STP-PT-023

GUIDELINES FOR IN-SERVICE INSPECTION OF COMPOSITE PRESSURE VESSELS

ASME STANDARDS TECHNOLOGY, LLC

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Prepared by:

John H. Smith

ASME STANDARDS TECHNOLOGY, LLC

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ASME Standards Technology, LLC
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FOREWORD

Commercialization of hydrogen fuel cells, in particular fuel cell vehicles, will require development of an extensive hydrogen infrastructure comparable to that which exists today for petroleum. This infrastructure must include the means to safely and efficiently generate, transport, distribute, store and use hydrogen as a fuel. Standardization of pressure retaining components, such as tanks, piping and pipelines, will enable hydrogen infrastructure development by establishing confidence in the technical integrity of products.

Since 1884, the American Society of Mechanical Engineers (ASME) has been developing codes and standards (C&S) that protect public health and safety. The traditional approach to standards development involved writing prescriptive standards only after technology has been established and commercialized. With the push toward a hydrogen economy, ASME has adopted a more anticipatory approach to standardization for hydrogen infrastructure which involves writing standards with more performance based requirements in parallel with technology development and before commercialization has begun.

The ASME B&PVC Standards Committee appointed a project team to develop new Code rules for hydrogen storage and transport tanks to be used in the storage and transport of liquid and gaseous hydrogen and metal hydrides. Rules for gaseous storage tanks with maximum allowable working pressures (MAWPs) up to 15,000 psig (103 MPa) will be needed. Research activities are being coordinated to develop data and technical reports concurrent with standards development and have been prioritized per Project Team needs. This technical report has been developed in response to Project Team needs and is intended to establish data and other information supporting separate initiatives to develop ASME standards for the hydrogen infrastructure.

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ABSTRACT

This report describes the procedures and recommendations for in-service inspection of high pressure composite tanks made to ASME code requirements and used for the shipping or storage of hydrogen. For the in-service inspection of high pressure composite tanks, only external visual inspection is recommended. Internal visual inspection is optional and may be performed when it is not certain that only pure dry hydrogen has been shipped or stored in the tanks. For certain applications, safety rules or regulations may also require a hydrostatic pressure test of the tanks.

Guidelines are given for acceptable methods of visual inspection of high pressure composite tanks and for acceptance criteria for any indications that are found by the visual inspection. This report does not specify or provide guidelines for the frequency of performing the in-service inspection. The frequency of the in-service inspection is determined by the operational requirements or specified by other safety rules and regulations.

1 INTRODUCTION

This report provides recommendations for in-service inspection of composite tanks that are used to store or transport hydrogen.

The scope of this study includes the in-service inspection of both stationary (e.g., storage) tanks and transport tanks used to store or transport gaseous hydrogen at maximum allowed working pressures (MAWP) up to 15,000 psi. The recommendations made in this report cover all types of ASME composite tanks used to store or transport hydrogen. This includes tanks with metallic liners (steel or aluminum) and tanks with non-metallic liners that are constructed by filament winding with fiberglass, aramid or carbon fibers.

Composite hydrogen tanks may require periodic inspection while in service. This report does not make specific recommendations about the time interval between in-service inspections and does not make specific recommendations about the useful life of the tanks. The time interval between required in-service inspections and the total useful life of the tanks will depend on the specific tank design, use and application. Procedures for establishing the time interval between required in-service inspections and the total useful life of the tanks should be based on an overall lifetime structural integrity assessment of the tanks and should be specified in the requirements for the construction of each type of tank.

The recommendations are limited to procedures and criteria for the visual inspection of the composite tanks. Nondestructive evaluation procedures (such as ultrasonic, acoustic emission, eddy current and radiography) are not addressed in this guide

The primary requirement for the in-service inspection of hydrogen tanks is for a periodic external visual inspection of the tank to evaluate any damage or degradation. Under certain conditions it may also be desirable or required to conduct an internal visual inspection of the hydrogen tanks. Safety regulations for transport tanks may also require periodic pressure testing of the tanks.

The justification for limiting the primary method of periodic in-service inspection of composite hydrogen tanks to external visual inspection only is that any damage or degradation to the tanks that is likely to occur can readily be seen by visual inspection alone. Internal visual inspection of the hydrogen tanks is generally not required and is not recommended because it is expected that the only degradation that can occur in the interior of the tanks is corrosion. If the tanks are used only for dry hydrogen service, corrosion of the interior tank liner is not expected to occur and it is preferable to not remove the tank valve to inspect the interior of the tank. The exception to this is that if it is known or suspected from operational practices that corrosion of the interior liner of the tank may occur, an optional internal visual inspection should be conducted.

In-service hydrostatic pressure testing of the tanks is not recommended and should be done only when required by other specific safety rules or regulations. Hydrostatic pressure testing requires the removal of valves and fittings from the tanks and the introduction of water into the interior of the tank. Opening the tanks and introducing water into them can create the necessary conditions for internal tank corrosion which is not present when the tanks are filled only with pure, dry hydrogen. The in-service hydrostatic pressure test serves little purpose for evaluating the structural integrity of the tanks and the water introduced into the tanks during the hydrostatic pressure test may cause degradation due to increased corrosion.

The stationary tank in-service inspection recommendations of this guide should be the same as those applied to tanks used in transportation. However, it should be noted that some tanks used in transportation may require additional in-service inspection as specified by other standards or regulations.

2 SCOPE

The purpose of this document is to provide recommendations for the procedures to be used for the in-service inspection of composite tanks used in the storage and transportation of high pressure hydrogen and to provide criteria for the acceptance or rejection of these tanks.

3 BACKGROUND INFORMATION

3.1 General

The composite tanks that are used in the storage and transportation of high pressure hydrogen are designed and built to the requirements of ASME Code. These tanks have markings that identify the ASME Code to which they are built, the type of construction used, the maximum allowed working pressure (MAWP) and the designated service life of the tank.

The composite tank design consists of: (1) a metallic or non metallic liner that provides a gas tight membrane and may carry some of the pressure loads, (2) filament wound fiber reinforcing that carries the primary pressure stresses and (3) a resin system that serves to transfer the loads among the fibers. The exterior surface of the tank may also be coated with a barrier coating for appearance's sake and/or environmental protection.

Composite tanks are designed with a fixed service life. Tanks must be condemned and rendered incapable of holding pressure when the designated service life is reached. A more detailed procedure for condemning cylinders is described in Sections 12.1 and 12.2 below.

Standards for the in-service inspection and testing of composite tanks and pressure vessels have been developed by the International Organization for Standardization (ISO) and the Compressed Gas Association (CGA) and others as shown in References [1] through [5]. These standards may be used to supplement the information that is provided in this document.

3.2 Application of Composite Tanks

Composite storage tanks may be either used in stationary applications as storage tanks or used as transport tanks to transport high pressure hydrogen. The stationary (e.g., storage) tanks are: (1) generally larger than the transport tanks, (2) generally permanently located in a fixed location for the life of the tanks, (3) may be protected from the environment and (4) are less subject to degradation and damage due to handling than are the transport tanks. The in-service inspection requirements for storage tanks will differ from the in-service inspection of transport tanks because the two types of tanks may be subject to different types of degradation and damage and may differ in their ability to be readily inspected. In addition, the transport tanks used in the United States are required to meet the requirements of the U.S. Department of Transportation (DOT) for periodic in-service inspection and requalification. Any ASME recommendation for the periodic in-service inspection and testing of transport tanks should be compatible with the DOT requirements.

3.3 Types of Composite Tank Construction

3.3.1 Hoop Wrapped, Metal Lined Tanks

Hoop wrapped, metal lined tanks have a metallic liner reinforced with fibers wound only in the hoop (circumferential) direction. Reinforcing fibers may be fiberglass, aramid or carbon. For hoop wrapped tanks, the metallic liner supports all of the longitudinal loads and a substantial portion of the circumferential pressure loads.

3.3.2 Full Wrapped, Metal Lined Tanks

Full wrapped, metal lined tanks are reinforced with fibers wound in both a helical (polar) pattern and the hoop direction. Reinforcing fibers may be fiberglass, aramid or carbon. For full wrapped tanks, the fiber wrapping supports both the longitudinal loads and most of the circumferential pressure loads.

3.3.3 Full Wrapped with Non-Metallic Liners

Full wrapped tanks with non-metallic liners typically have an interior liner assembly comprising a polymer based liner with attached metal boss ends. The liner assembly generally does not carry any significant part of the longitudinal or pressure load. The liner assembly is totally reinforced with resin impregnated continuous filament fibers wound in both a helical (polar) pattern and in the hoop direction. Reinforcing fibers may be fiberglass, aramid or carbon.

3.4 Required Marking Information

Each tank must have markings that show: the ASME Code to which it is manufactured, the date after which they must be removed from service (maximum service life), the manufacturer's identification, the tank serial number and the working pressure of the tank (MAWP).

3.5 Inspection of Composite Tanks

Composite tanks may be subject to the following types of damage and degradation in service.

- Chemical attack
- Fire or excessive heat
- Mechanical damage (i.e., abrasion, impact, cuts, dents, etc.)
- Environmental degradation (i.e., chemical, ultraviolet, etc.)
- Structural damage (i.e., over-pressurization, distortion, bulging, etc.)

The periodic in-service inspection should identify and evaluate each of these types of degradation or damage following the procedures and criteria described in these guidelines.

4 DEFINITIONS

Abrasion: Tank damage that results from grinding or rubbing away of the exterior of the tank material.

Autofrettage: For composite tanks with metallic liners, the autofrettage process is a process in which the tank is pressurized sufficiently to yield the metallic liner. The autofrettage process results in the liner being in compression when the tank is not pressurized due to the elastic response of the fiber reinforcement. The process is intended to improve the fatigue resistance of the tank but is not expected to affect the burst pressure of the tank.

Burst pressure: The minimum pressure at which the tank will fail due to excessive pressure. This is verified by prototype design qualification testing of the tanks.

Composite Tank: A tank consisting of a liner (metal or non-metal), filament wound fibers to carry most of the pressure loads and a resin matrix to protect the fibers and the transfer pressure loads to the fibers.

Condemned Tank: A tank that is found by in-service inspection to be no longer fit for further service and which cannot be repaired. A condemned tank must be altered so that it is physically unable to hold pressure.

Crazing: Small surface cracks in the resin that are not associated with any damage.

Cut: Damage to the tank caused by a sharp object impacting the tank.

Debond: A void between layers of two different fiber materials or between the fiber and the liner that is inherent in the structure. Debonding is not caused by impact damage.

Delamination: Composite damage in which a separation between layers of the composite wrapping. Delamination is normally caused by impact damage to the tank.

Exterior Coating: An external coating applied to the composite tank for environmental protection and/or improved appearance.

Fiber: The overwrap of continuous filaments that is the primary pressure load-carrying part of the composite tank. The fibers may be fiberglass, aramid or carbon.

Impact: Damage to the surface of the tank that may cut, gouge or dent the surface of the tank and may cause delamination of the fibers.

Maximum Allowable Working Pressure (MAWP): The maximum pressure that the tank will be subjected to (except for accumulation during a pressure relieving event) at any time in service. This pressure is limited by the pressure setting of the pressure relief device (rupture disk or relief valve).

Maximum Permissible Operating Pressure (MPOP): This is used for transport tanks, and is also termed "Developed Pressure." Typically, this must not exceed 125% of the "Working Pressure." This is the pressure developed during filling of the cylinder and while the tank is at the maximum ambient temperature while in service.

Mounting Supports: Mounting support or brackets used to support the weight of the tank and/or to fasten the tank to a transport vehicle.

Normal Operating Pressure: The pressure at which a tank is expected to operate for most of its life. It does not include short term variations in pressure.

Over-Pressurization: Tank pressure exceeding the maximum allowed working pressure (MAWP).

Pressure Relief Device (PRD): A device (rupture disk or relief valve) installed in the tank that will release excessive pressure. The PRD may be activated by excessive temperature, excessive internal pressure or both.

Resin: The material which is used to bind and hold the fibers in place and to transfer load among the fibers. It is generally a thermoplastic or thermosetting resin.

Tank Liner: The internal part of the composite tank that prevents leakage of the hydrogen gas through the composite cylinder structure and may carry a portion of the tank's load.

Tank Damage Levels:

> **Acceptable Damage**: Minor damage or degradation to the tank that may occur during normal use and that has no adverse effect on the structural integrity level of the tank.
>
> **Rejectable Damage**: Damage or degradation to the tank that reduces the structural integrity of the tank to a level that requires the tank to be condemned and removed from service.

Tank Markings: Marking that are required by the ASME Code that include, at least (1) the code (s) number(s), (2) the maximum allowed working pressure (MWAP), (3) the service life of the tank, (4) the manufacturer's identification, (5) the tank serial number, (6) the date of manufacture, and (7) the date by which the tank must be removed from service.

Tank Service Life: The maximum allowed service life of the tank that is specified by the design.

Tank Types:

> **Fully Wrapped Tank**: A composite tank with fibers wrapped in the circumferential and helical directions to provide both hoop reinforcement and longitudinal reinforcement.
>
> **Hoop (Circumferentially) Wrapped Tank**: A composite tank with circumferentially-oriented fibers to reinforce the liner of the cylinder. The longitudinal strength of the tank is entirely from the liner.

Working Pressure: For transport tanks, this is the maximum settled pressure at 21.1˚C (70˚F) to which the tank may be filled. For stationary tanks, this is the expected normal operating pressure for the tank.

5 QUALIFICATIONS OF THE INSPECTOR

The inspector shall be familiar with composite tank construction and qualified by training and experience to conduct such inspections. The inspector should have a thorough understanding of all required inspections, tests, test apparatus, inspection procedures, and inspection techniques and equipment applicable to the types of tanks to be inspected. The inspector should have basic knowledge of the container material types and properties.

6 GENERAL PROCEDURES FOR THE VISUAL INSPECTION

The visual examination of the tanks requires that all exposed surfaces of the tank are examined to identify any degradation, defects, mechanical damage or environmental damage on the surface of the tank.

The causes of damage to the tanks that may be found 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) blister, (7) delaminations, (8) surface degradation and (9) broken tank supports.

6.1 Tank Identification

The visual examination of the tanks requires that the identity of the tank must be verified. This should include the ASME Code to which the tank was constructed, the tank serial number, the maximum allowed operating pressure, the date of manufacture, the date of expiration of the service life of the tank and any other pertinent information shown on the tank or available from tank documents. The overall condition of the tank should be noted.

6.2 Preparation for Inspection

In preparation for the visual inspection, the tank should be clean, free of loose paint, coatings, tar, oil or other foreign matter and anything that will interfere with the visual inspection. The tank markings and manufacturer's labels should be clearly visible and should not be removed. In general, paint on the tank should not be removed because the process of removing the paint, either by chemical or mechanical means, can damage the fiber overwrap.

6.3 Tools for Inspection

Proper in-service inspection of composite tanks requires that the inspector have available the following tools:

- Depth and length gauge for measuring cuts, gouges, and abrasions.
- A high-intensity light capable of brightly illuminating all surfaces.
- Inspection mirrors or other suitable devices to aid in the examination of tank surfaces that may be are partially concealed.
- Various hand tools that may be necessary for the removal of covers, shields or other installed equipment so that the external tank surfaces can be properly viewed.
- Rulers and straightedge, in combination, for evaluating indentations and bulges and for determining the length and depth of cuts and gouges and the general size of areas of abrasion.
- Hand held magnifying glass.

7 PROCEDURES FOR THE VISUAL INSPECTION OF THE COMPOSITE TANK

7.1 Tank Service Life

Composite tanks have been designed and manufactured for a limited lifetime; this is indicated on the tank marking. This marking should first be checked to ensure that such tanks are within their designated service lifetime.

7.2 Identification of External Damage

The external surface should be inspected for damage to the composite. Any damage is classified into two levels of damage as shown in Section 9 of these guidelines. The acceptance/rejection criteria shown in Section 10 of these guidelines should be followed, as a minimum.

The external surface of the tank is subject to mechanical, thermal and environmental damage. The external surface of the tank may show damage from impact, 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 should be noted.

Tank support structures and attachments should be examined for damage such as cracks, deformation or structural failure.

7.3 Types of External Damage

7.3.1 General

Several types of damage to the exterior of composite tanks have been identified. Examples of specific type of damage are described below. The acceptance/rejection criteria for each type of damage are described in Section 10 of these guidelines.

7.3.2 Abrasion Damage

Abrasion damage is caused by grinding or rubbing away of the exterior of the tank. Minor abrasion damage to the protective outer coating or paint will not reduce the structural integrity of the tank. Abrasion that results in flat spots on the surface of the tank may indicate loss of composite fiber overwrap thickness.

7.3.3 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.

7.3.4 Impact Damage

Impact damage may appear as hairline cracks in the resin, delamination or cuts of the composite fiber overwrap.

7.3.5 Delamination

Delamination is a separation of layers of fibers of the composite overwrap. It may also appear as a discoloration or a blister beneath the surface of the fiber.

7.3.6 Heat or Fire Damage

Heat or fire damage will be evident by discoloration, charring or burning of the composite fiber overwrap, labels or paint. If the composite fiber overwrap is merely soiled by soot or other debris on the surface that can be easily removed, and the underlying fibers are intact with no evidence of charring or burning, the tank may be cleaned and returned to service.

7.3.7 Structural Damage

Structural damage will be evidenced by bulging, distortion or depressions on the surface of the tank.

7.3.8 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 composite tanks. Long-term contact with water can also contribute to corrosive damage. Chemicals can dissolve, corrode, remove or destroy tank 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 to the touch.

8 PROCEDURES FOR THE INTERNAL VISUAL INSPECTION (IF NECESSARY)

8.1 Requirements for Internal Visual Inspection

Internal visual inspection is normally not required. The purpose of an internal visual inspection is to determine if corrosion has occurred on the metal liner (for tanks having a metal liner) or on the plastic liner/metal boss assembly (for fully wrapped tanks with non-metallic liners). When the tanks have been filled only with pure, dry hydrogen, corrosion of the interior of the liner should not occur. Internal visual inspection of the tanks should only be carried out when:

(1) There is evidence that any commodity except pure dry hydrogen 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 tank will require an internal visual inspection.

(2) There is evidence of structural damage to the tank, such as denting or bulging.

(3) The tank valve is removed for maintenance or other reason.

When an internal visual inspection is conducted, the following procedures should be followed.

8.2 Identification of Internal Damage

8.2.1 Tanks with Metallic Liners

For tanks with metallic liners, the objective of the internal visual inspection is primarily to detect the presence of any corrosion or corrosion cracks. The internal surface of the tank should be inspected with adequate illumination to identify any degradation or defects present. Any foreign matter or corrosion products should be removed from the interior of the tank to facilitate the inspection. If any chemical solutions are used in the interior of the tank they should be selected to ensure that they do not adversely affect the liner or composite overwrap materials. After cleaning the tank should be thoroughly dried before it is inspected.

All interior surface of the tank should be inspected for any color differences, stains, wetness, roughness, or cracks. The location of any degradation should be noted.

Any tank showing significant internal corrosion, dents or cracks should be removed from service.

8.2.2 Tanks with Non-metallic Liners or No Liners

Tanks with non-metallic liners may show corrosion on the plastic liner or metal boss ends. Tanks 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 the tank should be inspected with adequate illumination to identify any degradation or defects present. Any foreign matter or corrosion products should be removed from the interior of the tank to facilitate the inspection. If any chemical solutions are used in the interior of the tank they should be selected to ensure that they do not adversely affect the liner or composite overwrap materials. After cleaning the tank should be thoroughly dried before it is inspected.

The inspector should 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.

9 LEVELS OF DAMAGE OR DEGRADATION

Damage or degradation that is found in composite tanks can be classified according to the severity of the damage or degradation. Two general levels are used describe the severity of damage or degradation.

9.1 Acceptable Damage

Acceptable damage or degradation is minor and is normally found in service and is considered to be cosmetic. This level of damage or degradation does not reduce the structural integrity of the tank. This level of damage or degradation should not have any adverse effect on the continued safe use of the tank. 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 tank, any damage or degradation should be limited to this layer. There should be no evidence of any cut filaments.

9.2 Rejectable Damage (Condemned—Not Repairable)

Rejectable damage or degradation is so severe that the structural integrity of the tank is reduced enough to consider the tank unfit for continued service. The tank must be condemned and removed from service. No repair is authorized for tanks with rejectable damage or degradation.

10 ACCEPTANCE CRITERIA

Certain specific types of indications can be identified by the external in-service visual inspection. Indications of certain types and sizes may not significantly reduce the structural integrity of the tanks and may be acceptable enough that the tanks can be left in service. Other types of indications and larger indications may reduce the structural integrity of the tanks and the tanks must be condemned and removed from service. Table 1 is a summary of the acceptance criteria for the indications that are found by external visual inspection of the tanks.

Table 1 - Visual Acceptance Criteria for Composite Pressure Vessels

Type of Degradation or Damage	Description of Degradation or Damage	Acceptable Level of Degradation or Damage	Rejectable Level of Degradation or Damage
Abrasion	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.	More than 0.050 in. depth in the pressure bearing thickness.
Cuts	Linear indications or flaws caused by an impact with a sharp object.	Less than 0.050 in. depth in the pressure bearing thickness.	More than 0.050 in. depth in the pressure bearing thickness.
Impact Damage	Damage to the tank caused by striking the tank with an object or by being dropped. This may be indicated by discoloration of the composite or broken filaments.	Slight damage that causes a frosted appearance or hairline cracking of the resin in the impact area.	Any permanent deformation of the tank or damaged filaments.
Delamination	Lifting or separation of the filaments due to impact or a cut.	Minor delamination of the exterior coating.	Any loose filament ends showing on the surface. Any bulging due to interior delaminations.
Heat or Fire Damage	Discoloration or melting 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 tank 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.	Any permanent discoloration or loss or softening of surface material.
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.	More than 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.
Over-pressurization	Excessive pressure due to operational malfunction.	None reported.	Any report of pressurization beyond the MAWP or any indication of distortion.

Type of Degradation or Damage	Description of Degradation or Damage	Acceptable Level of Degradation or Damage	Rejectable Level of Degradation or Damage
Corrosion	Degradation of the composite due to exposure to specific corrosive environments.	None visible.	Any surface damage identified as corrosion.
Dents	A depression in the exterior of the tank caused by impact or dropping.	None visible.	Any dents with a depth greater than 1/16 in. or with a diameter greater than 2 inches.
Reported collision, accident or fire	Damage to the tank 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.	None	Any discoloration that cannot be washed off.*
Crazing	Hairline surface cracks only in the composite resin.	Light hairline cracks only in the resin.	Any damage to the filaments.
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.

Note: Only damage beyond the sacrificial or coated layer should be considered, and any damage to sacrificial or coated layers should be repaired by suitable techniques (i.e., epoxy filler). Refer to ASME data report for sacrificial layer thickness.

*Washing off UV scale will accelerate attack into lower composite layers. For this reason, if there is superficial UV damage we recommend cleaning and painting the affected area with a UV tolerant paint. If broken, frayed or separated fibers in the non-sacrificial layer are discovered during the cleaning process then the cylinder must be condemned.

11 RECORD KEEPING

A detailed record of external and internal inspections shall be retained by the owner of the tank for the life of the tank. After satisfactory completion of the periodic in-service inspection, the tanks should be permanently marked or labeled with the date of the inspection, the mark of the inspector and the date of the next periodic in-service inspection. ASME data report shall be kept on file for the life of the vessel.

12 REMOVAL OF TANKS FROM SERVICE

12.1 At End of the Designated Service Life

Tanks that have reached their designated service life must be removed from service. These tanks must be condemned and made unserviceable. If residual gas is likely to be present, expired tanks should be flushed with an inert fluid such as water. The tanks can then be rendered unserviceable by cutting, crushing or drilling so they can no longer hold pressure.

12.2 Tanks Found to have Rejectable Damage or Degradation

Tanks that are found to have rejectable damage or degradation cannot be repaired and must be condemned and removed from service. If residual gas is likely to be present, the tanks should be flushed with an inert fluid such as water. The tanks can then be rendered unserviceable by cutting, crushing or drilling so that they can no longer hold pressure.