CERTIFICATE

By Authority Of
THE UNITED STATES OF AMERICA
Legally Binding Document

By the Authority Vested By Part 5 of the United States Code § 552(a) and Part 1 of the Code of Regulations § 51 the attached document has been duly INCORPORATED BY REFERENCE and shall be considered legally binding upon all citizens and residents of the United States of America. *HEED THIS NOTICE*: Criminal penalties may apply for noncompliance.

Document Name: API 652: Lining of Aboveground Petroleum Storage Tank Bottoms

CFR Section(s): 49 CFR 195.579(d)

Standards Body: American Petroleum Institute

APPROVED

Official Incorporator:
THE EXECUTIVE DIRECTOR
OFFICE OF THE FEDERAL REGISTER
WASHINGTON, D.C.

Lining of Aboveground Petroleum Storage Tank Bottoms

API RECOMMENDED PRACTICE 652
SECOND EDITION, DECEMBER 1997

STEP
Strategies for Today's Environmental Partnership

American Petroleum Institute

Helping You Get The Job Done Right.SM

Strategies for Today's Environmental Partnership

API ENVIRONMENTAL, HEALTH AND SAFETY MISSION AND GUIDING PRINCIPLES

The members of the American Petroleum Institute are dedicated to continuous efforts to improve the compatibility of our operations with the environment while economically developing energy resources and supplying high quality products and services to consumers. We recognize our responsibility to work with the public, the government, and others to develop and to use natural resources in an environmentally sound manner while protecting the health and safety of our employees and the public. To meet these responsibilities, API members pledge to manage our businesses according to the following principles using sound science to prioritize risks and to implement cost-effective management practices:

- To recognize and to respond to community concerns about our raw materials, products and operations.
- To operate our plants and facilities, and to handle our raw materials and products in a manner that protects the environment, and the safety and health of our employees and the public.
- To make safety, health and environmental considerations a priority in our planning, and our development of new products and processes.
- To advise promptly, appropriate officials, employees, customers and the public of information on significant industry-related safety, health and environmental hazards, and to recommend protective measures.
- To counsel customers, transporters and others in the safe use, transportation and disposal of our raw materials, products and waste materials.
- To economically develop and produce natural resources and to conserve those resources by using energy efficiently.
- To extend knowledge by conducting or supporting research on the safety, health and environmental effects of our raw materials, products, processes and waste materials.
- To commit to reduce overall emissions and waste generation.
- To work with others to resolve problems created by handling and disposal of hazardous substances from our operations.
- To participate with government and others in creating responsible laws, regulations and standards to safeguard the community, workplace and environment.
- To promote these principles and practices by sharing experiences and offering assistance to others who produce, handle, use, transport or dispose of similar raw materials, petroleum products and wastes.

Lining of Aboveground Petroleum Storage Tank Bottoms

Manufacturing, Distribution, and Marketing Department

API RECOMMENDED PRACTICE 652
SECOND EDITION, DECEMBER 1997

American Petroleum Institute

Helping You Get The Job Done Right.SM

SPECIAL NOTES

API publications necessarily address problems of a general nature. With respect to particular circumstances, local, state, and federal laws and regulations should be reviewed.

API is not undertaking to meet the duties of employers, manufacturers, or suppliers to warn and properly train and equip their employees, and others exposed, concerning health and safety risks and precautions, nor undertaking their obligations under local, state, or federal laws.

Information concerning safety and health risks and proper precautions with respect to particular materials and conditions should be obtained from the employer, the manufacturer or supplier of that material, or the material safety data sheet.

Nothing contained in any API publication is to be construed as granting any right, by implication or otherwise, for the manufacture, sale, or use of any method, apparatus, or product covered by letters patent. Neither should anything contained in the publication be construed as insuring anyone against liability for infringement of letters patent.

Generally, API standards are reviewed and revised, reaffirmed, or withdrawn at least every five years. Sometimes a one-time extension of up to two years will be added to this review cycle. This publication will no longer be in effect five years after its publication date as an operative API standard or, where an extension has been granted, upon republication. Status of the publication can be ascertained from the API Authoring Department [telephone (202) 682-8000]. A catalog of API publications and materials is published annually and updated quarterly by API, 1220 L Street, N.W., Washington, D.C. 20005.

This document was produced under API standardization procedures that ensure appropriate notification and participation in the developmental process and is designated as an API standard. Questions concerning the interpretation of the content of this standard or comments and questions concerning the procedures under which this standard was developed should be directed in writing to the director of the Authoring Department (shown on the title page of this document), American Petroleum Institute, 1220 L Street, N.W., Washington, D.C. 20005. Requests for permission to reproduce or translate all or any part of the material published herein should also be addressed to the director.

API standards are published to facilitate the broad availability of proven, sound engineering and operating practices. These standards are not intended to obviate the need for applying sound engineering judgment regarding when and where these standards should be utilized. The formulation and publication of API standards is not intended in any way to inhibit anyone from using any other practices.

Any manufacturer marking equipment or materials in conformance with the marking requirements of an API standard is solely responsible for complying with all the applicable requirements of that standard. API does not represent, warrant, or guarantee that such products do in fact conform to the applicable API standard.

FOREWORD

This recommended practice describes the procedures and practices for achieving effective corrosion control in aboveground storage tanks by application of tank bottom linings to existing and to new storage tanks. Legislation and regulations related to the design, installation, operation, and maintenance practices for aboveground petroleum storage systems are under development at the federal, state, and municipal levels. Therefore, the appropriate government agencies should be consulted for regulations that apply prior to taking any action suggested in this recommended practice. API publications may be used by anyone desiring to do so. Every effort has been made by the Institute to assure the accuracy and reliability of the data contained in them; however, the Institute makes no representation, warranty, or guarantee in connection with this publication and hereby expressly disclaims any liability or responsibility for loss or damage resulting from its use or for the violation of any federal, state, or municipal regulation with which this publication may conflict.

Suggested revisions are invited and should be submitted to the Director of Manufacturing, Distribution and Marketing, American Petroleum Institute, 1220 L Street, N.W, Washington, D.C. 20005.

CONTENTS

Page

Tables

Lining of Aboveground Petroleum Storage Tank Bottoms

1 Scope

This recommended practice presents procedures and practices for achieving effective corrosion control in aboveground storage tanks by application of tank bottom linings. It contains provisions for the application of tank bottom linings to both 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 recommended practice 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 recommended practice is intended to serve only as a guide. Detailed tank bottom specifications are not included.

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

2 Referenced Publications

The most recent edition or revision of the following standards, codes, or specifications shall, to the extent specified, form a part of this standard.

API

RP 575	*Inspection of Atmospheric and Low -Pressure Storage Tanks*
Std 620	*Design and Construction of Large, Welded, Low-Pressure Storage Tanks*
Std 650	*Welded Steel Tanks for Oil Storage*
RP 651	*Cathodic Protection of Aboveground Petroleum Storage Tanks*
Std 653	*Tank Inspection, Repair, Alteration, and Reconstruction*
Std 2015	*Safe Entry and Cleaning of Petroleum Storage Tanks*

ASTM[1]

D 2240	*Test Method for Rubber Property-Durometer Hardness*
D 2583	*Test Method for Indentation Hardness of Rigid Plastics by Means of a Barcol Impressor*
D 3363	*Test Method for Film Hardness by Pencil Test*
D 4414	*Practice for Measurement of Wet Film Thickness of Organic Coating by Notch Gauges*
D 4417	*Test Method for Field Measurement of Surface Profile of Blast Cleaned Steel*
D 5402	*Standard Practice for Assessing the Solvent Resistance of Organic Coatings Using Solvent Rubs*

NACE[2]

Ref. Book #1	*Forms of Corrosion Recognition and Prevention, Vol. 1 & 2, Cat. # 37531*
Ref. Book #2	*Corrosion Fatigue, Cat. # 37302*
NACE Publication	*Corrosion Data Survey/Metals, Cat. # 37519*
Comm. Report 6A187	*Reinforced Polyester and Epoxy Linings, Cat # 24082*
Comm. Report 6D163	*A Manual for Painter Safety, Cat. # 24014*
Comm. Report 6F164	*Curing of Interior Tank Linings, Cat. # 24112*
TM-01-74	*Laboratory Methods for the Evaluation of Protective Coatings Used as Lining Materials in Immersion Service*
RP-01-81	*Liquid-Applied Internal Protective Coatings for Oil Field Production Equipment*
RP-01-84	*Repair of Lining Systems*
RP-01-88	*Discontinuity (Holiday) Testing of Protective Coatings*
RP-02-87	*Field Measurement of Surface Profile of Abrasive Blast Cleaned Steel Surfaces Using a Replica Tape*
RP-02-88	*Inspection of Linings on Steel and Concrete*

SSPC[3]

VIS 1	*Visual Standard for Abrasive Blast Cleaned Steel*
PA 1	*Shop, Field, and Maintenance Painting*
PA 2	*Measurement of Dry Paint Thickness with Magnetic Gages*
PA 3	*A Guide to Safety in Paint Application*
SP 1	*Solvent Cleaning*
SP 2	*Hand Tool Cleaning*
SP3	*Power Tool Cleaning*

NACE/SSPC[2,3]

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

[1]American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania 19428-2959

[2]NACE International, P.O. Box 218340, Houston, Texas 77218.

[3]Steel Structures Painting Council, 40 24th Street, 6th Floor, Pittsburgh, Pennsylvania 15222

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

OSHA[4]

29 *CFR* 1926.62 — *Safety and Health Regulation for Construction*

29 *CFR* 1910.134 — *Respiratory Protection*

3 Definitions

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 percent of the tank volume is above surface grade.

3.2 adduct: A curing agent, generally an amine, that has been combined with a portion of the resin, usually an epoxy.

3.3 amine: An organic compound having amino functional groups which provide chemical reactivity and utility as a curative for epoxy and other resins.

3.4 anchor pattern: Surface profile or roughness.

3.5 anode: The electrode of an electrochemical cell at which oxidation (corrosion) occurs. Electrons flow away from the anode in the external circuit. Corrosion usually occurs and metal ions enter the solution at the anode. Antonym: cathode.

3.6 aromatics: Strong hydrocarbon solvents whose chemical structure has an unsaturated ring with delocalized pi electrons. Benzene, toluene, and xylene are common examples of aromatic solvents.

3.7 bisphenol-A polyester: A polyester whose chemical structure incorporates Bisphenol-A into the resin molecule in place of some or all of the glycol. The solid resin is generally provided as a solution in styrene, which acts as a solvent and as a cross-linking agent for the resin.

3.8 cathode: The electrode of an electrochemical cell at which a reduction is the principle reaction. Electrons flow toward the cathode in the external circuit. Antonym: anode.

3.9 cathodic protection: A technique to reduce corrosion of a metal surface by making that surface the cathode of an electrochemical cell.

3.10 coal tar: A black hydrocarbon residue remaining after coal is distilled.

3.11 coal tar epoxy: A coating in which the binder is a combination of coal tar and epoxy resin.

[4]Occupational Safety and Health Administration, U.S. Department of Labor. The *Code of Federal Regulations* is available from the U.S. Government Printing Office, Washington, D.C. 20402

3.12 copolymer: A large molecule whose chemical structure consists of at least two different monomers.

3.13 corrosion: The deterioration of a material, usually a metal, because of a reaction with its environment.

3.14 curing: The setting up or hardening, generally due to a polymerization reaction between two or more chemicals (resin and curative).

3.15 dew point: The temperature at which moisture condenses from the atmosphere.

3.16 differential aeration cell: An electrochemical cell, the electromotive force of which is due to a difference in air (oxygen) concentration at one electrode as compared with that at another electrode of the same material.

3.17 electrochemical cell: A system consisting of an anode and a cathode immersed in an electrolyte so as to create an electrical circuit. The anode and the cathode may be different metals or dissimilar areas on the same metal surface.

3.18 electrolyte: A chemical substance containing ions that migrate in an electric field.

3.19 epoxy: Resin containing epoxide (oxirane) functional groups that allow for curing by polymerization with a variety of curatives. Epoxy resins are usually made from Bisphenol-A and epichlorohydrin.

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

3.21 holiday: A discontinuity in a protective coating that exposes unprotected surface to the environment.

3.22 isophthalic polyester: A resin polymerized from isophthalic acid (or anhydride), ethylene or propylene glycol and malaic acid (or anhydride). The solid resin is generally provided as a solution in styrene, which acts as a solvent and as a cross-linking agent for the resin.

3.23 lining: A coating bonded to the internal surfaces of a tank to serve as a barrier to corrosion by the contained fluids.

3.24 mil: One one-thousandth of an inch (0.001").

3.25 mill scale: An oxide layer formed on steel during hot-forming operations.

3.26 phenolic: A resin of the phenol formaldehyde type.

3.27 polyamide: A resin whose chemical structure contains adjacent carbonyl and amino functional groups that is often used as a curative for epoxy resins. Commercially available polyamides are reaction products of dimerized and trimerized fatty acids and polyamines.

3.28 polyamidoamine: A resin whose chemical structure contains adjacent carbonyl and amino functional groups

that is often used as a curative for epoxy resins. Commercially available polyamidoamines are reaction products of monofunctional fatty acids and amines.

3.29 resin: A natural or synthetic substance that may be used as a binder in coatings.

3.30 vinyl ester: A polyester that usually contains Bisphenol-A in the resin backbone and two vinyl groups for reactivity. The solid resin is generally provided as a solution in styrene, which acts as a solvent and as a cross-linking agent for the resin.

3.31 vinyl group: A functional group on a resin molecule that consists of a carbon-to-carbon double bond at the end of the molecule.

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 crude oil or product service with no water present; however, accelerated 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 or during "breathing" of the tank, often contains corrosive compounds which can cause accelerated attack. For example, crude oil may contain salt water and sediment which settles out on the bottoms of storage tanks. Chlorides and other soluble salts contained in the water may provide a strong electrolyte which can promote corrosion. The common mechanisms of internal storage tank bottom corrosion include:

a. Chemical corrosion.
b. Concentration cell corrosion.
c. Galvanic cell corrosion.
d. Corrosion caused by sulfate-reducing bacteria.
e. Erosion-corrosion.

These are discussed in subsequent paragraphs of this section.

4.2 CHEMICAL CORROSION

Chemical corrosion may occur in environmental and product cleanup tanks as well as in chemical storage facilities. For example, a waste water 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.

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 storage tank bottom may occur at a rate as high as 80 mils 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.

Welding can produce large differences in the microstructure of the steel bottom plate and this can provide 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 CORROSION CAUSED BY SULFATE-REDUCING BACTERIA

Sulfate-reducing bacteria (SRB) are widespread in the petroleum industry. The role of SRB in corrosion is universally recognized but the mechanisms are not well understood. Generally, the effect of SRB on the corrosion of bare steel storage tank bottoms is negligible. In some cases, however, severe corrosion has been attributed to SRB. The SRB colonies form deposits on the steel which 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 SRB is important with regard to the corrosion of storage tank bottoms. SRB are strict anaerobes that do not proliferate in the presence of oxygen; however, the dense bacterial colonies create a local anaerobic condition

(generating oxygen concentration cells) 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. 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 which is then formed 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.

4.6 EROSION-CORROSION IN WATER TREATMENT

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 high localized metal loss in a well-defined pattern.

5 Determination of the Need for Tank Bottom Lining

5.1 GENERAL

Aboveground storage tank bottoms are generally fabricated from carbon steel plate sections that are typically .25 inch (6 millimeters) thick. Annular floor plates of storage tanks frequently have thicker plate sections of .25 to .5 inch (6 to 12 millimeters). 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 bottom plates of aboveground storage tanks are susceptible to internal and external corrosion.

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

a. Corrosion prevention.
b. Tank design.
c. Tank history.
d. Environmental considerations.
e. Flexibility for service change.
f. Upset conditions.
g. Federal, state, and local regulations.

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 Standard 653. An internal tank bottom lining may be deemed necessary if inspection shows that the minimum thickness of the bottom steel plate is less than 0.100 inch (2.5 mm), or if corrosion is expected to proceed so that the steel thickness may reach this minimum thickness prior to the next scheduled inspection.

When utilizing API Standard 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 DESIGN CONSIDERATIONS AND TANK INTERNALS

Existing tanks may have design and fabrication features that would make the application of a lining impractical or that would seriously jeopardize the integrity of a lining. For example, 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 failure by blistering or cracking.

5.4 TANK 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. How fast is corrosion proceeding?
c. Have there been significant changes in the corrosion rate?
d. What type of corrosion is occurring?
e. Has corrosion caused perforation of the steel tank bottom?

5.4.1 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 of the steel bottom may cause an internal bottom lining to fail by cracking.

The tank pad material beneath the steel bottom has a significant effect on underside corrosion. If the particle size of the cushioning material is large, differential aeration cells can form where the particles are in contact with the tank bottom and severe corrosion may result (see API Recommended Practice 651).

5.4.2 Methods of Construction

Irregular surfaces caused by rivets, butt straps, and skip welding 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. Welded tanks generally require less preparation than riveted tanks.

Cone-roof column supports and floating-roof support column landing plates may be necessary to make provisions for impact and wear in the areas where the roof support legs contact the bottom of the tank.

5.4.2.1 Presence of Prior Lining

If an aboveground storage tank has previously been lined, the tank history must be reviewed to determine the suitability and durability of the existing lining. If a new lining is deemed necessary, the new lining must be compatible with the previous lining, as discussed in Section 10.

5.4.2.2 Previous Repairs

The type and extent of previous repairs to the tank (such as internal lap patches or nozzle additions with no back weld) should be taken into consideration.

5.4.2.3 Prior Contents

Determine the cleaning methods and the extent of cleaning required prior to installation of the new lining.

5.5 ENVIRONMENTAL CONSIDERATIONS

Environmental considerations should be weighed when determining the need for a tank bottom lining. A properly applied internal bottom lining provides leak prevention by limiting internal corrosion of the steel tank bottom. Cathodic protection can often provide resistance to soil-side corrosion; however, not all installations are suitable for cathodic protection (see API Recommended Practice 651 for information on cathodic protection).

The following items should be considered in setting priorities for the application of linings to the bottom of aboveground storage tanks:

a. The potential for groundwater contamination in hydrogeologically sensitive areas.

b. Location of facility.

c. Presence and location of containment dikes.

d. Presence of secondary containment and leak detection systems.

5.6 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 10–20 years of service life in 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.

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.

6 Tank Bottom Lining Selection

6.1 GENERAL

Tank bottom linings can generally be divided into two classes: thin films (20 mils or less) and thick films (greater than 20 mils). 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.

6.2 THIN-FILM TANK BOTTOM LININGS

Thin-film tank bottom lining systems are frequently based on epoxy or epoxy-copolymer resins. Table 1 lists several generic types of thin-film linings and their suitability for various stored hydrocarbon and petrochemical products. 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.

Table 1—Thin-Film Tank Bottom Lining Systems

Lining System[a] (resin/curative)	Typical Services	Maximum Temperature Range °F[b]
Coal tar epoxy/amine	Foul water services and crude oil	120-170
Epoxy phenolic/amine	Light products, distillates, aromatics, high purity water, sour products, crude, and gasoline	180-220
Epoxy/amine	Water, light products, distillates, aromatics, crude, and gasoline	160-220
Epoxy/polyamide	Water, distillates, crude, and gasoline	160-180
Epoxy/polyamidoamine	Water, distillates, crude, and gasoline	160-180

Notes:
[a]Generally applied over a white or near-white abrasive blast cleaning in 2–3 coats. No primer is required. Information related to the performance limitations of specific products with regard to chemical immersion and elevated temperatures may be obtained from the lining manufacturer.
[b]For tanks containing a water layer on the bottom, the maximum temperature will be at the lower end of this range for this water immersion service.

Table 2—Thick-Film Tank Bottom Lining Systems

Glass-Reinforced Lining Systems[a]	Typical Services	Maximum Temperature Range °F[b]
Isophthalic Polyester	Water, crude oil, distillates, and gasoline	140-160
Bisphenol-A Polyester	Water, crude oil, distillates, and gasoline	160-180
Vinyl ester	Water, crude oil, aromatics, solvents, alcohols, gasohol, oil, and chemicals	180-220
Epoxy	Water, crude oil, aromatic distillates, and gasoline	180

Notes:
[a]Glass reinforcement includes flake, chopped strand, mat and roving. All applied over a white (NACE No. 1/SSPC-SP 5) or near-white (NACE No. 2/SSPC-SP 10) brasive blast cleaning in 1–4 coats. Primer frequently required. Dependent upon thickness, one or two body coats specified. Resin-rich topcoat or flood coat needed. Polyesters require wax addition to topcoats to ensure timely cure. Information related to the performance limitations of specific products with regard to chemical immersion and elevated temperatures may be obtained from the lining manufacturer.
[b]For tanks containing a water layer on the bottom, the maximum temperature will be at the lower end of this range for this water immersion service.

6.2.1 Advantages and Disadvantages of Thin-Film Linings

Thin-film lining systems are often used for application to the top side of the bottoms of new storage tanks. New steel plates provide a smooth surface that easily can be made ready for lining application. The 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 lower cost and ease of application compared to thick-film lining systems.

6.3 THICK-FILM TANK BOTTOM LININGS

Thick-film linings may be used as tank bottom linings for both new and old storage tanks. Several generic types of thick-film lining systems which are frequently used are listed in Table 2. (See NACE Publication 6A187 for additional information concerning these types of lining systems.) These systems are commonly reinforced with glass flake, chopped glass fibers, glass mat, glass cloth, or organic fibers.

6.3.1 Advantages of Thick Film Lining

Thick-film, reinforced linings are less susceptible to mechanical damage than thin film linings. Thick, glass-reinforced linings can provide sufficient strength to bridge over small perforations of the supporting steel bottom that may develop due to external corrosion. In addition, thick films are not as sensitive to pitting and other surface irregularities during lining installation. For these reasons, on older tanks, where internal corrosion may have occurred, thick-film linings are used in preference to thin-film linings.

Surface preparation is of utmost importance for proper adhesion and longevity of the lining; however, the grinding and removal of sharp corners, edges, offsets, and weld spatter and puttying of extremely rough areas, though still necessary, may not have to be taken to the extreme that is required for thin-film linings. Special consideration must be given to the coving at the transition from the tank bottom to the shell, to prevent cracking of the lining when the tank is put into service. As the tank is loaded, the hoop stress on the shell may cause the lining to crack at the transition from the bottom to the shell if the lining is not properly supported. The manufacturer's instructions for the lining system should be followed in this regard.

6.3.2 Disadvantages of Thick Film Lining

The principal disadvantages of thick-film linings are that they typically require more time and effort to apply, and they are normally more expensive than thin-film tank bottom linings. Also, when a thick-film lining is present, inspection of the steel bottom could be more difficult than when a thin-film

lining is present. Thick film linings are also more prone to cracking if tank bottom flexure occurs due to non-uniform soil support.

6.4 DESIGN OF STORAGE TANK BOTTOM LININGS

Storage tank bottom linings generally cover the entire tank bottom and extend 18–24 inches up the shell of the tank. The design of a lining system should follow the recommendations of the lining manufacturer. Generally, thin-film linings are sufficient for new tanks. For thin-film lining systems, application of 2–3 coats is often required to achieve the desired film thickness. For thick-film lining systems, 1–4 coats may be required to obtain the thickness of the desired lining. For new tanks or for older tanks where only internal corrosion is occurring, 35–55 mil thick linings may be used. For older tank bottoms that have corroded both internally and externally, 80–120 mil thick glass-reinforced linings can be used. Regardless of their thickness, linings should not be used to span perforations in the tank bottom. Minimum bottom thickness should be restored in accordance with API 653 prior to the application of the lining.

6.5 EXCEPTIONAL CIRCUMSTANCES AFFECTING LINING SELECTION

In addition to corrosion history and the potential for corrosion, there may be exceptional circumstances that must be taken into account during the selection of a tank bottom lining. Two of these are elevated temperature operation and product purity considerations.

Temperature (for example, temperature changes generated by steam coils) must be taken into account during the selection of an internal lining system. Storage tanks may operate above ambient temperature in order to maintain low viscosity of the stored product. As temperatures increase, this consideration 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. If this information cannot be obtained from the lining manufacturer, the owner may evaluate linings in accordance with NACE TM-01-74 prior to the selection of the lining system. Tables 1 and 2 list temperature limitations for some common generic lining systems.

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 purity. If selection is made principally on the basis of product purity, thin-film lining systems may be suitable. However, in some circumstances a combination of product purity and corrosion resistance must be considered. For jet fuel tanks there are guidelines (see Military Specification MIL-C-4556D) that can assist the owner in the selection and application of tank bottom lining systems. The owner may also have to evaluate the product immersion liquid to ensure that product contamination by the prospective internal lining will not occur.

7 Surface Preparation

7.1 GENERAL

Surface preparation is a critical part of the lining operation. 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 anchor pattern 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-SP 5) 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. 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 lined.

7.2 PRE-CLEANING

Before blasting, all oil, tar, grease, salt, and other contaminants must be removed from the area to be lined. Solvent cleaning (SSPC-SP1) and high-pressure water or steam cleaning, using the proper chemicals, are effective methods of accomplishing complete hydrocarbon removal. Cleaning is typically followed by a freshwater rinse to ensure complete removal of soluble salts and cleaning chemicals.

7.3 BOTTOM REPAIR AND WELD PREPARATION

The preferred technique for the repair of perforations of the steel tank bottom is welding of steel patches. API Standard 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.

7.4 ABRASIVE BLASTING

Abrasive blasting should not be performed if the temperature of the steel surface is less than 5°F (3°C) above the dew point or if the relative humidity is greater than 80 percent.

The surface to be lined should have the specified surface preparation at the time the lining is applied. If the surface is degraded or contaminated subsequent to surface preparation and prior to lining application, the surface should be restored before lining application.

7.5 SURFACE PROFILE OR ANCHOR PATTERN

If the storage tank bottom is to be cleaned by abrasive blasting, the abrasive should be selected to produce the necessary anchor pattern for the lining to be applied. The lining manufacturer's recommendation for surface profile 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 1.5–4 mils and generally increases with the thickness of the lining.

7.6 TYPES AND QUALITY OF ABRASIVES

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. 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.

8 Lining Application

8.1 GENERAL

For thick-film linings, the manufacturer may specify that the prime coat be applied at a film thickness less than that of the anchor pattern achieved by the abrasive blast cleaning. It is important to follow such requirements to prevent disbonding or delamination of the subsequently applied lining.

Subsequent coats must be applied within the recoat interval recommended by the lining manufacturer and/or as determined by the owner's inspector. Generally, the recommendations and procedures prescribed in SSPC-PA 1 should be followed. After application of the final coat and with sufficient air drying, defect testing (as described in 9.3.2.4) should be carried out. Any defects should be repaired per NACE RP-01-84 and approved by the owner's representative.

8.2 GUIDELINES FOR LINING APPLICATION

SSPC-PA 1 and NACE 6F164 are recommended as general guidelines for good lining application practice. Proper 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 prior to beginning the job.

8.3 TEMPERATURE AND HUMIDITY CONTROL

The temperature of the steel surface should conform to the lining manufacturer's application and curing ranges. As a general rule, the temperature must be at least 5°F (3°C) above the dew point and the relative humidity should be below 80 percent.

8.4 LINING THICKNESS

Insufficient film thickness will not provide adequate coverage or protection. Excessive film thickness 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; thickness should be determined in accordance with the methods outlined in 9.3.2.2. Uniform coverage and thickness of multicoat linings may be facilitated by changing or alternating colors between coats.

8.5 LINING CURING

Improper application and inadequate curing 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 placing the tank in service, the tank lining should be completely cured to obtain optimum service life. The proper curing conditions can be ensured, or forced-curing of the lining may be accomplished by circulating warmed, dehumidified air.

9 Inspection

9.1 GENERAL

Inspection is recommended to ensure that the lining specification has been met. The lining should be inspected during application and upon completion of the work.

9.2 QUALIFICATION OF INSPECTION PERSONNEL

All lining inspectors should be either NACE-certified or persons who have demonstrated a thorough knowledge of coating and lining practices.

9.3 RECOMMENDED INSPECTION PARAMETERS

9.3.1 Inspection Equipment

Recommended equipment for inspection may include the inspection equipment discussed in NACE RP-02-88.

9.3.1.1 Inspection Procedures

Where applicable, the inspection procedures outlined in NACE RP-02-88 should be followed.

9.3.1.2 Surface Cleanliness and Profile

Verification that the specified surface cleanliness and profile have been achieved prior to application of any lining is of utmost importance. SSPC-VIS 1 provides reference photographs and NACE "Visual Comparator for Surface of New Airblast Cleaned with Sand Abrasive," consisting of encapsulated steel reference panels depicting different finished blast conditions, may be used to visually assess surface cleanliness. NACE RP-02-87 provides a method of measuring surface profile. Other types of profile comparators are available from the SSPC and coating instrument vendors.

9.3.1.3 Film Thickness

Soon after lining application, wet film thickness measurements should be made in accordance with ASTM D 4414. After the lining has cured sufficiently to allow handling, dry film thickness measurements should be made in accordance with SSPC PA 2.

9.3.1.4 Hardness

Hardness determinations should be made in accordance with the following procedures as applicable:

a. ASTM D 2583.
b. ASTM D 2240.
c. ASTM D 3363.
d. ASTM D 5402.

9.3.1.5 Lining Discontinuities

Holiday testing of thick film linings shall be carried out with a high-voltage detector in accordance with NACE RP-01-88. Holiday testing of thin-film linings should be performed with a low-voltage (67.5 volts) wet sponge detector.

10 Repair of Tank Bottom Linings

10.1 GENERAL

A properly selected and applied lining should be expected to provide a service life of 10–20 years. When available, tank bottom linings should be thoroughly inspected to determine their condition. Minor repairs may be required. Care should be taken not to damage the lining (especially thin films) during cleaning and inspection. API Standard 653 provides guidance for visual in-service and detailed out-of-service inspection and repair methods for tanks. These inspections may reveal conditions that necessitate lining repair which is not covered in API Standard 653. All repairs to the tank should be completed prior to any repair of the lining. NACE RP-01-84 provides general guidelines for lining repairs to achieve the anticipated service life of the lining system.

10.2 DETERMINE CAUSE OF FAILURE

Before deciding how to repair a lining, the cause and extent of any failure must be established. A review of the tank's operating history and a visual examination of the lining should be conducted to determine whether the lining failed because of mechanical damage or environmental attack and if improper lining installation was a contributing factor.

10.3 TYPES OF REPAIR

There are three basic tank lining repair methods. Selection is based on the condition of the existing bottom lining.

10.3.1 Spot Repairs

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

10.3.2 Topcoating an Existing Lining

Topcoating is done where failure is more extensive but adhesion and integrity of the existing lining are generally good and the protection afforded by the lining has not been severely compromised. Accepted practice involves surface preparation and application of one or more topcoats. To ensure good adhesion of the repair, the lining manufacturer should be consulted to assess the compatibility of new coats with the existing lining.

10.3.3 Complete Relining

Replacement is done where the existing lining is beyond repair. Relining involves complete removal of the existing lining and reapplication of a new one.

10.4 LINING MANUFACTURER'S RECOMMENDATIONS

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

11 Safety

11.1 GENERAL

Prior to the application of internal tank linings, proper training of employees regarding safe work procedures and the provision of the necessary supervision and/or inspection throughout the progress of the job is required.

This section will not attempt to detail all of the safety precautions and procedures required to safely enter a tank, prepare the necessary surfaces for lining, and apply the specified lining material. Some of this information is presented in the

regulatory and industry documents referenced in 9.3 of this document. However, several general safety concerns are emphasized in 11.2 through 11.4.

11.2 TANK ENTRY

All necessary precautions to protect personnel shall be taken prior to the entry of 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 which must be addressed. "Tank entry" and/or "hot work" permits should be issued and enforced as local work rules and codes require. Guidelines for issuing permits and preparing a tank or confined space for entry are detailed in API Standard 2015. Federal and state regulations pertaining to confined space entry also should be consulted.

11.3 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:

a. OSHA Standard for Abrasive Blasting.
b. SSPC PA 3.
c. NACE 6D163.

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 Industry Standard 29 *CFR* 1926.62, "Safety and Health Regulations for Construction."

Relevant federal and state regulations should also be consulted.

11.4 MANUFACTURER'S MATERIAL SAFETY DATA SHEETS

The chemical make-up 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 emergency situations.

The purpose of an MSDS is to tell the worker:

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 prior to conducting any work.