Linings of Aboveground Petroleum Storage Tank Bottoms

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1 Scope

This recommended practice (RP) provides guidance on achieving effective corrosion control in aboveground storage tanks by application of tank bottom linings. It contains information pertinent to the selection of lining materials, surface preparation, lining application, cure, and inspection of tank bottom linings for existing and new storage tanks. In many cases, tank bottom linings have proven to be an effective method of preventing internal corrosion of steel tank bottoms.

The intent of this RP is to provide information and guidance specific to aboveground steel storage tanks in hydrocarbon service. Certain practices recommended herein may also be applicable to tanks in other services. This RP is intended to serve only as a guide. Detailed tank bottom lining specifications are not included.

This RP does not designate specific tank bottom linings for every situation because of the wide variety of service environments.

NACE No.10/SSPC-PA 6 and NACE No. 11/SSPC-PA 8 are industry consensus standards for installation of linings on tank floors and vessels. They are written in compulsory language and contain specific criteria intended for use by persons who provide written specifications for tank and vessel linings. These documents should be given consideration when designing and installing a lining system for steel bottom tanks.

2 Normative References

2.1 Codes, Standards, and Specifications

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

API Recommended Practice 575, *Inspection of Atmospheric and Low-Pressure Storage Tanks*

API Standard 620, *Design and Construction of Large, Welded, Low-Pressure Storage Tanks*

API Standard 650, *Welded Tanks for Oil Storage*

API Recommended Practice 651, *Cathodic Protection of Aboveground Petroleum Storage Tanks*

API Standard 653, *Tank Inspection, Repair, Alteration, and Reconstruction*

API Standard 2015, *Requirements for Safe Entry and Cleaning of Petroleum Storage Tanks*

API Recommended Practice 2016, *Guidelines and Procedures for Entering and Cleaning Petroleum Storage Tanks*

ASTM D2583 [1], *Standard Test Method for Indentation Hardness of Rigid Plastics by Means of a Barcol Impressor*

ASTM D4414, *Standard Practice for Measurement of Wet Film Thickness by Notch Gages*

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1 ASTM International, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania 19428, www.astm.org.

ASTM D4417, *Standard Test Methods for Field Measurement of Surface Profile of Blast Cleaned Steel*

ASTM D4940, *Standard Test Method for Conductimetric Analysis of Water Soluble Ionic Contamination of Blasting Abrasives*

ASTM D5402, *Standard Practice for Assessing the Solvent Resistance of Organic Coatings Using Solvent Rubs*

ASTM E96, *Standard Test Methods for Water Vapor Transmission of Materials*

ASTM G9, *Standard Test Method for Water Penetration into Pipeline Coatings*

DSTAN 80-97 [2], *Paint System, Medium Build for the Interior of Bulk Fuel Tanks and Fittings*

ISO Standard 8502-3 [3], *Preparation of steel substrates before application of paints and related products – Tests for the assessment of surface cleanliness—Part 3: Assessment of dust on steel surfaces prepared for painting (pressure-sensitive tape method).*

MIL-PRF-23236D [4], *Performance Specification: Coating Systems for Ship Structures*

NACE 37519 [5], *Corrosion Data Survey—Metals Section*

NACE TM0174, *Laboratory Methods for the Evaluation of Protective Coatings and Lining Materials on Metallic Substrates in Immersion Service*

NACE RP0188, *Discontinuity (Holiday) Testing of New Protective Coatings on Conductive Substrates*

NACE RP0178, *Fabrication Details, Surface Finish Requirements, and Proper Design Considerations for Tanks and Vessels to be Lined for Immersion Service*

NACE RP0287, *Field Measurement of Surface Profile of Abrasive Blast-Cleaned Steel Surfaces Using a Replica Tape*

NACE No. 1/SSPC-SP 5, *White Metal Blast Cleaning*

NACE No. 2/SSPC-SP 10, *Near-White Metal Blast Cleaning*

NACE No. 5/SSPC-SP 12, *Joint Surface Preparation Standard: Surface Preparation and Cleaning of Metals by Waterjetting Prior to Recoating*

NACE No. 10/SSPC-PA 6, *Fiberglass-Reinforced Plastic (FRP), Linings Applied to Bottoms of Carbon Steel Aboveground Storage Tanks*

NACE No. 11/SSPC-PA 8, *Thin-Film Organic Linings Applied in New Carbon Steel Process Vessels*

NACE 6A192/SSPC-TR 3, *Dehumidification and Temperature Control During Surface Preparation, Application, and Curing for Coatings/Linings of Steel Tanks, Vessels, and Other Enclosed Spaces*

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[2] UK Defence Standardization, Room 1138, Kentigern House, 65 Brown Street, Glasgow, G2 8EX. www.dstan.mod.uk

[3] International Organization for Standardization, 1, ch. de la Voie-Creuse, Case postale 56, CH-1211, Geneva 20, Switzerland, www.iso.org.

[4] Available online at http://assist.daps.dla.mil/quicksearch/ or http://assist.daps.dla.mil or from the Standardization Document Order Desk, 700 Robbins Avenue, Building 4D, Philadelphia, PA 19111-5094.

[5] NACE International (formerly the National Association of Corrosion Engineers), 1440 South Creek Drive, Houston, Texas 77084-4906, www.nace.org.

OSHA 29 *CFR* [6], *Part 1910—Occupational Safety and Health Standards by OSHA*

1910.94, *Ventilation*

1910.132, *Personal Protective Equipment, General Requirements*

1910.134, *Respiratory Protection*

1910.146, *Permit-Required Confined Spaces*

1910.147, *The Control of Hazardous Energy (Lockout/Tagout)*

1910.1000, *Air Contaminants*

1910.1200, *Hazard Communication*

1926.354, *Welding, Cutting, and Heating in way of Preservative Coatings*

1926.62, *Lead*

OSHA Publ. 2254 [7], *Training Requirements in OSHA Standards and Training Guidelines*

SSPC Guide 15 [8], *Field Methods for Extraction and Analysis of Soluble Salts on Steel and Other Nonporous Substrates*

SSPC-PA 1, *Shop, Field, and Maintenance Painting of Steel*

SSPC-PA 2, *Procedure for Determining Conformance to Dry Coating Thickness Requirements*

SSPC-PA 10, *Guide to Specifying and Testing Coatings Conforming to Volatile Organice Compound (VOC) Content Requirements*

SSPC-SP 1, *Solvent Cleaning*

SSPC-SP 11, *Power Tool Cleaning to Bare Metal*

SSPC-VIS 1, *Guide and Reference Photographs for Steel Surfaces Prepared by Dry Abrasive Blast Cleaning*

UFGS 09 97 13.15 [9], *Epoxy/Fluoropolyurethane Interior Coating of Welded Steel Petroleum Fuel Tanks*

2.2 Other References

Although not cited in the text, these publications may be of interest or contain related material.

API Recommended Practice 2009, *Safe Welding, Cutting and Hot Work Practices in the Petroleum & Petrochemical Industries*

[6] The Code of Federal Regulations is available from the U.S. Government Printing Office, Washington, DC 20402, www.gpo.gov.
[7] U.S. Department of Labor, Occupational Safety and Health Administration, 200 Constitution Avenue, NW, Washington, DC 20210, www.osha.gov.
[8] The Society for Protective Coatings, 40 24th Street, 6th Floor, Pittsburgh, Pennsylvania 15222, www.sspc.org.
[9] National Institute of Building Sciences (NIBS), 1090 Vermont Avenue NW, Suite 700, Washington, DC 20005, www.wbdg.org/ccb/ccb.php.

API Publication 2207, *Preparing Tank Bottoms for Hot Work*

ACGIH [10], Threshold Limit Values (TLVs®) and Biological Exposure Indices (BEIs®)

NACE Handbook 1, *Forms of Corrosion—Recognition and Prevention, Vol. 1 & 2*

SSPC-AB 1, *Mineral and Slag Abrasives*

SSPC-AB 2, *Cleanliness of Recycled Ferrous Metallic Abrasive*

SSPC-AB 3, *Ferrous Metallic Abrasive*

3 Terms and Definitions

For the purposes of this document, the following definitions apply.

3.1
aboveground storage tank
A stationary container, usually cylindrical in shape, consisting of a metallic roof, shell, bottom, and support structure where more than 90 % of the tank volume is above surface grade.

3.2
anchor pattern
Surface contour or roughness of a blast cleaned or substrate surface, when viewed from the edge. Also called **profile**.

3.3
anode
The electrode of an electrolytic cell in which oxidation is the principal reaction.

NOTE Electrons flow away from the anode in the external circuit. It is usually the electrode where corrosion occurs and metal ions enter solution.

3.4
caulk
Products used to fair or smooth surfaces, as well as seal seams and rivets in lining applications.

3.5
cathode
The electrode of an electrolytic cell at which reduction is the principal reaction. Electrons flow toward the cathode in the external circuit.

3.6
cathodic protection
A corrosion control system in which the metal to be protected is made to serve as a cathode, either by the deliberate establishment of a galvanic cell or by impressed current. (See **anode** and **cathode**.)

[10] American Conference of Governmental Industrial Hygienists, 1330 Kemper Meadow Drive, Cincinnati, Ohio 45240-1634, www.acgih.com.

3.7
coal tar epoxy
A combination of epoxy, curing agent, and tar products which give a very water resistant film.

3.8
coating
A paint or other finish used to create a protective or decorative layer.

3.9
concentration cell
An electrolytic cell where the electromagnetic force (EMF) is caused by a difference in concentration of some component in the electrolyte.

NOTE This difference leads to the formation of discrete cathode and anode regions.

3.10
corrosion
The chemical or electrochemical reaction between a material, usually a metal, and its environment that produces a deterioration of the material and its properties.

3.11
cure, curing
The process whereby a liquid coating becomes a hard film. Curing is complete when the lining is ready to accept immersion in the designated service.

NOTE Methods of testing cure include solvent rub and hardness testing.

3.12
dew point
Temperature at which moisture will condense from vapors into a liquid state.

3.13
differential aeration cell
oxygen concentration cell
A concentration cell caused by differences in oxygen concentration along the surface of a metal in an electrolyte. (See **concentration cell**.)

3.14
electrochemical cell
An electrochemical system consisting of an anode and a cathode in metallic contact and immersed in an electrolyte.

NOTE The anode and cathode may be different metals or dissimilar areas on the same metal surface.

3.15
electrolyte
A nonmetallic substance that carries an electric current, or a substance which, when dissolved in water, separates into ions which can carry an electric current.

3.16
epoxy
Extremely tough and durable synthetic coating resins that are highly resistant to chemicals, abrasion, moisture, and in some cases, alcohols.

3.17
forced-curing
Acceleration of curing by increasing the temperature above ambient, accompanied by forced air circulation.

3.18
holiday
A discontinuity in a protective coating that exposes unprotected surface to the environment. Application defects whereby small areas are left uncoated.

3.19
lining
A liquid paint applied to the interior surfaces of a vessel that develops strong adhesion to the substrate and is designed for immersion service or vapor-space service for a specified stored product.

NOTE A lining can be reinforced or unreinforced.

3.20
mil
One one-thousandth of an inch (0.001 in.).

NOTE One mil = 25.4 µm; it is common practice to use 1 mil = 25 µm.

3.21
mill scale
The heavy oxide layer formed during hot fabrication or heat treatment of metals, typically a black-blue colored smooth layer found on the surface.

3.22
phenolic
A resin of the phenol formaldehyde type.

NOTE Phenolic and novolac epoxies tend to be more chemically resistant.

3.23
primer
First complete coat applied to the prepared surface.

NOTE Holding primers are often used in tank linings when operational issues require daily coating of the blasted surface.

3.24
profile
See anchor pattern.

3.25
thick-film lining
A lining with a dry film thickness of 20 mils (500 µm) or more.

3.26
thin-film lining
A lining with a dry film thickness less than 20 mils (500 µm).

3.27
vinyl ester
A chemically resistant resin frequently used in flake coatings as well as in the fiberglass reinforced thick-film systems.

NOTE This product contains styrene, which is on the HAPS list and is a carcinogen.

3.28
volatile organic compound
VOC
Compounds that have a high vapor pressure [greater than 0.27 kPa (2 mm of mercury) at 25 °C] and low water solubility, excluding methane.

NOTE VOCs typically are industrial solvents, fuel oxygenates, or components of petroleum fuels. VOC content in coatings is highly regulated. Specifiers should be aware of the jurisdiction and regulations in the geography where the coating is to be applied prior to specifying a coating product.

4 Corrosion Mechanisms

4.1 General

Corrosion rates of carbon steel in various hydrocarbons have been determined and are given in many reference texts such as *NACE Corrosion Data Survey–Metals Section*. These rates apply only if there are no accelerating mechanisms. For example, corrosion would not be expected in ambient temperature crude oil or product service with no water present; however, corrosion may occur when a layer of water settles to the bottom of a crude oil, intermediate product, or finished product storage tank. This water, which may enter the tank with the product, through the seals, or during "breathing" of the tank, often contains corrosive compounds. For example, crude oil may contain salt water and sediment that settles out on the bottoms of storage tanks. Chlorides and other soluble salts contained in the water may provide a strong electrolyte that can promote corrosion. The common mechanisms of internal tank bottom corrosion include:

a) chemical corrosion;

b) concentration cell corrosion;

c) galvanic cell corrosion;

d) Microbiologically Influenced Corrosion (MIC);

e) erosion-corrosion;

f) fretting-related corrosion.

These mechanisms are discussed in detail in the following sections.

4.2 Chemical Corrosion

Chemical corrosion may occur in environmental and product cleanup tanks as well as in chemical storage facilities. For example, a wastewater treatment tank operates by adding heat and/or concentrated sulfuric acid to the water to break the emulsion of oil and water. The acid, unless added properly, immediately becomes diluted and hence much more corrosive, especially in the area of the acid inlet piping. Chemical attack is also prevalent in corrosive services such as caustic, sulfuric acid, ballast water, and water neutralization services. Proper coating selection is crucial when considering this type of service.

4.3 Concentration Cell Corrosion

Concentration cell corrosion may occur when a surface deposit, mill scale, or crevice creates a localized area of lower oxygen concentration. The area under a surface deposit may be penetrated by a thin layer of electrolyte, which soon becomes depleted of oxygen. The difference in oxygen concentration between the inaccessible area and the bulk electrolyte creates a galvanic cell, with the contact area of the surface deposit being anodic to the surrounding tank plate. Concentration cell corrosion will cause pitting and may result in significant localized metal loss. Pitting of a bare steel tank bottom may occur at a rate as high as 80 mils (2.0 mm) per year.

4.4 Galvanic Cell Corrosion

Hot-rolled carbon steel, typically used for the construction of petroleum storage tanks, is covered with a thin layer of oxide called mill scale, which is cathodic to the base steel. In the presence of a corrodent (such as dissolved oxygen) and an electrolyte, a galvanic corrosion couple forms at breaks in the mill scale. Accelerated pitting corrosion of the steel at breaks in the mill scale can result. Mill scale may be removed from both sides of the tank bottom plate by abrasive blast cleaning or by pickling, but removal of mill scale from the underside of the steel bottom is not commonly done. Removal of mill scale from the underside of new steel bottoms may be considered in an effort to promote a more uniform corrosion and minimize accelerated pitting corrosion that may occur.

In some cases, welding can produce large differences in the microstructure of a steel bottom plate resulting in a built-in galvanic couple. In the presence of a corrodent and an electrolyte, preferential corrosion can occur at the heat-affected zones (HAZ) of the base metal near the welds. This type of corrosion can cause significant localized metal loss.

4.5 Microbiologically Influenced Corrosion (MIC)

Bacteria [e.g. sulfate reducing bacteria (SRB) and acid producing bacteria (APB)] are widespread in the petroleum industry. The role of bacteria in corrosion is universally recognized but the mechanisms are not well understood. Generally, the effect of bacteria on the corrosion of bare steel tank bottoms is negligible. In some cases, however, severe corrosion has been attributed to MIC. The bacteria colonies form deposits on the steel that may provide an effective barrier to the diffusion of dissolved oxygen. Thus, the mere physical presence of bacterial deposits can promote aggressive pitting corrosion by the concentration cell mechanism described in 4.3.

The metabolism of bacteria is important with regard to the corrosion of storage tank bottoms. Most bacteria found in the petroleum industry are strict anaerobes that do not proliferate in the presence of oxygen; however, the dense bacterial colonies create a local anaerobic condition, even if some oxygen is available. By creating the local anaerobic condition, the bacteria can stay alive in the presence of oxygen, even though the colonies do not expand. In the case of SRB, colonies derive energy principally from the reduction of sulfates to sulfide, and this metabolic end product is corrosive to steel. Moreover, the iron sulfide corrosion product is cathodic to the base steel and may promote accelerated pitting corrosion by a galvanic mechanism, as described in 4.4, if dissolved oxygen is available as a corrodent. This type of corrosion can often be found in tanks containing diesel or fuel oils.

4.6 Erosion-Corrosion

Erosion-corrosion may occur in wastewater treating or mixing tanks where soil or small abrasive aggregate is present. To a lesser extent, erosion-corrosion can also occur at tank mixers in crude oil storage tanks. A water treatment tank blends chemicals into contaminated water to break any emulsions of oil and water. Agitation may increase corrosion by delivering more corrodent, such as dissolved oxygen, from the bulk of the stored product to the surface of the tank steel. Turbulence also moves any fine aggregate that is present, creating an abrasive environment in which adherent, semi-protective corrosion products can be dislodged, exposing the underlying steel to the corrosive environment. Severe erosion conditions may scour the base metal directly. Erosion-corrosion causes highly localized metal loss in a well-defined pattern. Erosion corrosion may be found at tank inlets and outlets where product flow occurs.

4.7 Fretting-Related Corrosion

Fretting-related corrosion may occur in hydrocarbon service on the bottoms of external floating roof tanks. When the tank is emptied, the floating roof is typically supported on roof-support legs constructed of open-ended pipe. Most bottom designs require “striker plates” under each roof support leg. When the floating roof is landed, the pipe legs rest on the striker plates supporting the weight of the roof. Repeated, frequent contact between the striker plate and the open end of the pipe leg removes any protective layer of rust scale that may have formed on the striker plate surface. When the roof is floated again, any water on the tank bottom causes corrosion at the location on the striker plate where the coating and/or any protective rust scale has been damaged. Experience has shown that frequent roof landings over a long period of time causes corrosion severe and localized enough to corrode a hole through the striker plate and the floor plate like a cookie cutter.

5 Determination of the Need for Tank Bottom Lining

5.1 General

The bottom plates of aboveground storage tanks are susceptible to internal and external corrosion. Storage tank bottoms are generally fabricated from carbon steel plate sections that are typically 0.25 in. (6 mm) thick. Annular floor plates of storage tanks frequently have thicker plate sections ranging from 0.25 in. to 1.0 in. (6 mm to 25 mm). The bottom plate sections and the attachment fillet lap welds are intended to function as a membrane and prevent leaks. Uniform soil support beneath the bottom plate minimizes stress in the bottom plate.

The need for an internal tank bottom lining in an aboveground storage tank is generally based on several considerations:

a) corrosion prevention;

b) tank design;

c) tank history;

d) environmental considerations;

e) reduce time and effort for future tank cleaning;

f) federal, state, and local regulations;

g) product quality;

h) considerations under API Standard 653 with respect to next inspection interval.

5.2 Linings for Corrosion Prevention

The proper selection, application, and maintenance of tank bottom linings can prevent internal corrosion of the steel tank bottom. Unless means of corrosion prevention are used on the soil side, perforation of the tank bottom may still occur.

The minimum thickness of the steel tank bottom should be determined according to API 653. An internal tank bottom lining may be deemed necessary if corrosion is expected to proceed so that the steel thickness may reach this minimum thickness, generally 0.100 in. (2.5 mm), prior to the next scheduled inspection.

If the minimum bottom thicknesses at the end of the in-service period of operation are calculated to be less than the minimum bottom renewal thicknesses given in API 653, or less than the minimum bottom renewal thicknesses providing acceptable risk as determined by an RBI assessment per API 653, the bottom shall be lined, repaired, replaced, or the interval to the next internal inspection shortened.

When using API 653 to determine appropriate internal inspection intervals for aboveground storage tanks, the anticipated life of the lining as well as the corrosion rate anticipated in the event of premature lining failure should be considered.

5.3 Tank Corrosion History

The corrosion history of a particular tank should be considered when determining the need for an internal lining. The corrosion history of tanks in similar service should also be considered. The items to be considered are dictated by individual circumstances, but some of the more important considerations are as follows.

a) Where is the corrosion occurring (product side, soil side, or both)?

b) What is the internal and soil-side corrosion rate?

c) Have there been significant changes in the corrosion rate?

d) Is the corrosion uniform or localized?

e) Has corrosion caused perforation of the steel tank bottom?

f) What was the prior service of the tank and how corrosive was that product?

5.4 Tank Foundation

The foundation must be adequate to prevent excessive settlement of the tank. If uniform foundation support is not provided, flexing of the tank bottom can result as the tank is filled or emptied. Flexing occurs on all steel floors; however, excessive flexing of the steel bottom may cause an internal bottom lining to crack.

The tank pad material beneath the steel bottom has a significant effect on the potential for underside corrosion. If there is pad contamination (e.g. rock, lumps of clay, welding electrodes, paper, plastic, wood, etc.) in contact with the underside of the steel, differential aeration or other corrosion cells can form where the contaminates are in contact with the tank bottom and severe corrosion may result (see API 651). The use of wood under a tank floor is not recommended given that it promotes bacterial activity and will cause accelerated corrosion.

6 Tank Bottom Lining Selection

6.1 General

Tank bottom linings can generally be divided into two classes: thin-films [with a dry film thickness less than 20 mils (500 µm)] and thick-films [with a dry film thickness of 20 mils (500 µm) or more]. Linings may be applied to the bottoms of storage tanks when they are first constructed or they may be installed after some period of service. Generally, thin-film linings may be applied to new tanks and to bottoms of storage tanks that have experienced minimal corrosion. The advantages and disadvantages of thin and thick-film tank bottom lining systems are discussed in this section.

Most tank bottom lining materials are initially selected based on chemical resistance or compatibility with the stored product. However, resistance to moisture permeation should also be a major consideration for long-term service since most storage tanks will typically have a layer of water on the floor. All lining materials absorb moisture over time and this absorption can ultimately result in its failure. The moisture vapor transmission of various lining materials can be comparatively tested using ASTM E96, ASTM G9, or other equivalent test methods. Because tank bottoms flex during operation, a bend test on coating candidates should be performed to ASTM standards prior to coating selection.

Recent advancements in technology have produced coatings with zero VOCs. These 100 % solid coatings provide reduced safety concerns during the application, can be applied in a single coat and offer a reduction in the tank turnaround schedule. With exceptions, typically these coatings are classified as thick-film linings, although 100 % solids coatings may be applied as thin-film linings where the excess thickness is not required.

6.2 Thin-film Tank Bottom Linings

6.2.1 General

Thin-film tank bottom lining systems are frequently based on epoxy or epoxy-copolymer resins. All linings that are employed to protect tank bottoms also must be resistant to water, since water must be present at the tank bottom for electrochemical corrosion to occur. NACE No. 11/SSPC-PA 8 should be given consideration when designing and installing a thin-film lining system for steel bottom tanks.

Inorganic zinc (zinc silicates) are often applied to internal tank surfaces. These coatings are typically applied at 3 mils to 5 mils dry film thickness (DFT). These linings are not considered thin-film linings for purposes of API 653 calculations.

6.2.2 Advantages of Thin-film Linings

Thin-film lining systems are often used for application to the product side of the bottoms of new storage tanks. New steel plates provide a smooth surface that easily can be made ready for lining application. Corrosion of bare steel tank bottoms is rarely uniform. Generally, corrosion due to immersion exposure creates a surface that is rough and pitted, and it is often difficult to completely coat and protect a corroded steel bottom with a thin-film lining system. The principal advantages of thin-film linings are as follows.

a) Initial cost is typically less than thick-film reinforced linings.

b) Most are easier to apply than thick-film reinforced linings.

c) Experience has shown that when properly selected, applied, and not damaged, the life of thin-film linings can be greater than 20 years.

d) Most thin-film epoxy linings exhibit good flexibility.

e) Generally more accurate magnetic flux leakage (MFL) floor scans.

f) It is often easier to remove a thin-film lining at the end of its useful life.

g) A thin-film lining may be all that is needed to prevent internal corrosion from occurring based on the condition of the steel substrate.

6.2.3 Limitations of Thin-film Linings

Limitations of thin-film linings include the following.

a) API 653 allows a minimum of 0.050 in. (1.3 mm) remaining bottom plate thickness at the next internal inspection, if thick-film reinforced linings are used. Thick-film reinforced linings may be used to extend the inspection interval depending on the particular tank inspection results and calculations.

   In the case of thin-film linings, however, API 653 only allows the bottom plate thickness be a minimum of 0.100 in. (2.5 mm) at the end of the next service interval.

b) Thin-film linings are more susceptible to mechanical damage than thick-film linings.

c) Rough weld surfaces and weld spatter can protrude through the finished lining thickness and result in holidays, therefore, weld surfaces should be relatively smooth and weld spatter removed before a lining is applied. If it is not feasible to create relatively smooth welds free from weld spatter by grinding or other processes, caulking or thick-film coatings may be considered as an alternative in order to create a film free from holidays. Optimally, requirements for weld surface quality are part of the welding specification and not part of the lining contractor's responsibility. In the case of reinforced thick-film systems, caulking may be one of the requirements for proper installation. See NACE 10/SSPC-PA6, *Fiberglass-Reinforced Plastic (FRP) Linings Applied to Bottoms of Carbon Steel Aboveground Storage Tanks*, for information on caulking.

d) Some thin-film linings require the application of multiple coats.

e) Thin-film linings are most often solvent-borne coatings that require the evaporation of solvent from the film to achieve proper cure. If the solvent vapors are not effectively removed from the tank or vessel, because they are heavier than air, they will hover at the floor level and impede the progress of the cure. VOC regulations shall be considered when specifying thin-film coatings.

f) Presence of moisture in the air during the cure can cause amine blush, which must be removed before the application of subsequent coats. Amine blush can cause issues with intercoat adhesion if not properly removed between coats.

6.3 Thick-film, Unreinforced Linings

6.3.1 General

Thick-film, unreinforced linings may be used as tank bottom linings for both new and old storage tanks. However, it is important to note that only fiber-reinforced linings are well proven to have hole-bridging capability.

6.3.2 Advantages of Thick-film Unreinforced Linings

Advantages of thick-film unreinforced linings include the following.

a) Some thick-film linings can be built up to 100 mils (2540 μm) in a single coat.

b) Better coverage over rough surfaces.

c) No overlap or intercoat contamination and blushing issues with a single coat application.

d) High solids may have better edge retention with reduced material shrinkage.

e) Typically, fast curing and can be put back in service after 24 hours at normal ambient temperatures.

f) Few or no discontinuities to repair following the "holiday" test.

g) Reduced labor costs compared to multi-coat thin-film or labor-intensive reinforced thick-film linings.

h) Promotes a reduced tank turn around schedule.

i) Long term service—may be greater than 20 years resulting in low life-cycle costs.

j) Generally provides greater resistance to moisture permeation.

6.3.3 Limitations of Thick-film, Unreinforced Linings

Limitations of thick-film unreinforced linings include the following.

a) Typically requires the use of plural component spray equipment.

b) Difficult to install on complex geometry due to plural component application.

c) Contractor experience level should be a consideration.

d) MFL Floor Scan Inspection of underlying steel condition may be limited on linings of very high thickness.

e) Depending on resin type and thickness, cracking due to plate flexure may be a concern.

6.4 Thick-film Reinforced Linings

There are currently two systems being specified to restore heavily corroded and pitted tank floors: fiberglass reinforced plastic (FRP) laminates and reinforced thick-film linings. FRP laminates and reinforced thick-film linings each represent a viable alternative to replacing steel tank floors.

FRP systems consist of either a 1.5 oz glass mat or chopped fiberglass roving embedded in a resin, typically either polyester, vinyl ester, or epoxy. Hand lay-up systems with glass mat do not require special equipment and can be applied with a “dump and roll method.” A “chopped system” with glass roving requires heated plural spray equipment and a chopper gun to cut the glass roving and disperse it into the resin as it is being sprayed onto the floor. Chopped systems require specific applicator expertise, as the device held and controlled by the applicator must deposit not only the correct ratio of components in the resin mixture, but also the correct proportion of fibers and resin.

FRP composites require multiple installation steps which include, in addition to blasting and priming, caulking of all weld seams and shell-to-bottom weld for smooth transition of glass, fabrication of the laminate with either glass mat or glass roving with the appropriate resin, and finally a protective gel coat of resin to ensure complete wetting of the glass to prevent wicking problems.

Many tests have been performed over the years to determine the ability of FRP systems to bridge perforations due to soil side corrosion. Most published tests to date relate to FRP systems because of their 50 plus year record of successful performance. Single FRP laminates have been documented as being able to bridge perforations up to 8 in. (203 mm) in diameter with a maximum pressure of 37 psi.

Double FRP laminates have been shown to bridge perforations up to 8 in. (203 mm) in diameter with a maximum pressure of 82 psi. Since an internal hydraulic pressure of 22 psi is normal for most petroleum tanks, single or double laminates offer an added measure of protection from a leaking tank bottom.

Any of the systems described above are suitable for tank floor restoration when poor steel conditions are found. Information related to the performance limitations of specific coatings with regard to chemical immersion, elevated exposure temperatures, and low temperature application should be obtained from the coating manufacturer. A final decision requires a determination of the current extent of product side corrosion, thickness of the tank floor, and a judgment on the potential for underside corrosion based on tank specific historical information.

While API 653 does not allow an inspection interval whereby the steel may be expected to have perforations or be less than a minimum thickness of 0.050 in. with a reinforced thick-film liner, the use of thick-film reinforced coatings may provide a level of comfort in knowing that there is additional protection in the event that a minor perforation occurs.

6.5 Circumstances Affecting Lining Selection

6.5.1 General

In addition to corrosion history and the potential for corrosion, circumstances that must be taken into account during the selection of a tank bottom lining are described in 6.5.2 through 6.5.7.

6.5.2 Temperature

Temperature must be taken into account during the selection of an internal lining system.

Internal steam coils, which are used to heat a product to maintain a desirable viscosity, limit accessibility to the tank bottom during surface preparation and application of the lining. As a result, a good quality installation may be difficult to achieve. In service, steam coils create local areas where the temperature can be much greater than that of the bulk product. The resulting thermal effects on a tank bottom lining may cause localized coating damage such as blistering or cracking. The distance between the coils and the tank bottom are an important factor in determining the temperatures that the coating may be exposed to. If the coils are sufficiently close to the tank floor, heat may be conducted into the floor if there is any sludge build up over the service life of the tank. Storage tanks may operate above ambient temperature in order to maintain low viscosity of the stored product. As temperatures increase, this becomes more critical and the need for careful lining selection is required. Information related to performance limitations with elevated service temperatures may be obtained from the lining manufacturer. The owner should always consult the manufacturer for coating selection, suitable service, temperature limitations, and curing schedule and testing procedure.

6.5.3 Product Quality

With many refined products, such as gasoline, jet fuel, lubricating oils, solvents and other petrochemical products, tank bottoms may be lined not only to prevent internal corrosion but also to maintain product quality. If lining selection is principally based on product purity and the steel is in suitable condition for proper application of a thin-film lining, thin-film lining systems may be suitable to fulfill this need. However, in some circumstances a combination of product quality and corrosion resistance must be considered. Coatings that are certified to MIL-PRF-23236D for fuel service must meet a range of test requirements that are designed to ensure that a lining does not negatively impact key properties of jet fuel and aviation gasoline.

The owner may also have to evaluate the product immersion liquid to ensure that product contamination by the prospective internal lining will not occur. Certain products, such as fiber-grade ethylene glycol, methanol and other solvents, have quality requirements that can be affected by solvent residues leaching from a newly applied lining into the stored product. In the case of ethylene glycol, these contaminants (even at very low levels) can interfere with the quality control tests for the high purity fiber-grade ethylene glycol (used in the manufacture of polyurethane fiber). In situations such as this, linings should be evaluated to determine their suitability for the intended service. Linings intended for product quality and corrosion protection must be resistant to the intended tank service and the probable presence of a contaminated water layer on the floor. The manufacturer shall be advised of the type of testing for product contamination that the lining will be subjected to in order to determine if the lining selection is suitable for the service.

6.5.4 Presence of Tank Internals

Existing tanks may have design and fabrication features that make the application of a lining impractical or can seriously jeopardize the integrity of a lining. Examples of this include the coil supports and striker plates and cone roof legs. The detail for the termination of the coatings where these features are encountered are critical to a good installation. For example, steel reinforcing or striker plates should be fully welded to the tank floor, where feasible. Floor coatings can properly be terminated on these reinforcing plates. The owner can select to coat or not coat items such as cone roof columns and coil supports that are designed to be free from connection with the floor or are designed to be self-centering. When electing to terminate a coating on a bottom reinforcing plate near a feature, it is important that the surface preparation be performed to the specification beyond the location of the coating termination. The coating should be terminated in the reinforcing plate no less than 2 in. (51 mm) from any weld, if feasible. If it is suggested to coat the striker plates, the coating should be performed before the plates are installed, leaving the weld areas for field coating installation.

6.5.5 Flexibility for Service Change

Changes in tank service may affect the performance of an existing tank bottom lining. Tank linings do not offer universal resistance. A properly applied tank bottom lining may provide more than 20 years of service life in storing a particular product. A lining that has provided many years of satisfactory protection in one product may have inadequate resistance to a new service environment. The need for operational flexibility at some facilities requires that some tanks be available for swing service. Such factors should be considered during the selection and design of a lining system. Many linings will need to recover between product changes. Consult the manufacturer to determine if there are any specific recommendations (e.g. cleaning, ventilation, etc.) when changing the stored product.

6.5.6 Construction Details that Can Impact the Lining

It is difficult to achieve lining continuity when irregular surfaces caused by discontinuous connections such as rivets, butt straps, and skip welding exist because they are difficult to cover and protect with a lining. In old tanks, the problem of poor coverage may be complicated by chemical contaminants, which may be difficult to remove. It is common to use caulk to seal lap joints between riveted plates and around rivets to provide a continuous surface for the lining application. Caulking shall be selected and specified based on the conditions encountered with consideration for the temperatures and the tank service requirements. Welded tanks generally require less preparation than riveted tanks. See NACE 10/SSPC-PA6, *Fiberglass-Reinforced Plastic (FRP) Linings Applied to Bottoms of Carbon Steel Aboveground Storage Tanks*, for information on caulking.

NOTE Caulk may be used with thin-film lining systems, as well as thick-film linings where needed, to work with surface irregularities.

Consideration should be given to the design of the striker plates beneath the cone roof support columns and internal floating roof legs. Abrasion may occur from contact between the legs and the tank floor. While coatings may be required on the tank floor, a steel striker plate that is fully seal welded will act as protection of the tank bottom. Coatings may or may not have to be continuous beneath the legs, depending on the details concerning the installation of striker plates. If striker plates are not installed, a provision must be made (e.g. protective shoes or similar) to protect the coating in the event that the roof lands. Cable suspended roofs have made this detail moot.

6.5.7 Upset Conditions

The degradation of a lining is a complex process and, unlike the steel that is to be protected, degradation is not readily quantified by a corrosion rate. A relatively short-term exposure to an unusually aggressive environment can cause irreversible damage to a lining, compromising the protection afforded to the steel. For this reason, a lining must resist potential upset conditions in addition to the usual service environment.

7 Surface Preparation

7.1 General

As recommended in the scope of this document, NACE No. 10/SSPC-PA 6 and NACE No. 11/SSPC-PA 8 should be considered when determining specific criteria for surface preparation and lining application. Following is a general outline of surface preparation considerations covered in these referenced documents.

Surface preparation is a critical part of the lining application. Continuous immersion is a severe exposure. Inadequate surface preparation is a major cause of lining failure. Surface preparation is performed to provide the appropriate combination of surface cleanliness and surface profile, or the anchor pattern (see 7.5) required to establish good chemical and mechanical adhesion of the lining resin to the steel. Generally, abrasive blast cleaning to a white metal finish (NACE No. 1/SSPC-SP5) is desired. Abrasive blast cleaning to a near-white metal finish (NACE No. 2/SSPC-SP10) is often specified as the minimum degree of surface cleanliness. For small areas, SSPC SP 11 is often desirable to avoid damage to the surrounding lining that may be in very good condition. Use of power tools to meet SSPC SP 11 requirements must include the use of abrasive disks or flapper wheels that provide the specified anchor profile and must be followed by solvent wipe per SSPC SP 1 to remove oil contaminants from the power tool.

To facilitate inspection and to ensure good adhesion of the lining, surface preparation by abrasive blasting should extend several inches beyond the area to be lined. This practice of framing the area where lining is to be applied helps to ensure that unprepared steel is not inadvertently coated.

7.2 Pre-cleaning

7.2.1 Residue Removal

Prior to abrasive blasting, all hydrocarbon residues such as oil, tar, and grease, must be removed from the area to be lined. Solvent cleaning (see SSPC-SP 1) and high or ultra-high pressure water or steam cleaning, using the proper chemicals, are effective methods of accomplishing complete hydrocarbon removal. Cleaning is typically followed by a fresh water rinse to ensure complete removal of cleaning chemicals.

7.2.2 Soluble Salts

It is important to note that typically abrasive blasting is not effective in the removal of soluble salts. The presence of soluble salts on the steel can adversely affect the performance of a lining resulting in blistering by osmosis. Consideration should be given to a field evaluation for the presence of soluble salts whenever there is the possibility of such contamination. SSPC Guide 15 describes common methods for this evaluation. The use of high pressure and ultra-high pressure water jetting (NACE No. 5/SSPC-SP 12) can reduce soluble salt contamination; however an acceptable reduction may not occur due to the presence of chemically adsorbed molecules. Typically the NACE No. 5/SSPC-SP 12 specification is used for substrates that already possess a surface profile and do not require abrasive blasting.

Commercial products assist in reducing the presence of soluble salts if they are found on the substrate during testing. Follow the manufacturer’s recommended procedures for use of these products. Be sure to test again following any treatment method.

7.2.3 Water Quality

Water that is used for surface cleaning should be of sufficient purity and quality that it does not preclude the surface from meeting the surface cleanliness criteria. Where salt water is used for hydrostatic testing, the substrate should be tested for contaminates prior to the start of the lining process. Different cleaning and treatment may be required to return the substrate to acceptable condition.

7.3 Bottom Repair and Weld Preparation

The repair of perforations of the steel tank bottom shall be by welding of steel patch plates or replacement of bottom plate. Epoxies shall not be used to repair perforations. API 653 should be consulted for information on tank bottom repair.

Welds should be inspected before and after blast cleaning. All sharp edges and protrusions should be ground to provide a smooth surface that can be completely and uniformly covered with the lining material. Sharp edges and protrusions may be caused by such things as weld spatter, sharp weld crests, undercutting of the weld, arc burns, erection clips, plate joints, burrs, and gouges. Chipping, followed by grinding, can be used to remove sharp edges.

NACE RP0178 can be used to specify the surface finish of welds. Typically, weld finish “C” or “D” is specified where feasible.

7.4 Surface Cleanliness

The surface to be lined should be of the specified level of cleanliness at the time the lining is applied. If the surface is degraded or contaminated subsequent to surface preparation and before lining application, the specified level of cleanliness should be restored before lining application. Holding primers must be applied before the surface has degraded, if specified. It may be difficult when using recycled media on tank linings to ensure that the surface is clean. Recycled media may collect contaminants on each successive recycle process and impinge these contaminants into the steel profile, which are often difficult to detect by inspection. Owners should weigh the benefits of recycled media against the risk of having surface contamination that may interfere with the life of the internal lining.

7.5 Surface Profile or Anchor Pattern

The abrasive used for blasting should be selected to produce the necessary profile depth, or anchor pattern, for the lining to be applied. The lining manufacturer’s recommendation for surface profile depth must be achieved in order to optimize the mechanical adhesion of the lining to the steel tank bottom. The anchor pattern required for linings is typically 1.5 mils to 4.0 mils (38 microns to 102 microns) and generally increases with the thickness of the lining. To achieve adhesion necessary for long-term performance, it is important that the anchor pattern is sharp and angular. It may be difficult when using recycled media on tank linings to ensure a uniform proper profile depth, as well as a proper degree of sharpness and angularity. Owners should weigh the benefits of recycled media against the risk of not having adequate surface profile that may be required for internal linings.

7.6 Air and Abrasive Cleanliness

The abrasive and compressed air supply used for abrasive cleaning of tank bottoms should be free of contaminants such as water soluble salts, dirt, clay, oil, and grease (per SSPC AB1, AB2, AB3, and ASTM D4940, as appropriate). If present in the blasting abrasive, small amounts of these contaminants may be delivered to the steel surface during the cleaning operation. This contamination will reduce the useful life of the lining.

7.7 Removal of Salts

Corrosion inducing anions from water soluble salts, if present, may be lodged on the substrate surface. Section 7.2.2 covers soluble salts and their treatment. Testing for the presence of chloride and other contamination should be considered prior to proceeding with any lining installation.

7.8 Removal of Dust

Spent abrasive, as well as spent abrasive dust, must be removed from surfaces prior to coating application. Standard practice has been to blow-down surfaces with clean, compressed air, and use vacuum cleaning methods. Follow OSHA regulations when using compressed air for cleaning surfaces. Vacuum cleaning methods have proven to be more efficient. ISO 8502-3 may be used to determine the effectiveness of cleaning methods.

8 Lining Application

8.1 General

When a holding primer is used, it is important that it is applied according to the manufacturer’s instructions for film thickness, as excess thickness may have an adverse effect on intercoat adhesion and will adversely affect the performance of the coating system. Recoat windows must be strictly followed when using multi coat systems. If coatings exceed the suggested recoat windows, then the coating must be properly prepared in accordance with the manufacturer’s recommendations prior to proceeding to any subsequent coats or processes.

Subsequent coats must be applied within the recoat interval recommended by the lining manufacturer. The inspector shall ensure the contractor follows the manufacturer's specifications for the product, as well as the complete coating system. The inspector shall record and report to the owner the conditions and the time intervals. Generally, the recommendations and procedures prescribed in SSPC-PA 1 should be followed. After sufficient curing of the completed lining, holiday testing (as described in 9.3.4) should be carried out. Any defects should be repaired in accordance with the coating material manufacturer's recommendations and the written specification.

8.2 Guidelines for Lining Application

SSPC-PA 1 provides general guidelines for good lining application practice. Proper on-site storage conditions, mixing, applying, and curing of the lining are essential procedures, and the lining manufacturer's recommendations should be followed. Any differences between the owner's specification and the lining manufacturer's recommendations should be resolved before beginning the job.

8.3 Temperature and Humidity Control

The temperature of the steel surface should conform to the lining manufacturer's recommended application and curing ranges. As a general rule, the surface temperature must be at least 5 °F (3 °C) above the dew point temperature in the tank and the relative humidity should be below 80 % at the steel surface. If the surface temperatures and/or humidity level expected to deviate from the recommended range, climate control equipment should be employed to ensure the proper conditions are maintained. It should be noted that durations of surface preparation, lining application, and cure may be continuous over a 24-hour period. If so, the required environmental conditions must be maintained around the clock. Owner operations may interfere with continuous use of environmental control equipment. These operational considerations should be reviewed prior to the execution of the tank lining project.

NACE 6A192/SSPC-TR 3 provides guidance on the use of dehumidification and heating equipment for environmental controls during tank lining work.

Climate control equipment is also used to advantage by protecting workers from heat stress during hot summer months. Improved productivity, due to better working conditions, is a secondary benefit.

8.4 Lining Thickness

Insufficient film thickness will not provide adequate coverage or protection and can result in reduced service life of the lining. Excessive film thickness, beyond the manufacturer's recommended range, can compromise lining adhesion and film integrity. Excess primer thickness is a common cause of failure of thick-film lining systems. The lining thickness shall be in accordance with the lining specification. Excess thickness of any particular coat shall be remedied in accordance with the manufacturer's recommendations prior to proceeding to any subsequent coats or processes. Changing or alternating colors between coats can aid in ensuring uniform coverage and thickness.

8.5 Lining Curing

Improper application and inadequate curing time are major causes of premature lining failure. The adhesion and integrity of the film are adversely affected if a lining has not been applied and cured properly. Prior to removing forced ventilation or closing the tank, the lining should be completely cured to obtain optimum service life. Refer to the coating manufacturer to determine the proper cure time and temperature. The proper curing conditions should be ensured for the full duration of the cure time, where feasible. The proper conditions or forced-curing of the lining may be accomplished by circulating warmed, dehumidified air (see 8.3 and NACE No. 10/SSPC-PA 6).

The owner shall not rely on estimates of time and temperature. The owner and the applicator shall ensure that the lining is fully cured for service by use of any of the methods specified to determine complete cure prior to returning the tank to service.

Solvent-borne linings require forced ventilation of the air space adjacent the lining. As the heavier-than-air solvents evolve from the wet lining, they will rest atop the lining, impairing the completion of this process. Dissipation of solvent vapors must occur so enough solvent can evolve from the film to achieve a level of cure necessary for hydrocarbon or chemical resistance.

9 Inspection

9.1 General

Independent Quality Assurance inspection is highly recommended to oversee the contractor's quality control process. This shall ensure that the criteria in the lining specification have been met. The lining should be inspected during all phases of the work and upon completion of the work. The performance life of a lining is directly related to the quality of the surface preparation, application and curing, combined with thorough inspection. Documentation should include daily inspection records to capture the project activity and issues per the written specifications.

Project records should be made to briefly describe the products and procedures that were used during installation of the lining. These records will be important the next time the tank is opened to associate the lining product and installation process with the lining performance. Records will also be valuable if repairs are needed and a repair product and repair procedure must be developed.

9.2 Qualification of Inspection Personnel

All lining inspectors should be either NACE or SSPC certified, or should have demonstrated a thorough knowledge of coating and lining practices.

9.3 Recommended Inspection Parameters

9.3.1 Surface Cleanliness and Profile

Quality assurance and quality control personnel shall verify that the recommended practices reviewed in Section 7, as well as the manufacturer's specifications, are strictly followed.

9.3.2 Film Thickness

Inspection shall verify that as the lining is applied, wet film thickness measurements are being made in accordance with ASTM D4414. After the lining has cured sufficiently to allow handling, dry film thickness measurements should be made in accordance with the specified method to determine dry film thickness or SSPC PA 2, if not otherwise stated.

9.3.3 Final Cure

If specified to aid in determination of degree of cure, hardness of the lining should be measured in accordance with the manufacturer's recommendations, following any specified ASTM methods. It should be noted that this test could be destructive to organic resin linings that are not sufficiently thick, hard, and/or cured.

9.3.4 Lining Discontinuities

Holiday testing of thick-film linings shall be carried out with a high-voltage detector in accordance with NACE RP0188. Holiday testing of thin-film linings should be performed with a low-voltage (67.5 volts) wet sponge detector. When testing with high voltage detectors, it is important that the voltage be properly set in accordance with the manufacturers recommended volts per mil and that the film thickness properly matches the specified thickness. Otherwise, damage may occur from the testing operation. Also, nothing in this document shall preclude the testing of a thin-film lining using a high voltage detector, if there are temperature considerations, provided that the voltage be properly set to correspond with the film thickness.

10 Evaluation and Repair of Existing Linings

10.1 General

A properly selected and applied tank bottom lining should be expected to provide a minimum service life of 20 years. Some lining systems, most notably thick-film laminates, have provided 25 to 30 years of service life. Lining "failure" is not well defined and fitness for service is not well established for polymeric coatings. Linings degrade with time. However, blistering is a common mode of lining deterioration. However, blistered linings may remain fully functional, providing corrosion protection to the steel for many years. Lining degradation does not necessarily translate to putting the steel at significant corrosion risk.

When available, tank bottom linings should be thoroughly inspected to assess their condition and determine the need for repairs. Timely maintenance can keep repairs to a minimum and greatly extend lining service life. Care should be taken not to damage the lining (especially thin-films) during cleaning, inspection and mechanical repair procedures. API 653 provides guidance for visual in-service and detailed out-of-service inspection and repair methods for tank components. These inspections may reveal conditions that necessitate lining repair, which are not covered in API 653. All repairs to the tank should be completed before any repair of the lining.

10.2 Evaluation Methods

Lining evaluation methods include the following.

a) Visual inspection.

b) Adhesion measurement.

c) Audible testing (to find areas of delamination on thick-film reinforced linings via tapping with a solid metal object).

d) Physical examination of lining sample, including possible laboratory testing (to determine permeation by the tank's previous product, film thickness, brittleness, and/or adequacy of cure).

e) Holiday testing. (This is not typically recommended for linings that have been in previous service, since the presence of moisture in the film can cause damage when exposed to voltage. In some instances, this has been successfully achieved after tank has remained open and the lining exposed to normal ventilation for several months. Consultation with the coating manufacturer prior to attempting this type of inspection is necessary.)

NOTE This holiday test requirement may pose a challenge, as many regulatory agencies rely on the holiday test to establish the efficacy of a lining that has been in service. If a lining that has been in service fails the holiday test in areas that are not obviously deficient, the holiday test should not be used as the only criteria. Adequate cleaning of the tank is critical to successful and meaningful holiday testing of tank linings that have been in service.

10.3 Evaluation Criteria for Linings

Evaluation of existing tank linings should be based on the following criteria.

a) How long has the existing lining been in-service?

b) How well has the existing lining performed to date?

c) The desired service life of the lining (i.e. how long must the lining do its job before it will be inspected and receive required maintenance?).

d) The intended exposure conditions (i.e. intended service of the tank, operating temperature, whether water will be present, whether other contaminants or chemicals will be present and their concentrations).

e) The specifications and characteristics of the existing lining.

10.4 Evaluating Serviceability of Existing Linings

The evaluation methods listed in 10.2 should be used to determine if an existing lining is suitable for service. Blistering, cracking, crazing, discoloration, and areas of missing lining are modes of degradation that can be detected by visual inspection. However, these types of degradation may not be readily visible unless the floor is thoroughly lighted, cleaned, and accessible. Other modes of degradation, that may not be readily visible, are permeation of the lining by hydrocarbon, delamination, and loss of thickness due to abrasion and/or chemical attack. These modes of degradation may require the use of the other examination techniques in 10.2 to be detected. Following the examinations, the evaluator should apply the criteria in 10.3 to determine if the lining is suitable for service.

10.5 Determining the Cause of Lining Degradation/Failure

If lining degradation is detected, the cause and extent of coating degradation must be established, as well as whether or not the existing lining is suitable for a repair. When evaluating the condition of an existing lining, one should consider whether deterioration is premature or whether the lining has achieved its anticipated performance life.

If degradation or failure of a lining is premature, it is important to understand and address the cause of such degradation prior to determining whether the lining should be repaired, refurbished or completely replaced. A review of the tank's operating history and a visual examination of the lining should be conducted to determine whether the problems were a result of environmental attack, local mechanical damage, and/or if inadequate surface preparation or improper lining installation were contributing factors.

10.6 Lining Repair and Replacement

10.6.1 General

The term "repair" of a lining is typically used when either portions of the lining will be replaced or when all or a portion of the lining will be top coated. The term "replacement" is used when all of the existing lining is completely removed to the steel substrate and a new lining is applied.

10.6.2 Lining Repairs

10.6.2.1 Localized vs General Degradation

The amount of the floor area that has failed or deteriorated and the size of the tank are significant factors in determining whether only portions of, or the entire lining, should be replaced. If only a few, small areas require lining replacement, and the tank is fairly large, it is usually more cost effective to use power tools to achieve the required level of cleanliness and anchor profile depth rather than to introduce abrasive into the tank. For thin-film linings in good condition, open blasting in a tank is not advised as the removal of the abrasive material often damages the existing lining. When new patch plates or other weldments are installed, it is important that the patch plates be properly cleaned and properly profiled in accordance with the lining manufacturer's requirements for immersion service. This is especially true if power tool cleaning is used in lieu of abrasive blast cleaning on the new plates.

10.6.2.2 Spot Repairs

Spot repairs are made when there are only localized failures, such as blisters, pinholes, delamination, or mechanical damage. Usually, the existing lining is removed, the surface is prepared, and lining materials are applied at the failed areas only.

10.6.2.3 Top Coating an Existing Lining

Thick-film reinforced linings can be top coated to extend the life of an existing coating that has good adhesion and integrity. The top coat is applied to ensure the fibers are not exposed to the product. Accepted practice involves removal of contaminants, then brush-blasting and application of one or more top coats. To ensure good adhesion of the repair, the lining manufacturer should be consulted to assess the compatibility of the top coat material with the existing lining. Thin-film and thick-film reinforced and unreinforced linings may be top coated as part of a repair procedure in certain situations. The decision to top coat will depend on the condition of the existing coating and the extent of holidays and coating repairs required.

10.6.2.4 Repair and Top Coating Specifications

Consideration should be given to the lining manufacturer's recommendations when developing the repair specifications. All differences between this RP and any other should be resolved before starting any lining repairs.

10.6.2.5 Lining Removal Methods

Considerations that affect the method of lining removal are:

a) size of repair;

b) type of lining;

c) whether steel is contaminated with oil or chemicals;

d) lead content of liner and regulatory requirements for testing, removal, and disposal.

If the mode of degradation of a thick-film, reinforced lining included delamination, it should be noted that manual removal of the un-adhered laminate is more cost effective.

Care must be taken with manual and power tool removal of linings to avoid damage to the floor and lower shell substrate from gouging. Techniques such as electromagnetic induction and ultrahigh water blasting may be more effective in removing failed laminates and should be considered as an alternative to power tool cleaning or abrasive blasting.

10.6.2.6 Sequence of Contamination Removal vs. Lining Removal by Blasting

Regardless of whether a lining will be completely removed and replaced or will receive spot repairs or top coating, it is important to detect and to identify visible and/or non-visible contaminants. If such contaminants include hydrocarbons, grit blasting without first removing the oily hydrocarbon may adversely affect the new lining's adhesion. If oily hydrocarbon has come into contact with the steel, it is critical that the contaminant be removed before abrasive blasting.

11 Maximizing Lining Service Life by Proper Material Selection and Specification

11.1 General

Corrosion on the product side of the tank bottom is a factor in determining a proper interval between tank inspections. Corrosion protection afforded by an internal lining mitigates the corrosion rate on the product side of the tank bottom and allows the service interval between tank inspections to be maximized.

However, linings do not last forever. Typically, they become less effective over time. The deterioration rate can be fast or slow. Experience has shown that some linings have failed in less than a year and some linings have been found to provide adequate corrosion protection after more than 20 years of service.

11.2 Lining Material Selection

Unless the specifier has experience with a given lining material's performance in a given service, the owner/operator should require verifiable test data along with references supporting the considered material's suitability for the intended service and operating conditions.

11.3 Written Specification

The specification should be job-specific and include a detailed scope, a specific description of the components to be lined, and a list of all responsibilities and tasks of the contractor. As a minimum, the specification should address the relevant aspects covered by NACE No.10/SSPC-PA 6 and NACE No. 11/SSPC-PA 8 as follows:

a) steel plate preparation and weld surface quality;

b) applicator qualifications and submissions;

c) surface preparation, including criteria describing the abrasive; steel cleanliness; anchor profile; removal of dust, salts; and other contaminants; and waste handling and removal;

d) environmental controls;

e) control of solvent vapors;

f) need for wet film thickness measurements;

g) applicable heat curing requirements;

h) dry film thickness range required and criteria as to method of measurement;

i) holiday testing requirements;

j) method for determination of cure;

k) final inspection requirements;

l) labeling or stenciling requirements for lining identification;

m) inspection requirements.

12 Health, Safety, and Environmental

12.1 General

Prior to the application of internal tank linings, proper training of employees regarding health, safety, and environmental procedures and the provision of the necessary supervision and/or inspection throughout the progress of the job is required. Guidance on federal training requirements is given in OSHA 2254. A documented hazard evaluation, as outlined in OSHA 29 *CFR* 1910.132, is required to determine what personal protective equipment (PPE) may be needed.

Users of this RP are responsible for reviewing appropriate health, safety, environmental, and regulatory documents and for determining their applicability in relation to this RP prior to its use. This RP does not address all potential health and safety issues or environmental hazards associated with the use of materials, equipment, and/or operations detailed or referred to within this RP. Users of this RP are also responsible for establishing appropriate health, safety, and environmental protection practices, in consultation with appropriate regulatory authorities, if necessary, to achieve compliance with any existing applicable regulatory requirements prior to the use of this RP.

General health and safety concerns are emphasized in 12.2 through 12.4.

12.2 Tank Entry

All necessary precautions to protect personnel shall be taken before entry and while working in a storage tank. Working in a confined space such as a petroleum storage tank presents special respiratory, explosion, and fire hazards that must be addressed. Tank entry and/or hot work permits should be issued and enforced, as local work rules and applicable regulations require. Guidelines for issuing permits and preparing a tank or confined space for entry are detailed in API 2015 and API 2016, including evaluation of the atmospheric hazards and lockout-tagout of process lines and equipment. Federal, state, and local regulations (or international regulations if applicable) pertaining to confined space entry also should be reviewed and followed to ensure conformance. In the U.S., 29 *CFR* 1910.146 governs permit-required confined spaces under the OSHA General Industry standard.

12.3 Surface Preparation and Lining Application

Health hazards are a prime concern during surface preparation and lining application. Proper respiratory equipment and personal protective clothing should be employed where necessary. Information regarding safety precautions and procedures during surface preparation and lining application are found in SSPC Guide 10.

NOTE This is the general industry standard for ventilation and abrasive blasting shop operations. Most of the provisions do not apply to field conditions. There is no abrasive blasting standard under OSHA Construction Standards.

If lining materials containing or previously exposed to lead are to be removed, special precautions are required to protect both the personnel and the environment. The specific requirements for worker protection from lead can be found in OSHA 29 *CFR* 1926.62. OSHA Construction Industry Standard is more stringent and applies to most tank repair work.

12.4 Manufacturer's Material Safety Data Sheets

The chemical constituents of high performance internal tank lining materials can present health hazards to workers if not handled properly. Material safety data sheets (MSDS) concisely inform employees about the materials being used so that they can protect themselves and respond properly to emergencies.

The purpose of an MSDS is to inform the worker of the following.

a) A material's physical properties, which make it hazardous to handle.

b) The type of personal protective equipment needed.

c) The first aid treatment necessary if exposed to a hazard.

d) The planning needed for safely handling normal operations, as well as emergencies such as spills and fires.

e) The appropriate response to accidents.

The applicable MSDS should be consulted for all materials before conducting any work.

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