<b>Attachment Page 21</b>
<p><b>General Description:</b> Life extension for high pressure vessels above 20 years</p> <p><b>Subgroup:</b> FRP</p> <p><b>Task Group:</b> M. Gorman (PM)</p> <p><b>Meeting Action:</b> Mr. Gorman stated that he could be present in some capacity to discuss this item at the July NBIC meeting. Further discussion was held as to why FRP items are not being passed beyond the subgroup level. Mr. Ellis will provide PM contact information for FRP items to the applicable subcommittee chairs to help answer questions pertaining to these items prior to the July NBIC meeting.</p>		

<b>Item Number: NB16-1403</b>	<b>NBIC Location: Part 3, S4</b>	<b>Attachment Page 26</b>
<p><b>General Description:</b> Add information to NBIC on repair of high pressure vessels</p> <p><b>Subgroup:</b> FRP</p> <p><b>Task Group:</b> N. Newhouse (PM)</p> <p><b>Meeting Action:</b> Mr. Newhouse will incorporate the changes proposed in the review and comment ballot and then send the updated proposal to Mr. Ellis to be balloted for approval to the group.</p>		

<b>Item Number: 17-137</b>	<b>NBIC Location: Part 3, S4.18.2.1 b) 2)</b>	<b>Attachment Page 29</b>
<b>General Description:</b> Remove "sand" blasting and replace with "abrasive" in Part 3, S4.18.2		
<b>Subgroup:</b> FRP		
<b>Task Group:</b> T. Cowley (PM)		
<b>Meeting Action:</b> This item was not discussed by Subcommittee R&A at the last NBIC meeting. Mr. Shelley requested that Mr. Ellis reach out to SC Chairs and Vice Chairs with FRP contact information on these items.		

**New Items:**

<b>Item Number: 19-19</b>	<b>NBIC Location: Part 3, S4.2</b>	<b>Attachment Page 31</b>
<b>General Description:</b> Part 3 - S4.2 RTP references to "Inspector"		
<b>Subgroup:</b> FRP		
<b>Task Group:</b> Brian L. (PM)		
<b>Explanation of Need:</b> The current use of the term "inspector" in S4.2 does not mean a Commissioned Inspector as defined in Section 9. Clarification is needed.		
<b>Meeting Action:</b> Mr. Shelley introduced the item and led discussion on the proposal and why the change needs to be made. Mr. Brian Linnemann will work on a draft proposal for the next meeting.		

**7. Additional Business**

**8. Future Meetings**

October 21, 2020: Las Vegas, NV

April, 2020: TBD

Next NBIC Meeting: July 15<sup>th</sup>-18<sup>th</sup> - Kansas City, MO

**9. Adjournment**

A motion was made, seconded, and approved to adjourn the meeting at 3:37 PM local time.

Respectfully submitted,

Jonathan Ellis

Secretary



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**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 ~~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 ~~after the first three years from the date of manufacture. Thereafter, vessels shall have 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[NN1].

**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 <u>less than a depth of 0.050 in.</u>	Any loose filament ends showing on the surface <u>at a depth ≥ 0.050 in.</u> 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 severe impact or dropping.	None	Any visible distortion, bulging, or depression.

Type of Degradation or Damage	Description of Degradation or Damage	Acceptable Level of Degradation or Damage	Rejectable Level of Degradation or Damage
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 <u>or evidence of permanent damage.</u>	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.	<u>None reported</u> <u>[NN2] Pressure between MAWP and test pressure, with approval of the</u>	Any report of pressurization beyond the <u>MAWP test pressure</u> or any indication of distortion.
Corrosion	Degradation of the composite due to exposure to specific corrosive environments.	None <u>visible in excess of manufacturer's specification</u> [NN3]	Any surface damage to structural <u>material</u> identified as corrosion <u>beyond the manufacturer's specification.</u> (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 Manu-

facturer'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 0.050 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 <u>less than a depth of 1.3 mm.</u>	Any loose filament ends showing on the surface <u>at a depth ≥ 0.050 in.</u> 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 <u>or evidence of permanent damage.</u>	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 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.

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Type of Degradation or Damage	Description of Degradation or Damage	Acceptable Level of Degradation or Damage	Rejectable Level of Degradation or Damage
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.	<u>None reported Pressure between MAWP and test pressure, with approval of the manufacturer</u>	Any report of pressurization beyond the <u>MAWP Test Pressure</u> or any indication of distortion.
Corrosion	Degradation of the composite due to exposure to specific corrosive environments.	None visible <u>in excess of manufacturer's specification</u>	Any surface damage to structural <u>material identified as corrosion beyond the manufactuere's specificaton.</u>
Dents	A depression in the exterior of the vessel caused by impact or dropping.	< 1.6 mm depth	Any dents with a depth $\geq$ 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 plus 1.3 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<sup>[NN4]</sup>

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 [NNS] 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.[NN6]

### **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**

- 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

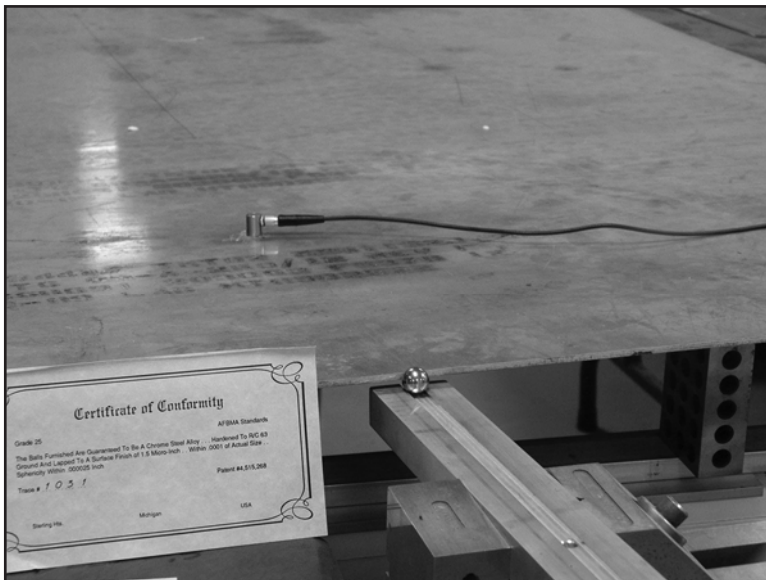
Sensors shall have a flat frequency response from 50 kHz to 400 kHz. Deviation from flat response (signal coloration) shall be corrected by using a sensitivity curve obtained with a Michelson interferometer calibration system similar to the apparatus used by NIST (National Institute for Standards and 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

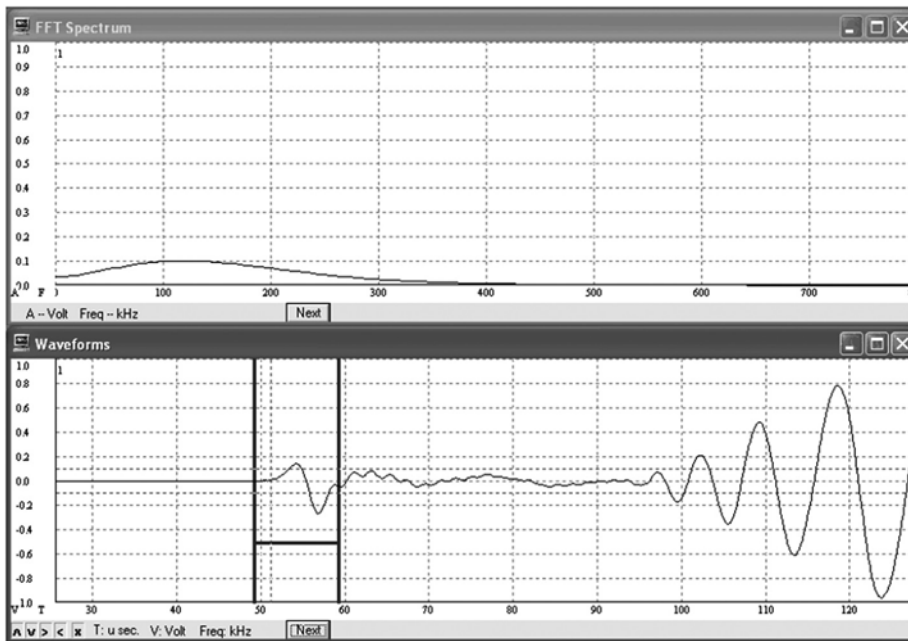
The wave energy shall be computed by the formula:

$$u = \int v^2 dt / z$$

**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 ( $\Omega$ ). 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  $\frac{1}{2}$  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  $\frac{1}{8}$  inch (3.2 mm) in thickness and be simply supported by steel blocks. The inclined plane shall be aluminum with a machined square groove  $\frac{3}{8}$  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  $125 \text{ kHz} \pm 10 \text{ kHz}$ . 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 ( $\mu\text{s}$ ) 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  $C_E = 0.2 \text{ in./}\mu\text{s}$  (5080 m/s) and  $C_F = 0.05 \text{ in./}\mu\text{s}$  (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.

$L / C_E = T1 \mu\text{s}$ . This is when the first part of the direct E wave will arrive.

$L / C_F = T2 \mu\text{s}$ . This is when the last part of the direct F wave will arrive.

$(T2 - T1) \times 1.5$  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 
$$W = \frac{V^2 N Z T}{2Z}$$
 joules at each frequency, where  $V=0.1$  volts,  $N = 20$ ,  $Z$  is the preamplifier input impedance in ohms ( $\Omega$ ) and  $T$  is the period of the cycle in seconds (s).

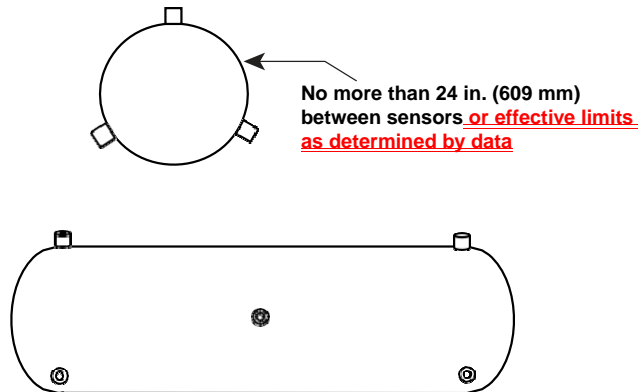
### S10.10.5 SENSOR PLACEMENT

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  $\frac{1}{2}$  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.

Maximum distance between sensors in the axial and circumferential directions shall not exceed 24 inches (609 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.

**FIGURE S10.10.5**  
SENSOR SPACING AND PATTERN



### 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.

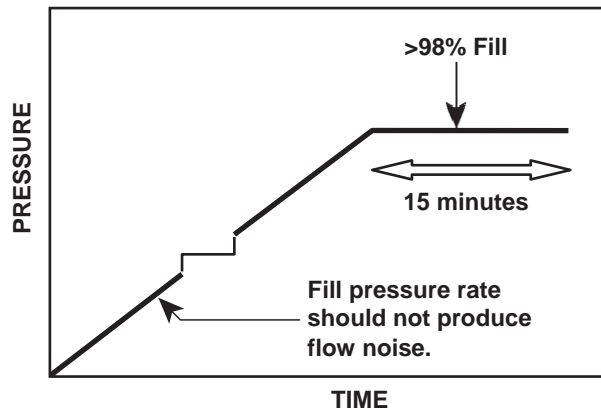
Recording threshold shall be 60 dB ref 1  $\mu$ V at the transducer.

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  $\mu$ V 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  $y = ae^{Bt} + C$ .

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  $y = ae^{Bt}$ .

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
- Vessel B values shall be tracked and compiled in order to develop a statistically significant database.
  - B is the critical value that measures the frequency of occurrence of events during pressure hold.
  - Not every vessel will have the exact same B value.
  - Data on B values should cluster.

#### **S10.10.7.1 THE CRITERIA GIVEN BELOW APPLY TO EACH INDIVIDUAL SENSOR ON THE VESSEL**

- a) 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:
- Cumulative Event Decay Rate  $-0.1 < B < -0.0001$ ,  $R^2 \geq 0.80$
  - 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.

- b) 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:

$$50 - 400 \text{ kHz: } U_0$$

$$100 - 200 \text{ kHz: } U_1$$

$$250 - 400 \text{ kHz: } U_2$$

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

$$U_{FBB} = \frac{E * A * l * \epsilon^2}{2}$$

where E is the Young's modulus of the fiber in pascals (Pa),  $\epsilon$  is the strain to failure of the fiber, A is area of the fiber in square meters (m<sup>2</sup>), 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  $U_{FBB} = 100 * U_{FB}$ , 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  $d = 7 \mu\text{m}$ ,  $E = 69.6 \text{ GPa}$  and  $\epsilon = 0.01$  (average breaking strain) for some carbon fiber. Using  $A = \pi d^2/4$  and  $l = 4d$ ,

$$U_{FBB} = \frac{E * A * l * \epsilon^2}{2}$$

$$U_{FBB} = \frac{69.6 * 10^9 * \pi * \frac{(7 * 10^{-6} \text{ m})^2}{4} * 2.8 * 10^{-5} \text{ m} * (0.01)^2}{2}$$

$$U_{FBB} = 3.75 * 10^{-8} \text{ J}$$

d) Example of Scaling Calculation

Suppose that the rolling ball impact (RBI) acoustical energy measured by a particular high fidelity AE transducer is  $U_{RBI}^{AE} = 5 * 10^{-10} \text{ J}$  and the impact energy  $U_{RBI} = 1.9 * 10^{-3} \text{ J}$  (due to gravity). Suppose  $d = 7 \mu\text{m}$ ,  $E = 69.6 \text{ GPa}$  and  $\epsilon = 0.01$  (average breaking strain) for some carbon fiber. Using  $A = \pi d^2/4$  and  $l = 4d$ ,  $U_{FB} = 3 * 10^{-8} \text{ J}$ . A carbon fiber with a break energy of  $U_{FB} = 3 * 10^{-8} \text{ J}$  would correspond to a wave energy.

$$U_{FB}^{AE} = U_{FB} \times U_{RBI}^{AE} / U_{RBI}$$

$$U_{FB}^{AE} = 3 \times 10^{-8} \text{ J} \times 5 \times 10^{-10} \text{ J} / 1.9 \times 10^{-3} \text{ J}$$

$$U_{FB}^{AE} = 7.9 \times 10^{-15} \text{ J.}$$

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  $3 \times 10^{-8}$  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  $(F) \times U_{FB}$  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.

## Item NB16-1402 (NBIC Part 3, Section 6)

### **Supplement 14**

#### **Life Extension of High Pressure Fiber Reinforced Plastic Pressure Vessels**

##### **S14.1 Scope**

This document may be used to evaluate whether the service life of high pressure fiber reinforced plastic pressure vessels (FRP) can be extended for an additional lifetime. High pressure means vessels with a working pressure from 3,000 psi (20 MPa) to 15,000 psi (103 MPa). For vessels intended for cyclic service, fatigue testing of new vessels is carried out by the vessel manufacturer to be certain that the vessel will not fail in service and such testing is typically required by regulatory authorities. Fatigue design and testing is the starting point for consideration of life extension.

##### **S14.2 General**

- a) The procedure for in-service testing of high pressure composite pressure vessels, **Supplement 10** herein, is incorporated by reference into this procedure for life extension of high pressure composite pressure vessels. Supplement 10 is based on acoustic emission (AE) testing, specifically modal AE (MAE) testing. The MAE inspection procedure employs detection and analysis techniques similar to those found in seismology and SONAR. Much as with earthquakes, transient acoustical impulses arise in a composite material due to the motion of sources such as the rupture of fibers. These transients propagate as waves through the material and, if properly measured and analyzed by the methods in Supplement 10, the captured waves reveal, for example, how many fibers have ruptured. Similar information about other sources is also determinable, such as the presence and size of delaminations. Delaminations can play a significant role in vessel fatigue life, particularly delaminations near the transition regions and in the heads. The rupture behavior can be used to determine the integrity of the vessel. However, the development of criteria for life extension (LE) requires an understanding of the vessel design and fatigue life.
- b) Fatigue testing of out of life vessels is a crucial part of the life extension process. It is used to validate the mechanical behavior of the vessels and to develop the numerical values for the allowables in the MAE pass/fail criteria for the particular design, material and construction.

##### **S 14.3 Life Extension Procedure**

- a) New vessel fatigue life testing data shall be obtained from the Manufacturer's Design Report (MDR) and the number of cycles in a lifetime shall be determined from the MDR. The type of vessel under consideration for life extension shall have been shown through testing to be capable of sustaining at least three lifetimes of cycles to developed fill pressure followed by a subsequent burst test at a pressure greater than minimum design burst pressure.
- b) An evaluation of the service the vessel has seen should take into account any operational conditions that may have differed from those used in the design testing and analysis. Such conditions include for example exposure to more severe weather than expected, more cycles

per year, constant high temperature and humidity, chemical attack or any other of a number of conditions under which operations take place that were not specifically included in testing at manufacture. Any such conditions shall be listed on the attached form. If no such conditions exist, it shall be so noted on the form. The test program delineated herein shall be revised to reflect the modified conditions as documented by the user and submitted for approval to the proper authorities.

- c) Data and records for all vessels considered for life extension shall be kept and made readily available to inspectors or examination personnel. This includes an operating log, number of operating cycles since the previous examination, total number of operating cycles, examinations, examination techniques and results, maximum operating pressure and any unexpected pressures, temperatures, temperature cycles, damage events or other significant events that were outside the intended operating parameters or conditions.
- d) A life extension test program shall be carried out for each type of vessel under consideration. Type of vessel means the particular manufacturer, materials (fiber and resin), water volume and design. If the type of vessel passes all requirements, then that type shall be eligible for life extension testing. If such a vessel passes the life extension MAE test its lifetime can be extended for one additional lifetime in five-year increments. In order to maintain life extension a vessel must be requalified every five years using the MAE test.

#### **S14.4 Life Extension Test Program**

- a) The type of vessel under consideration for LE shall be noted. Manufacturer, place of manufacture and manufacturing date shall be recorded. The vessel dimensions shall be recorded. The specific fiber, matrix and winding pattern shall be recorded. If the fiber, matrix and winding pattern are not available from the manufacturer, then a vessel of the type under consideration shall be used to verify the winding pattern (hoop and helical angles and number of plies) through destructive testing.
- b) Ten out-of-life vessels of the particular type shall be tested in the manner described herein. MAE techniques shall be applied to every vessel tested. Analysis of the MAE data is described herein. Two strain gages, one in the 0-degree and one in the 90-degree direction, shall be applied to every vessel pressure tested under this program. The purpose of strain gage data is to compute the 0 and 90 modulus values and to confirm that the modulus values of the material do not vary during the fatigue cycling required herein. Strain data shall be recorded and analyzed as described later on.
- c) The LE test program proceeds by Steps. If the Step 1 is not successful, then there is no need to proceed to Step 2, and so forth.

#### **S14.5 Life Extension Test Program Steps**

##### **S14.5.1 Step 1**

Three vessels shall be selected from the ten and pressurized to burst. The vessels shall be inspected for visible damage, i.e., cuts, scrapes, discolored areas, and the vessel appearance shall be documented with photographs. MAE testing shall be done in conjunction with this testing as specified in Supplement 10, except for transducer spacing, pressurization plan and accept/reject criteria values. The values in Supplement 10 are for requalification testing. The transducer spacing shall be determined by the distance at which the 400 kHz component of a suitable pulser source is detectable along the axis of the vessel (essentially across the hoop fibers) and in the perpendicular direction (essentially parallel to the hoop fibers). Detectable means that the resulting signal component has an amplitude with at least a signal to noise ratio of 1.4. Transducer frequency response calibration and energy scale shall be carried out as specified in SUPPLEMENT 10. The pressurization plan shall follow that in ASME Section X Mandatory Appendix 8, i.e., there shall be two pressure cycles to test pressure with holds at test pressure as prescribed therein, however, the time interval between the two cycles may be reduced to one minute. For the purposes of life extension, the fiber fracture energy and BEO (background energy oscillation) values shall be as specified below.

- a) No BEO greater than 2 times the quiescent energy (see Supplement 10) shall be observed up to test pressure or during pressure holds.
- b) No fiber break event energy shall be greater than  $24 \times 10^3 \times U_{FB}$  (see Supplement 10) during the second pressurization cycle.
- c) No single event shall have an energy greater than  $24 \times 10^5 \times U_{FB}$  during the second pressurization cycle.

Note: The numerical values specified in b) and c) can be adjusted through documented testing and stress analysis methods in order to account for the particular design, material and construction.

- d) At least two sensors shall remain on each vessel all the way to burst in order to establish the BEO pressure for this type of vessel.
- e) Plots of stress versus strain shall show linear behavior up to 90% of burst pressure.
- f) The burst pressures of all three vessels shall be greater than the minimum design burst pressure.
- g) If the burst pressure of any one of the three vessels is not greater than the minimum design burst pressure, then these vessels shall not be eligible for life extension and there is no need to proceed with Step 2 below.

Note: It is possible that one or more of the vessels selected had damage not obvious to visual inspection. If during this burst testing phase the MAE test identifies a vessel as damaged, the substitution of three other randomly selected vessels is allowed.

## S14.5.2 Step 2

If the vessels pass Step 1, fatigue testing shall be carried out on a minimum of three vessels of the same type being considered for life extension.

- a) Prior to testing, the vessels shall be inspected for visible damage, i.e., cuts, scrapes, discolored areas, and the vessel appearance shall be documented with photographs.
- b) Prior to fatigue testing, MAE testing as specified in Step 1 shall be done in conjunction with the fatigue testing, hereinafter called the MAE test or MAE testing, in order to determine the suitability of the vessels for fatigue testing, i.e., that they pass the MAE test.
- c) Next, the vessels shall be subjected to fatigue cycles. Pressure shall be 100 psi +0, -50% to at least  $1.05 \times$  working pressure. Vessels shall survive one and one-half (1.5) additional lifetimes. If they survive then they shall be tested by an MAE test as was done prior to fatigue cycling.

- d) Provided they pass the MAE test, they shall be burst tested. At least two sensors shall remain on each vessel all the way to burst in order to establish that the BEO (background energy oscillation) pressure for the fatigued vessels is consistent, i.e., is the same percentage of ultimate, with that of the vessels tested in Step 1.
- e) Plots of stress versus strain shall show linear behavior up to 90% of burst pressure.
- f) The burst pressures at the end of the fatigue testing shall be greater than or equal to the minimum design burst. If the burst pressure of any one of the three vessels is not greater than the minimum design burst pressure, then these vessels shall not be eligible for life extension.

### S14.5.3 Step 3

If the vessels pass Step 2, impact testing shall be carried out on a minimum of three vessels of the same type being considered for life extension.

- a) Prior to testing, the vessels shall be inspected for visible damage, i.e., cuts, scrapes, discolored areas, and the vessel appearance shall be documented with photographs. Prior to impact testing, MAE testing shall be done in order to determine the suitability of the vessels for impact testing, i.e., that they pass the MAE test.
- b) Two vessels shall be subjected to an ISO 11119.2 drop test and then subjected to the MAE test. If they pass the MAE test, then one vessel shall be burst tested. At least two sensors shall remain on the vessel all the way to burst in order to establish that the BEO (background energy oscillation) pressure for the fatigued vessels is consistent, i.e., is the same percentage of ultimate, with that of the vessels tested in Step 1.
- c) Plots of stress versus strain shall show linear behavior up to 90% of burst pressure.
- d) If the burst pressure is not greater than the minimum design burst pressure, then these vessels shall not be eligible for life extension.
- e) If the first vessel passes the burst test, the other dropped vessel shall be fatigue cycled and subsequently subjected to the MAE test and, if it passes, shall be burst tested under the same conditions as before. If the vessel fails during fatigue cycling, i.e., bursts or leaks, then these vessels shall not be eligible for life extension.
- f) If the modulus changes by more than 10%, then these vessels shall not be eligible for life extension. The strain gages should be mounted in a location that is away from the impact zone.
- g) The burst pressure at the end of the fatigue testing of the dropped vessel shall be greater than or equal to the minimum design burst. The vessels shall have MAE testing applied during burst testing as before and the BEO shall be consistent with the previously established percent of burst  $\pm 10\%$ .

### S14.5.4 Step 4

If the vessels pass Step 3, cut testing shall be carried out on a minimum of two vessels of the same type being considered for life extension.

- a) Prior to testing, the vessels shall be inspected for visible damage, i.e., cuts, scrapes, discolored areas, and the vessel appearance shall be documented with photographs. Prior to cut testing, MAE testing shall be done in order to determine the suitability of the vessels for cut testing, i.e., that they pass the MAE test.

- b) Two vessels shall be subjected to an ISO 11119.2 cut test and then subjected to the MAE test. If they pass, then one shall be burst tested under all the conditions and procedures delineated in Step 2. If the burst pressure is not greater than the minimum design burst pressure, then these vessels shall not be eligible for life extension.
- c) If the cut vessel passes, then the other cut vessel shall be fatigue cycled as described in Step 2 and subsequently subjected to the MAE test and then burst tested with at least two MAE sensors remaining on and monitoring the vessel as before. If it does not survive fatigue cycling, then these vessels shall not be eligible for life extension.
- d) The burst pressure at the end of the fatigue testing of the cut vessel shall be greater than or equal to the minimum burst pressure specified by ISO 11119.2.

If the vessel type passes Steps 1 to 4, then that type is eligible for life extension. An out of life vessel of the type subjected to the program above may have its life extended for one additional lifetime if it passes the MAE test. The vessel shall pass the MAE test at subsequent five-year intervals or at one-third of the lifetime, whichever is less, in order to continue in service. The vessel shall be labeled as having passed the NBIC life extension test.

**PART 3  
SUPPLEMENT 4  
REPAIR AND ALTERATION OF FIBER-REINFORCED THERMOSETTING PLASTIC  
PRESSURE EQUIPMENT**

**S4.1 SCOPE**

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**S4.2 INSPECTOR QUALIFICATIONS**

...

**S4.3 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;
- h) depth and length gages; and
- i) metallic tap tester (e.g. quarter dollar).

**S4.4 LIMITATIONS**

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**S4.5 REPAIR LIMITATIONS FOR FILAMENT WOUND VESSELS**

When the MAWP is greater than 200 psig (1.38 MPa), and less than 1500 psi (10.34 MPa) field repair of filament wound ASME Code Section X, Class I vessels shall be limited to corrosion barrier or liner repairs only, provided there is access to the vessel interior. ~~No structural repairs, re-rating, or alterations~~ are allowed for filament wound ASME Code Section X, Class 1 vessels that have an MAWP equal to or greater than ~~200 psig (1.38 MPa)~~ 1500 psi (10.34 MPa) and Class III vessels in accordance with the requirements of S4.19.

**S4.6 VESSELS FABRICATED USING ELEVATED TEMPERATURE CURED RESIN SYSTEMS**

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**S4.18 REPAIR AND ALTERATION METHODS**

...

**S4.19 REPAIR OF HIGH PRESSURE FILAMENT WOUND VESSELS**

S4.19.1 Scope

Types of damage that are addressed in this section include abrasion, cuts and scratches, impact, chemical, fire and heat, and weathering.

S4.19.2 Level of damage

- Level 1 damage, up to 0.010 inch, is repairable any time

- Level 2 damage, defined by the manufacturer (or up to 0.050 if not defined), is repairable with the manufacturer's concurrence



- Level 3 damage, defined by the manufacturer (or 0.050 or greater if not defined), is not repairable

Softening of the resin due to chemical attack, or charring due to exposure to fire, are considered to be Level 3 damage.

The manufacturer's guidance for assessing damage depth and levels shall be followed if it conflicts with general guidelines in this document.

Table S4.19.2-1 Damage Levels and Assessment

<u>Type of damage</u>	<u>Definition</u>	<u>Level 1 — accept</u>	<u>Level 2</u>	<u>Level 3 — reject</u>	<u>Comment</u>
<u>Cuts/scratches</u>	<u>A sharp impression where material has been removed or redistributed</u>	<u>When depth is less than 0.010 in</u>	<u>Depth from 0.010 in to the limit defined by the manufacturer, or 0.050 if not defined.</u>	<u>Greater than the limit defined by the manufacturer, or greater than 0.050 if not defined</u>	
<u>Abrasion</u>	<u>An area that is scuffed or worn thinner by rubbing or scraping</u>	<u>When depth is less than 0.010 in</u>	<u>Depth from 0.010 in to the limit defined by the manufacturer, or 0.050 if not defined.</u>	<u>Greater than the limit defined by the manufacturer, or greater than 0.050 if not defined</u>	
<u>Charring/soot</u>	<u>Blackening or browning of an area, burning of an area</u>	<u>Soot only, which washes off</u>	<u>Minor discoloration; manufacturer's recommendation</u>	<u>Charring</u>	
<u>Chemical attack, including stress corrosion cracking</u>	<u>Vessel is subjected to a chemical that softens or dissolves the composite</u>	<u>Residue may be cleaned off, no evidence of softening or dissolving.</u>	<u>Permanent discoloration.</u>	<u>Softening or dissolving of the material, cracking of the composite due to stress and chemical exposure</u>	
<u>Impact</u>	<u>Composite material was struck or hit; the resin has a frosted or smashed appearance</u>	<u>Damaged area is less than 0.20 in<sup>2</sup> and no other damage is apparent</u>	<u>Damage is uncertain, requiring the manufacturer's advice</u>	<u>Permanent deformation of cylinder or liner, evidence of underlying delamination</u>	
<u>Weathering</u>	<u>Composite affected by UV exposure and general weather</u>	<u>Minor gloss loss or chalking, only non-structural materials affected.</u>	<u>Structural laminate affected to a level less than defined by the manufacturer, or 0.050 inch.</u>	<u>Structural laminate affected to a level greater than defined by the manufacturer, or 0.050 inch</u>	

S4.19.3 Thickness considerations

Damage to a depth greater than 5% of the structural laminate thickness is not repairable, and the vessel shall be removed from service. Depth of damage does not include paint thickness, or material designated by the manufacturer as protective (non-structural) rather than structural.

S4.19.4 Impact damage considerations

Impact damage may result in rejection, without possibility of repair, regardless of the measurable depth due to risk of internal fracture or delamination. Impact damage may be characterized by noting permanent deformation, softness or deflection of the surface, or localized surface crazing.

S4.19.5 Assessment of damage depth

All loose fibers and affected resin are to be removed. This includes material that is softened by actions of chemicals or heat. Confirmation that the material remaining is sound shall be determined by a tap test, Barcol hardness measurement, and/or visual inspection.

#### S4.19.6 Repair procedure

- a) Non-structural material, including paint, shall be removed from any area involved in the repair.
- b) Resin used in structural repairs shall be compatible with the resin used to fabricate the vessel.
- c) Cloth patches made of glass or carbon fiber may be used in the repair and to cover the repaired area.
  - 1) Cloth patches shall extend at least 0.5 inches beyond the edge of the repair area, and subsequent layers must extend at least 0.25 inch beyond the edge of the previous patch.
  - 2) Total patch thickness shall not be more than 5% of the structural thickness of the original laminate.
- d) A layer of fiber wound continuously in the hoop direction may be applied over the repair.
- e) Non-structural material may be applied to the repaired area for protection if originally used in the vessel design.
- f) The repaired area may be covered with epoxy, polyurethane, or other compatible paint.
- g) The repaired area shall be cured at a temperature that will not degrade the resin in the vessel. It may be cured prior to applying any non-structural material or paint.
- h) The repair shall be confirmed by either:
  - 1) A tap test or Barcol hardness measurement conducted on the structural material after cure and prior to applying any non-structural material or paint, or
  - 2) A Modal Acoustic Emission test conducted after cure of the structural material
- i) A hydrostatic proof test shall be conducted following confirmation of the repair.

#### S4.19.7 Acceptance of the vessel for return to service

The repair shall meet the repair confirmation requirement (i.e. confirmation of soundness using the tap test or Barcol hardness measurement, or confirmation using MAE). There shall be no delamination of the repaired area resulting from the hydrostatic proof test. A vessel that does not meet the requirements of the repair confirmation or hydrostatic proof test shall not be returned to service.

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Part 3, S4.18.2.1 2) d. 2. and 4.

1) ...

2) Applying Test Patches to Verify Adequate Surface Preparation

- a. Test patches should be applied to any substrate that will require a secondary bond to determine the integrity of the primer bond prior to the application of the laminate.
- b. The subsequent steps shall be followed:
  1. Apply the primer (0,003 -0.005 in. (0.08 to 0.13 mm)) to the prepared surface, and allow primer to cure.
  2. Coat the primed surface with the same resin to be used in the laminate repair. Apply 4 in. (100 mm) x 14 in. (360 mm) piece of polyester, such as Mylar®, strip to one edge of primed area. Allow the polyester film to protrude from beneath the patch.
  3. Apply two layers of 1-1/2 oz/sq. ft (0.46 kg/sq. m) chopped strand mat saturated with the same resin that will be used for the repair. Mat shall be 12 in. (305 mm) x 12 in. (305 mm) square.
  4. Allow the mat layers to cure completely, this may be verified by checking the hardness of the laminate.
  5. Pry patch from surface using a screwdriver, chisel, or pry bar.
  6. A clean separation indicates a poor bond.
  7. Torn patch laminate or pulled substrate indicates that the bond is acceptable.
- c. If the bond is not adequate, go back to step a) and repeat the procedure.

**Note:** If the repair area is smaller than the test patch dimensions, decrease the test patch size accordingly.

- d. As a last resort, if the previous procedure does not provide an adequate bond, the permeated laminate must be handled differently using the following procedure:
  1. Hot water wash the equipment.
  2. Abrasive blast ~~with #3 sand, or equal~~ to achieve a 0.003 to 0.005 in. (0.08 to 0.12 mm) anchor pattern, and allow to completely dry.
  3. Prime with the recommended primer, an area 12 in. (305 mm) x 12 in. (305 mm) and apply a test patch.
  4. Prime a second spot 12 in. (305 mm) x 12 in. (305 mm) and prime with a recommended ~~epoxy resin~~ alternate primer.
  5. Allow this primer to cure.

Part 3, S4.18.2.2 2)

- 1) ...
- 2) Note that any cracks, delaminations, or permeated surfaces must be removed. If the damage is deeper than the corrosion barrier and the material removed reaches the structural laminate, the vessel is not repairable. An adequate size abrasive or proper sanding disc must be used to obtain a ~~0.003 to 0.005~~ 0.002 to 0.003 in (0.05 to 0.08 mm) anchor pattern to the area that requires the repair.
- 3) Preparation of any surface requires that basic rules, common to all substrates, be followed. These rules are as outlined below:
  - a. Surface must be free of contaminants;
  - b. Surface must be structurally sound;
  - c. Surface must have adequate anchor pattern;
  - d. Surface must be dry;
  - e. Surface must be primed with recommended primer.

**Note:** After the surface has been properly prepared, it must be kept clean and dry until laminating can be started. Dust, moisture, or traces of oil that come in contact with the surface may act as a mold release or act to inhibit the cure and prevent a good secondary bond. Laminating should be done within two hours of the surface preparation.

## SUPPLEMENT 4

### REPAIR AND ALTERATION OF FIBER-REINFORCED THERMOSETTING PLASTIC PRESSURE EQUIPMENT

#### S4.1 SCOPE

- a) This supplement provides requirements and guidelines that apply to repairs and alterations to fiber-reinforced pressure-retaining items.
- b) The letters "RP" shall be included on the "R" *Certificate of Authorization* for those organizations authorized to perform repairs/alterations of fiber-reinforced plastic pressure equipment.

#### S4.2 ~~INSPECTOR QUALIFICATIONS~~ FOR "R" STAMP HOLDER DESIGNEE

The "R" Stamp Holder ~~s inspector shall have~~ shall designate an employee who will have the responsibility of verifying the repair and/or alteration activity meets the requirements of the NBIC. The designee 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-designee~~ shall meet the following visual and educational requirements:
  - 1) be able to read a Jaeger Type No. 1 standard chart at a distance of not less than 12 in. (305 mm);
  - 2) be capable of distinguishing and differentiating contrast between colors;
  - 3) have visual acuity checked annually to assure natural or corrected near distance vision; and
  - 4) be a high school graduate or hold a state or military approved high school equivalency diploma.

- | c) The ~~employer of the inspector~~ "R" Certificate Holder shall certify that the ~~employee-designee~~ complies with the above qualification requirements.

#### **S4.3 TOOLS**

| The following tools may be required by the ~~Inspector~~ R Stamp Holder's designee.:

- 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.

#### **S4.4 LIMITATIONS**

All field work shall be limited to secondary bonding.