

UL 1746

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Underwriters Laboratories Inc. (UL)
333 Pfingsten Road
Northbrook, IL 60062-2096

UL Standard for Safety
for
External Corrosion Protection Systems for Steel Underground Storage Tanks, UL 1746

Second Edition, Dated July 27, 1993

Revisions: This Standard contains revisions through and including December 16, 1996.

A change is indicated by a note following the affected item. The note is preceded and followed by an asterisk.

The new and/or revised requirements are substantially in accordance with UL's Bulletin on this subject dated October 7, 1996. The bulletin is now obsolete and may be discarded.

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INTRODUCTION

1 Scope

1.1 These requirements cover preengineered corrosion protection systems. Part I covers factory-installed galvanic-type cathodic protection. Part II covers factory assembled composite systems. Part III covers factory assembled jacket systems.

1.2 These corrosion protection systems are intended to be completely installed at the factory on carbon steel underground storage tanks.

1.2 revised September 13, 1996

1.3 Part II of this standard covers fiberglass reinforced plastic (FRP) materials only. Part III of this standard covers FRP and high density polyethylene (HDPE) materials only. The use of other materials or thicknesses requires consideration.

1.3 revised September 13, 1996

1.4 These corrosion protection systems are intended to be installed, operated and maintained in accordance with the manufacturer's instructions.

1.5 A product that contains features, characteristics, component, materials, or systems new or different from those covered by the requirements in this standard, and that involves a risk of fire, electric shock, or injury to persons shall be evaluated using the appropriate additional component and end-product requirements as determined necessary to maintain the acceptable level of safety as originally anticipated by the intent of this standard. A product whose features, characteristics, components, materials, or systems conflict with specific requirements or provisions of this standard cannot be judged to comply with this standard. Where considered appropriate, revision of requirements shall be proposed and adopted in conformance with the methods employed for development, revision, and implementation of this standard.

1.5 revised September 13, 1996

2 General

2.1 Components

2.1.1 Except as indicated in 2.1.2, a component of a product covered by this standard shall comply with the requirements for that component.

2.1.2 A component is not required to comply with a specific requirement that:

- a) Involves a feature or characteristic not required in the application of the component in the product covered by this standard, or
- b) Is superseded by a requirement in this standard.

2.1.2 revised September 13, 1996

2.1.3 A component shall be used in accordance with its recognized rating established for the intended conditions of use.

2.1.4 Specific components are recognized as being incomplete in construction features or restricted in performance capabilities. Such components are intended for use only under limited conditions, such as certain temperatures not exceeding specified limits, and shall be used only under those specific conditions for which they have been recognized.

2.1.5 The identification tests indicated in Supplement A are to be conducted on FRP and HDPE materials used in the construction of composite (Part II) and jacketed (Part III) tanks.

Added 2.1.5 effective January 27, 1995

2.2 Units of measurements

2.2.1 When a value for measurement is followed by a value in other units in parentheses, the first stated value is the requirement.

2.2.1 revised September 13, 1996

2.3 References

2.3.1 Any undated reference to a code or standard appearing in the requirements of this standard shall be interpreted as referring to the latest edition of that code or standard.

2.4 Terminology

2.4.1 In the following text, a requirement that applies only to a particular type of tank is so identified by a specific reference in that requirement to the type or types of tank involved. Absence of such specific reference or use of the term "tank" indicates that the requirement applies to all underground storage tanks unless indicated otherwise.

3 Glossary

3.1 CATHODICALLY PROTECTED TANK – A steel tank with a preengineered, factory installed galvanic type cathodic protection system which provides corrosion protection.

3.2 CLAD – The words "clad" or "cladding" refer to an FRP (fiberglass-reinforced plastic) coating, of substantial (0.100 inch (2.54 mm) or more) thickness, as used for the exterior surface of a Composite Tank (Part II).

3.3 COMPOSITE TANK – A steel tank with a non metallic external cladding bonded to the steel tank which provides for protection against corrosion.

3.4 HOLIDAY – A small fault or pin hole that permits current drainage through the dielectric coating.

3.5 JACKETED TANK – A steel primary tank completely contained within a non metallic external tank jacket which provides both secondary containment and corrosion protection. The non metallic jacket is wrapped 360° circumference on the primary steel tank and forms an interstitial (annular) space which is monitored for leakage.

3.6 revised and combined with 3.5 December 16, 1996

3.6 *Revised and combined with 3.5 December 16, 1996*

CONSTRUCTION

4 General

4.1 The construction and assembly of a corrosion protection system shall be evaluated based on its intended application and use.

4.2 Only new materials and components shall be used in the fabrication of corrosion protection systems for steel underground storage tanks.

4.3 Cathodically protected, composite and jacketed tanks shall be fabricated using steel tank constructions, i.e., welds, joints, heads, bulkheads, fittings, manways, etc., that comply with the Standard for Steel Underground Tanks for Flammable and Combustible Liquids, UL 58.

4.3 revised December 16, 1996

4A Steel Thickness

4A.1 General

4A.1.1 Tanks shall be designed either by using the Roark Equation or shall comply with the External Pressure Test described in 12.6, 16.10 and 20.11.

4A.1.1 effective September 15, 1997

4A.2 Roark Equation

4A.2.1 The calculated pressure from the Roark equation shall be equal to or greater than the external pressure at the bottom of the tank surrounded by only water and submerged 5 feet (1.52 m) or at a depth equal to the manufacturer's specified maximum burial depth, whichever is greater. The buckling pressure shall be calculated using the following equation:

$$\text{Roark equation: } P = [.807 E_s t_s^2 / (Lr)] [(1 - u^2)^{-3} (t_s / r)^2]^{.25}$$

in which:

P is the buckling pressure, psi

E_s is the modulus of elasticity of steel (29.5×10^6 psi for structural grade A36 carbon steel)

t_s is the thickness of steel tank shell (inches)

L is the length of tank (inches)

r is the radius of tank (inches), and

u is the Poisson's Ratio (0.287 for structural grade A36 carbon steel)

Reference: Roark's Formulas for Stress and Strain, 6th Edition, Warren Young, Table 35, Case 19b, Page 690.

4A.2.1 effective September 15, 1997

4A.2.2 Using the Roark formula, the minimum steel shell thickness ($t_{s \min}$) or the maximum tank length ($L_{\max}$) can be calculated using the following equations, respectively:

$$t_{s \min} = [(P_1 L r^{3/2} (1 - u^2)^{3/4}) / (.807 E_s)]^4$$

$$\text{or } L_{\max} = [.807 E_s t_s^2 / P_1 r] [(1 - u^2)^{-3} (t_s / r)^2]^{.25}$$

in which:

P_1 is the calculated external pressure at the bottom of a submerged tank in water, psi. The water depth equals 5 feet (1.52 m) or the maximum burial depth for the tank, whichever is greater, plus the tank diameter.

E_s is the modulus of elasticity of steel (29.5×10^6 psi for structural grade A36 carbon steel)

t_s is the thickness of steel tank shell (inches)

L is the length of tank (inches)

r is the radius of tank (inches), and

u is the Poisson's Ratio (0.287 for structural grade A36 carbon steel)

Note – Values for " E_s " and " u " for other than A36 structural grade carbon steel shall be from recognized technical reference books or established by an engineering evaluation of the material.

4A.2.2 effective September 15, 1997

4A.2.3 The Roark equation applies to commercial or structural grade A36 carbon steel and Type 304 or 316 stainless steel as described in the Standard for Steel Underground Tanks for Flammable and Combustible Liquids, UL 58.

4A.2.3 effective September 15, 1997

4A.2.3.1 When the external pressure test, described in 12.6, 16.10 and 20.11 is conducted successfully, the minimum steel thickness for the shell is reduced 25% from the calculated value using the Roark equation for the same length and diameter tanks.

Added 4A.2.3.1 effective September 15, 1997

4A.2.4 The minimum steel thickness for a primary tank is 0.123 inches (3.12 mm). The minimum steel thickness for a secondary tank is 0.093 inches (2.36 mm).

4A.2.4 effective September 15, 1997

4A.2.5 The minimum head thicknesses for all tanks, except the outer head of Type I tanks, are noted in Table 4A.1. The minimum head thicknesses for the outer head of Type I tanks are noted in Table 4A.2.

Revised 4A.2.5 effective September 15, 1997

Table 4A.1
Tank head thickness

Tank diameter,		Minimum head thickness,	
Inches	m	Inches	mm
Up to 64	Up to 1.62	.123	3.12
64.1 to 90	1.63 to 2.28	.167	4.24
90.1 to 126	2.29 to 3.20	.240	6.10
126.1 to 144	3.20 to 3.66	.302	7.67

Table 4A.1 effective September 15, 1997

Table 4A.2
Type I tank outer head thickness

Tank Diameter		Minimum Head Thickness	
Inches	m	Inches	mm
Up to 64	Up to 1.62	0.123	(3.12)
64.1 to 96	1.63 to 2.44	0.167	(4.24)
96.1 to 144	2.45 to 3.66	0.240	(6.10)

Added Table 4A.2 effective September 15, 1997

4A.2.6 The equivalent steel thickness for a Type I double wall steel tank is $(t_{\text{inner}}^{2.5} + t_{\text{outer}}^{2.5})^{.4}$. This value is substituted into the Roark Equation. For a given water head, radius and steel thickness, the corresponding permissible tank length is then calculated.

4A.2.6 effective September 15, 1997

4A.2.7 The steel thicknesses for the inner and outer walls of a Type II tank are calculated independently (not summed) using the Roark Equation.

4A.2.7 effective September 15, 1997

4A.2.8 The equivalent steel thickness (t_{equiv}) for a composite tank (FRP Clad) is calculated as follows:

$$t_{equiv} = (12I_x)^{1/3}$$

$$\text{where } I_x = wt_f^3 / 12 + wt_f (t_s + (t_f / 2) - y_n)^2 + t_s^3 / 12 + t_s (y_n - (t_s / 2))^2$$

$$y_n = (wt_f (t_s + t_f / 2) + t_s^2 / 2) / (wt_f + t_s)$$

in which:

I_x is the moment of inertia about the neutral axis

y_n is the distance to neutral axis (inches)

t_f is the thickness of cladding (inches)

t_s is the thickness of steel tank shell (inches)

w is the equivalent width of cladding (E_f/E_s)

E_s is the modulus of steel (29.5×10^6 psi for structural grade A36 carbon steel), and

E_f is the modulus of FRP cladding

4A.2.8 effective September 15, 1997

4A.2.9 The buckling resistance that an FRP or thermoplastic jacket (jacketed tank) provides is calculated using the Roark Equation with the appropriate material modulus. The buckling pressures of the tank and jacket are calculated independently and then summed together.

4A.2.9 effective September 15, 1997

4A.3 Stiffeners

4A.3.1 With the addition of one stiffener at the midpoint of a tank, the tank length can be increased 25%. When two stiffeners are placed at the 1/3 and 2/3 positions of a tank, the tank length can be increased 40%. The overall length of a tank shall not be greater than six times its diameter. Other arrangements of stiffeners will require an engineering evaluation.

4A.3.1 effective September 15, 1997

4A.3.2 Stiffeners shall be intermittently welded and extend 360 degrees around the tank. The stiffeners shall have an opening at the top and bottom so that liquid and vapor can move past the stiffener.

4A.3.2 effective September 15, 1997

4A.3.3 The minimum required moment of inertia (I_{req}) of the stiffener is described below:

$$I_{req} = 0.11PLD^3 / E_s \text{ in}^4$$

in which:

P is the calculated external pressure at the bottom of a submerged tank in water (psi). The water depth equals 5 feet (1.52 m) or the maximum burial depth for the tank, whichever is greater, plus the tank diameter.

L is the rib spacing (inches)

D is the outer diameter of tank (inches), and

E_s is the modulus of elasticity of steel (29.5×10^6 psi for structural grade A36 steel)

The moment of inertia of the stiffener shall be verified from tables or calculations from recognized technical reference books, or the tank with stiffeners shall be subjected to the External Pressure Test, Section 16.10.

Revised 4A.3.3 effective September 15, 1997

4A.3.4 A bulkhead is to be treated as a stiffener.

Added 4A.3.4 effective September 15, 1997

4A.3.5 The minimum steel thickness of a tank with stiffeners shall be in accordance with 4A.2.4 and 4A.2.5.

Added 4A.3.5 added September 15, 1997

No Text on This Page

16.4.2 Following this test, the tank is to be subjected to the holiday and leakage tests specified in 16.6.1 – 16.7.2.

16.5 Tank impact test

16.5.1 There shall be no damage to the tank as indicated by a crack, debonding, delamination visible from the outside, or detection of holidays (per 16.7.1 and 16.7.2) at impact heights of 40 inches (1016 mm) or less. There shall be no breaking of pieces, separation of cladding, uplift of cladding, or puncture with impact heights greater than 40 inches (1016 mm) and less than 72 inches (1829 mm). Holidays shall not occur unless they are a result of an impact at a height greater than 40 inches (1016 mm) and less than 72 inches (1829 mm).

16.5.1 revised September 13, 1996

16.5.2 A representative sample tank is to be subjected to blows from a 12 pound (5.4 kg) steel ball swung on a 6 foot (1.8 m) tether. The tether is to be fixed at a point directly above the impact point and the ball swung backward and up away from the tank to the indicated distance measured vertically above the point of impact and then allowed to swing freely to the tank. The vertical height above the impact point is to be varied from 10 to 72 inches (254 to 1829 mm) with no two impacts on the same point. Both head and shell are to be tested.

16.5.3 Following this test, the tank is to be subjected to the leakage test and the holiday test specified in 16.6.1 – 16.7.2.

16.6 Leakage test

16.6 revised September 13, 1996

16.6.1 There shall be no leakage when a complete composite tank assembly, including fittings and manways, is pressurized with air to 5 psig (34 kPa) and brushed or sprayed with a leak-detection solution.

16.6.2 Formulation of sustained bubbles is evidence of leakage.

16.7 Tank examination and holiday test

16.7.1 Following each of the tests specified in this section the complete tank assembly is to be physically examined for damage.

16.7.2 A complete tank assembly is to be subjected to a holiday test using a 35,000 volt electrical resistance holiday detector.

16.8 Water load test

Deleted 16.8 effective September 15, 1997

16.9 Earth load test

Deleted 16.9 effective September 15, 1997

16.10 External pressure test

Revised 16.10 effective September 15, 1997

16.10.1 The tank shall not leak, collapse, implode or buckle (defined as deflection of 5% of the tank diameter) when subjected to the External Pressure test described in 16.10.2. The tank selected shall represent the worst case for the range of tank sizes under evaluation.

16.10.2 An empty tank is to be installed in a test fixture that will facilitate the tank to be submerged in water. The support structure for the test tank shall not add additional tensile or compressive stresses to the bottom of the test tank. Clean water is then added to the test fixture until the tank is submerged 5 feet (1.52 m) or to a depth equal to the manufacturer's specified maximum burial depth, whichever is greater. The tank is to remain submerged for 1 hour and the pressure inside the tank is to be maintained at atmospheric pressure for the duration of the test.

Added 16.10.2 effective September 15, 1997

PART III – JACKETED TANKS

CONSTRUCTION

17 Components

17.1 Jacketed tank corrosion protection systems shall consist of a steel tank with a nonmetallic external FRP or thermoplastic jacket and caps to cover external attachments (such as lift lugs) and unused tank openings. The tank and jacket are separated by an interstitial space with the jacket acting as a secondary containment barrier.

17.2 *Deleted September 13, 1996*

17.3 Nonmetallic external FRP or thermoplastic jackets shall be fabricated using material at least 0.100 inch (2.5 mm) thick.

17.4 These tanks shall have provisions for monitoring the annular space for leakage.

PERFORMANCE

18 Physical Properties of Materials Tests

18.1 General

18.1.1 Samples representative of the manufacturing process are to be used for these tests. Sample requirements for fiber reinforced plastic jacketed tank systems are specified in Table 18.1. Sample requirements for thermoplastic material are specified in Table 18.2.

24.3 A pressure-sensitive label or a label secured by cement or adhesive shall comply with the applicable requirements for "Outdoor" use labels in the Standard for Marking and Labeling Systems, UL 969.

24.4 Each cathodically protected tank, and its installation instruction sheet, shall be marked with the following (or equivalent):

- a) "DO NOT REMOVE OR CROSSTHREAD NONMETALLIC ISOLATING BUSHING/GASKET."
- b) "DO NOT DISCONNECT ANODE LEAD WIRE(S)."
- c) "RUN TEST STATION WIRE TO SURFACE."
- d) "REMOVE ANY PLASTIC COVERING TO EXPOSE ANODE ASSEMBLY PRIOR TO INSTALLATION. FAILURE TO DO THIS RENDERS THE CATHODIC PROTECTION INEFFECTIVE."

24.4 revised September 13, 1996

24.5 In addition to the statements specified in 24.4, the installation instructions for each cathodically protected tank shall include the following statements or the equivalent:

- a) "THIS TANK IS TO BE MONITORED AND INSPECTED FOR PROPER OPERATION WITHIN 6 MONTHS OF INSTALLATION AND THEREAFTER IN ACCORDANCE WITH FEDERAL AND LOCAL REGULATIONS."
- b) "WHEN TANK-TO-SOIL POTENTIAL IS LESS THAN -0.85 V, CONTACT CATHODIC PROTECTION SYSTEM MANUFACTURER."

24.5 revised September 13, 1996

24.6 Each tank shall be marked with the following (or equivalent):

- a) "FOLLOW INSTALLATION INSTRUCTIONS."
- b) "LIFT TANK ONLY WITH LIFT FITTINGS PROVIDED." (For tanks with lift lugs)

24.6 revised December 16, 1996

24.7 When a manufacturer produces tanks at more than one factory, each tank shall have a distinctive marking to identify it as the product of a particular factory.

24.7 revised September 13, 1996

24.8 When a pressure or vacuum monitoring system is used the tank shall be marked:

- a) "Maximum Pressure ____ psig. Do Not Pressure Test Until Backfilled"; or
- b) "Maximum Vacuum ____ In. Hg."

24.8 revised September 13, 1996

24.9 Each tank shall be marked with the maximum burial depth.

Added 24.9 effective September 15, 1997

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INTRODUCTION

1 Scope

1.1 These requirements cover preengineered corrosion protection systems. Part I covers factory-installed galvanic-type cathodic protection. Part II covers factory assembled composite systems. Part III covers factory assembled jacket systems.

1.2 These corrosion protection systems are intended to be completely installed at the factory on carbon steel underground storage tanks.

1.2 revised September 13, 1996

1.3 Part II of this standard covers fiberglass reinforced plastic (FRP) materials only. Part III of this standard covers FRP and high density polyethylene (HDPE) materials only. The use of other materials or thicknesses requires consideration.

1.3 revised September 13, 1996

1.4 These corrosion protection systems are intended to be installed, operated and maintained in accordance with the manufacturer's instructions.

1.5 A product that contains features, characteristics, component, materials, or systems new or different from those covered by the requirements in this standard, and that involves a risk of fire, electric shock, or injury to persons shall be evaluated using the appropriate additional component and end-product requirements as determined necessary to maintain the acceptable level of safety as originally anticipated by the intent of this standard. A product whose features, characteristics, components, materials, or systems conflict with specific requirements or provisions of this standard cannot be judged to comply with this standard. Where considered appropriate, revision of requirements shall be proposed and adopted in conformance with the methods employed for development, revision, and implementation of this standard.

1.5 revised September 13, 1996

2 General

2.1 Components

2.1.1 Except as indicated in 2.1.2, a component of a product covered by this standard shall comply with the requirements for that component.

2.1.2 A component is not required to comply with a specific requirement that:

- a) Involves a feature or characteristic not required in the application of the component in the product covered by this standard, or
- b) Is superseded by a requirement in this standard.

2.1.2 revised September 13, 1996

2.1.3 A component shall be used in accordance with its recognized rating established for the intended conditions of use.

2.1.4 Specific components are recognized as being incomplete in construction features or restricted in performance capabilities. Such components are intended for use only under limited conditions, such as certain temperatures not exceeding specified limits, and shall be used only under those specific conditions for which they have been recognized.

2.1.5 The identification tests indicated in Supplement A are to be conducted on FRP and HDPE materials used in the construction of composite (Part II) and jacketed (Part III) tanks.

Added 2.1.5 effective January 27, 1995

2.2 Units of measurements

2.2.1 When a value for measurement is followed by a value in other units in parentheses, the first stated value is the requirement.

2.2.1 revised September 13, 1996

2.3 References

2.3.1 Any undated reference to a code or standard appearing in the requirements of this standard shall be interpreted as referring to the latest edition of that code or standard.

2.4 Terminology

2.4.1 In the following text, a requirement that applies only to a particular type of tank is so identified by a specific reference in that requirement to the type or types of tank involved. Absence of such specific reference or use of the term "tank" indicates that the requirement applies to all underground storage tanks unless indicated otherwise.

3 Glossary

3.1 CATHODICALLY PROTECTED TANK – A steel tank with a preengineered, factory installed galvanic type cathodic protection system which provides corrosion protection.

3.2 CLAD – The words "clad" or "cladding" refer to an FRP (fiberglass-reinforced plastic) coating, of substantial (0.100 inch (2.54 mm) or more) thickness, as used for the exterior surface of a Composite Tank (Part II).

3.3 COMPOSITE TANK – A steel tank with a non metallic external cladding bonded to the steel tank which provides for protection against corrosion.

3.4 HOLIDAY – A small fault or pin hole that permits current drainage through the dielectric coating.

3.5 JACKETED TANK – A steel primary tank completely contained within a non metallic external tank jacket which provides both secondary containment and corrosion protection.

3.6 SECONDARY CONTAINMENT – A non metallic jacket wrapped 360° circumference of the primary steel tank forming an interstitial (annular) space which is monitored for leakage.

3.6 revised September 13, 1996

CONSTRUCTION

4 General

4.1 The construction and assembly of a corrosion protection system shall be evaluated based on its intended application and use.

4.2 Only new materials and components shall be used in the fabrication of corrosion protection systems for steel underground storage tanks.

4.3 Cathodically protected, composite and jacketed tanks shall be fabricated using steel tank constructions, i.e., welds, joints, fittings, manways, etc., that comply with the Standard for Steel Underground Tanks for Flammable and Combustible Liquids, UL 58.

4.3 added September 13, 1996

4A Steel Thickness

Added Section 4A effective September 15, 1997

4A.1 General

4A.1.1 Tanks shall be designed either by using the Roark Equation or shall comply with the External Pressure Test described in 12.6, 16.10 and 20.11.

4A.2 Roark Equation

4A.2.1 The calculated pressure from the Roark equation shall be equal to or greater than the external pressure at the bottom of the tank surrounded by only water and submerged 5 feet (1.52 m) or at a depth equal to the manufacturer's specified maximum burial depth, whichever is greater. The buckling pressure shall be calculated using the following equation:

$$\text{Roark equation: } P = [.807E_s t_s^2 / (Lr)] [(1 - u^2)^{-3} (t_s / r)^2]^{.25}$$

P = buckling pressure, psi

E_s = modulus of elasticity of steel (29.5×10^6 psi for structural grade A36 carbon steel)

t_s = thickness of steel (inches)

L = length of tank (inches)

r = radius of tank (inches)

u = Poisson's Ratio (0.287 for structural grade A36 carbon steel)

Reference: Roark's Formulas for Stress and Strain, 6th Edition, Warren Young, Table 35, Case 19b, Page 690.

4A.2.2 Using the Roark formula, the minimum steel thickness ($t_{s \min}$) or the maximum tank length ($L_{\max}$) can be calculated using the following equations, respectively:

$$t_{s \min} = [(P_1 L r^{3/2} (1 - u^2)^{3/4}) / (.807 E_s)]^4$$

$$\text{or } L_{\max} = [.807 E_s t_s^2 / P_1 r] [(1 - u^2)^{-3} (t_s / r)^2]^{.25}$$

P_1 = calculated external pressure at the bottom of a submerged tank in water, psi. The water depth equals 5 feet (1.52 m) or the maximum burial depth for the tank, whichever is greater, plus the tank diameter.

E_s = modulus of elasticity of steel (29.5×10^6 psi for structural grade A36 carbon steel)

t_s = thickness of steel (inches)

L = length of tank (inches)

r = radius of tank (inches)

u = Poisson's Ratio (0.287 for structural grade A36 carbon steel)

Note – Values for " E_s " and "u" for other than A36 structural grade carbon steel shall be from recognized technical reference books or established by an engineering evaluation of the material.

4A.2.3 The Roark equation applies to commercial or structural grade A36 carbon steel and Type 304 or 316 stainless steel as described in the Standard for Steel Underground Tanks for Flammable and Combustible Liquids, UL 58.

4A.2.4 The minimum steel thickness for a primary tank is 0.123 inches (3.12 mm). The minimum steel thickness for a secondary tank is 0.093 inches (2.36 mm).

4A.2.5 The minimum head thicknesses for primary and secondary tanks are noted in Table 4A.1.

Table 4A.1
Tank head thickness

Tank diameter,		Minimum head thickness,	
Inches	m	Inches	mm
Up to 64	Up to 1.62	.123	3.12
64.1 to 90	1.63 to 2.28	.167	4.24
90.1 to 126	2.29 to 3.20	.240	6.10
126.1 to 144	3.20 to 3.66	.302	7.67

4A.2.6 The equivalent steel thickness for a Type I double wall steel tank is $(t_{\text{inner}}^{2.5} + t_{\text{outer}}^{2.5})^{.4}$. This value is substituted into the Roark Equation. For a given water head, radius and steel thickness, the corresponding permissible tank length is then calculated.

4A.2.7 The steel thicknesses for the inner and outer walls of a Type II tank are calculated independently (not summed) using the Roark Equation.

4A.2.8 The equivalent steel thickness (t_{equiv}) for a composite tank (FRP Clad) is calculated as follows:

$$t_{\text{equiv}} = (12/I_x)^{1/3}$$

$$\text{where } I_x = wt_f^3 / 12 + wt_f (t_s + (t_f / 2) - y_n)^2 + t_s^3 / 12 + t_s (y_n - (t_s / 2))^2$$

$$y_n = (wt_f (t_s + t_f / 2) + t_s^2 / 2) / (wt_f + t_s)$$

I_x = moment of inertia about the neutral axis

y_n = distance to neutral axis (inches)

t_f = thickness of cladding (inches)

t_s = thickness of steel (inches)

w = equivalent width of cladding (E_f/E_s)

E_s = modulus of steel (29.5×10^6 psi for structural grade A36 carbon steel)

E_f = modulus of FRP cladding

4A.2.9 The buckling resistance that an FRP or thermoplastic jacket (jacketed tank) provides is calculated using the Roark Equation with the appropriate material modulus. The buckling pressures of the tank and jacket are calculated independently and then summed together.

4A.3 Stiffeners

4A.3.1 With the addition of one stiffener at the midpoint of a tank, the tank length can be increased 25%. When two stiffeners are placed at the 1/3 and 2/3 positions of a tank, the tank length can be increased 40%. The overall length of a tank shall not be greater than six times its diameter. Other arrangements of stiffeners will require an engineering evaluation.

4A.3.2 Stiffeners shall be intermittently welded and extend 360 degrees around the tank. The stiffeners shall have an opening at the top and bottom so that liquid and vapor can move past the stiffener.

4A.3.3 The minimum required moment of inertia (I_{req}) of the stiffener is described below:

$$I_{req} = 0.11PLD^3 / E_s \text{ in}^4$$

P = calculated external pressure at the bottom of a submerged tank in water (psi). The water depth equals 5 feet (1.52 m) or the maximum burial depth for the tank, whichever is greater, plus the tank diameter.

L = rib spacing (inches)

D = outer diameter of tank (inches)

E_s = modulus of elasticity of steel (29.5×10^6 psi for structural grade A36 steel)

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PART I – PREENGINEERED CATHODIC PROTECTION SYSTEMS**CONSTRUCTION****5 Components****5.1 Galvanic anodes**

5.1.1 A galvanic anode for use in a cathodic protection system shall be one of the following:

a) High-purity zinc anode with the composition specified in Table 5.1 and complying with ASTM B418-88(Type II), Specification for Cast and Wrought Galvanic Zinc Anodes for Use in Saline Electrolytes, or

b) Magnesium anode with one of the compositions specified in Table 5.2.

Table 5.1
Zinc anodes

Element	Percent Composition
Aluminum	0.005 maximum
Cadmium	0.003 maximum
Iron	0.0014 maximum
Zinc	Remainder

Table 5.2
Magnesium anodes

Element	Percent composition	
	Type III ^a	MG-MN Alloy ^b
Aluminum	5.3 – 6.7	0.010 maximum
Zinc	2.5 – 3.5	0.05
Manganese	0.15 minimum	0.5 – 1.30
Copper	0.02 maximum	0.02 maximum
Silicon	0.10 maximum	0.05
Iron	0.003 maximum	0.03 maximum
Nickel	0.002 maximum	0.001 maximum
Others	0.3 maximum	0.05 each or 0.3 maximum total
Magnesium	Remainder	Remainder
^a These anodes are commonly referred to as AZ-63 Type I, II, and III H1.		
^b High-potential anode		

5.1.2 Anodes shall be packaged in a water-permeable container and the assembly shall comply with the Anode Assembly Durability Test specified in Section 7. Anodes shall be surrounded by at least 1 inch (25.4 mm) of backfill mixture complying with the requirements of 5.2.1.

5.1.3 A cored anode shall be fabricated with a galvanized steel core situated axially within the anode.

5.1.4 A cored anode shall be provided with a No. 12 AWG Type TW or larger solid conductor copper lead wire soldered or welded to the core. The anode lead wire shall comply with the gasoline- and oil-resistance requirements of the Standard for Thermoplastic-Insulated Wires and Cables, UL 83. The lead wire-anode joint shall be insulated by filling the joint recess with an electrical potting compound.

5.1.5 A weld-on anode shall be provided with an integral weldable steel core for welding directly to the tank.

5.2 Backfill materials

5.2.1 Backfill material, used in the "bag" around the anode, shall be a low-resistivity mixture consisting of:

- a) 75 percent hydrated gypsum, 20 percent bentonite, and 5 percent anhydrous sodium sulfate by weight; or
- b) An equivalent mixture that provides a backfill resistivity of 50 ohm-cm or less and which provides equivalent resistance to anode passivation.

5.3 Insulating devices (bushings and gaskets)

5.3.1 Insulating devices shall be fabricated of nonconductive materials and shall comply with Section 11, Tests for Insulating Devices (Bushings and Gaskets). These insulating devices shall electrically isolate the tank from attached piping.

5.4 Dielectric coatings test

5.4.1 Dielectric coatings shall comply with the requirements in Section 10, Dielectric Coatings.

5.5 Pressure wire connectors

5.5.1 The clamping movement of a connector shall be constructed in such a manner that it is capable of accepting a wire size of at least No. 12 AWG (3.3 mm²).

5.5.2 Examples of clamping means include:

- a) Direct-bearing screws with or without use of a pressure plate.
- b) A pressure plate and a screw.
- c) Deformation of the connector barrel (crimping) using a special tool, or
- d) A nut threaded onto a split screw.

5.5.2 revised September 13, 1996

5.5.3 There shall be no sharp edges or corners on the outer edge of a connector.

5.5.3 revised September 13, 1996

5.5.4 A pressure wire connector shall comply with the Pullout Test specified in Section 8.

5.6 Test station provision

5.6.1 Each tank fitted with a preengineered cathodic protection system shall be provided with a factory installed test lead or pressure wire connector welded to the tank heads or upper 3/4 portion of the tank shell, for connection to a test station. The connector shall comply with the requirements in Section 8, Torque and Pullout Tests for Pressure Wire Connectors.

6 Cathodic Protection System Assembly

6.1 General

6.1.1 Preengineered cathodic protection system shall consist of the following components:

- a) Dielectric coating
- b) Electrical insulating devices (bushings and gaskets)
- c) Galvanic anodes
- d) Test station provision

6.1.2 Cathodic protection systems shall be constructed to provide a minimum system design based upon a 4000 ohm-cm soil resistivity.

6.2 Dielectric coatings

6.2.1 Dielectric coatings shall be applied to all exposed exterior tank surfaces, including attachments such as anode holders and attachment lugs. Crevices into which the coating does not penetrate or is not properly bonded shall be seal-welded prior to application of the coating.

6.2.1 revised September 13, 1996

6.3 Electrical isolation devices

6.3.1 All tank openings shall be supplied with electrical insulating devices (bushings or gaskets) installed prior to shipment.

6.3.2 Tank openings and insulating devices shall be closed with a wooden plug, metal cover, or equivalent to protect the threads or flange and gasket face from damage and to exclude foreign material while the tank is in storage or transit.

6.4 Galvanic anodes

6.4.1 The effective coverage radius of galvanic anodes as used in this standard shall be 17 feet (5.2 m). Therefore, tanks greater than 34 feet (10.4 m) long require both head- and shell-mounted anode assemblies.

6.4.2 A minimum of two anodes shall be installed on each tank. Anodes shall be mounted a distance of one-sixth the tank diameter from the tank bottom. Multiple head-mounted anodes shall be centered about this location.

Exception: Shell-mounted anodes shall not be mounted in other positions when required for shipping purposes unless they are mounted below the diametrical midpoint of the tank.

6.4.2 revised September 13, 1996

6.4.3 Anodes shall be located so as to distribute the anode system current uniformly about the length of the tank. When the tank length is 34 feet (10.4 m) or less, anodes shall be equally distributed on each head of the tank. When the tank length is greater than 34 feet (10.4 m), anodes shall be equally distributed on the tank heads and shell.

6.4.3 revised September 13, 1996

6.4.4 Galvanic anode requirements for each tank are to be calculated in accordance with the method specified in 6.4.5 – 6.4.8, or by a method shown to be equivalent by test or derivation.

6.4.5 The sum of the available anode current for the individual anode shall be equal to or greater than the total system current requirements. The total system current requirement is to be calculated as follows:

$$I = 0.025 \times 10^{-3} \frac{\text{amperes}}{\text{ft}^2} \times A$$

where:

I = total system current requirement, amperes

A = total tank exterior surface area including welded-on attachments, square feet

6.4.6 The resistance of galvanic anodes in soil shall be calculated by the following equation:

$$R = \frac{250.4 \times (\ln (4 \times L/r) - 1)}{L}$$

where:

R = anode resistance, ohms

L = anode length, inches

r = equivalent radius, inches = radius of cylindrical anodes, or square root (A/π) for noncylindrical anodes

A = cross-sectional area of anode, square inches

6.4.7 Available galvanic anode current shall be calculated on the basis of anode-cathode driving potential and the resistance of the anode in soil as follows:

$$i = \frac{EC - EA}{R}$$

where:

i = available anode current, amperes

EC = cathode solution potential, volts = minus 0.85 volts

EA = anode solution potential, volts as specified in Table 6.1

R = anode resistance, ohms

6.4.8 The galvanic anode weight shall be greater than the value determined by the following equation:

$$W = \frac{262,800 \times i}{C \times N \times U}$$

where:

W = minimum required anode weight, pounds

i = available anode current, amperes

See Table 6.1 for definition and values of C , N , and U .

Table 6.1
Anode data

Item	Anode type		
	Zinc	Magnesium	
		AZ-63	Mg-Mn
C	372	1000	1000
N	0.9	0.50	0.50
U	0.85	0.85	0.85
EA	-1.1	-1.55	-1.73

C – Anode energy capability, ampere-hours per pound.
 N – Anode efficiency.
 U – Anode utilization factor.
 EA – Anode solution potential, volts.

6.4.9 The lead wire of cored anodes shall be: thermite-welded; brazed or; mechanically fastened to the tank using a weldable steel pressure wire connector complying with the requirements of Section 8, Torque and Pullout Tests for Pressure Wire Connectors. Prior to connecting the lead wire or pressure connector to the tank, the weld area is to be cleaned by scraping or an equivalent method. Anodes shall be installed with a loop consisting of at least 8 inches (203 mm) of free wire to provide strain relief.

6.4.9 revised September 13, 1996

6.4.10 Cored anodes shall be secured to the tank by means of anode holder assemblies complying with Section 7, Anode Pull and Durability Test.

6.4.11 Wire connectors and any exposed bare lead wire conductor shall be covered with insulating tape complying with the requirements for weather resistant insulating tape as described in the Standard for Insulating Tape, UL 510, or equivalent means.

6.4.12 Weld-on anodes shall be seal-welded directly to the tank. Weld-on anodes shall be installed with a gap of at least 2 inches (50.8 mm) between the anode and the tank.

PERFORMANCE

7 Anode Pull and Durability Tests

7.1 Anode lead wire pull test

7.1.1 The lead wire of the anode shall withstand a direct pull of 70 pounds (311 N) for a period of 1 minute. The test is to be performed using a tension-testing machine, or equivalent, that increases the force gradually until the test force is achieved.

7.1.1. revised September 13, 1996

7.2 Anode assembly durability test

7.2.1 An anode assembly shall not become inoperable nor shall the anode shift to a position closer than 0.50 inch (12.7 mm) from the container wall after being subjected to the durability test described in 7.2.2.

7.2.2 A representative anode assembly is to be first centered, soaked in water for a period of 4 hours and then allowed to dry for a minimum period of 48 hours. The packaged anode assembly is then to be mounted onto a fixture simulating its attachment to a tank. The test fixture is to be mounted onto a vibration test machine with a platform having a horizontal surface that produces a sinusoidal vibration in the vertical linear plane. The test fixture is to be loosely restrained to limit the area of travel. The speed of the apparatus is to be adjusted so that the vibration frequency generates a 1/16 inch (1.6 mm) vertical displacement of the test fixture from the table. The sample is to be vibrated for a period of 1 hour.

7.2.2 revised September 13, 1996

8 Torque and Pullout Tests for Pressure Wire Connectors

8.1 General

8.1.1 After being subjected to the tests specified in 8.2.1 and 8.3.1, there shall be no breakage of the conductor, stripping of threads, shearing of parts, separation of the conductor from the connector, or other damage to the connector.

8.2 Tightening torque

8.2.1 The connection between the wire and the connector is to be made in accordance with Tables 8.1, 8.2, and 8.3. The specified torque is to be applied by:

- a) Tightening the fastening until the specified value of torque is attained; and
- b) Maintaining this value, with a static torque reading, for 5 seconds.

Table 8.1
Tightening torque for screws, pound-inches (N-m)

Wire Size, AWG (mm)	Slotted head No. 18 and larger		Hexagonal Head	
	Slot width 0.047 inch (1/2 mm) or less and slot length 0.25 inch (6.4 mm) or less	Slot width over 0.047 inch (1.2 mm) or slot length over 0.025 inch (6.4 mm)	Split bolt	Other
12 – 10 (3.3 – 5.3)	20 (2.3)	35 (4.0)	80 (9.0)	75 (8.5)
8 (8.4)	25 (2.8)	40 (4.5)	80 (9.0)	75 (8.5)

Table 8.2
Tightening torque for screws less than No. 10

Slot length of screw,		Tightening torque, pound-inches (N-m)	
		Slot width of screw, inch (mm)	
		Smaller than 0.047 (1.2)	0.047 (1.2) and larger
Inch	(mm)		
Less than 5/32	(4)	7 (0.79)	9 (1.0)
5/32	(4)	7 (0.79)	12 (1.4)
3/16	(4.8)	7 (0.79)	12 (1.4)
7/32	(5.6)	7 (0.79)	12 (1.4)
1/4	(6.4)	9 (1.0)	12 (1.4)
9/32	(7.1)		15 (1.7)
Above 9/32	(7.1)		20 (2.3)

Table 8.3
Tightening torque for socket head
screws

Socket size,		Tightening torque,	
inch	(mm)	pounds-inches	(N-m)
1/8	(3.2)	45	(5.1)
5/8	(4.0)	100	(11.3)
3/16	(4.8)	120	(13.6)
7/32	(5.6)	150	(16.9)
1/4	(6.4)	200	(22.6)
5/16	(7.9)	275	(31.1)
3/8	(9.5)	375	(42.4)
1/2	(12.7)	500	(56.5)
9/16	(14.3)	600	(67.8)

8.3 Pullout test

8.3.1 A connector-wire assembly shall be subjected to a direct pull of 70 pounds (311 N) for a period of 1 minute without separation or movement of the parts relative to one another. The test is to be performed using a tension-testing machine, or equivalent, that increases the force gradually until the test force is achieved.

8.3.1 revised September 13, 1996

9 Pullout Test for Test Lead

9.1 A test lead is to be subjected to a direct pull of 70 pounds (311 N) for one minute without separation or loosening. The test is to be performed using a tension testing machine, or equivalent, that increases the force gradually.

9.1 revised September 13, 1996

10 Dielectric Coating Tests

10.1 General

10.1.1 Representative samples of the dielectric coating as specified in Table 10.1 are to be used for these tests. The steel used in the preparation of samples is to be representative of the steel for which the coating is intended, with respect to composition and surface conditions. The samples are to be prepared by the same procedures of surface cleaning, pretreatment, application of the coating system, drying or curing, and minimum dry film thickness that is used in the production procedure.

10.1.1 revised September 13, 1996

Table 10.1
Samples for dielectric coating tests

Exposure/Test	Number of test coupon	Coupon type (see below)
"As-received" – impact	5	A
Air-oven aging	6	A
Light and water exposure	5	A
Impact and cold	2	A
Environmental fluids	60	B
Flexibility	5	A
Abrasion resistance	5	A
Cathodic disbondment	2	A

A - 5 by 9 inch (127 by 229 mm) coated flat No. 14 MSG (0.075 inch nominal) steel plate fabricated in accordance with the proposed production procedure of the minimum allowable production thickness. The coating shall be applied to both sides of the coupon and on the edge.

B - Identical to A, except the panels have an insulated No. 12 gauge copper wire welded to the top right corner of the coupon. The wire is to be attached prior to coating the coupon.

Table 10.1 revised September 13, 1996

10.2 Impact test following conditioning

10.2.1 Unconditioned samples and the samples conditioned as specified in 10.2.2 – 10.2.4 are to be subjected to the impact test specified in 10.2.5. The samples shall not be affected by the impact to the extent that holidays form further than 1 inch (25.4 mm) from the point of impact when tested in accordance with ASTM G62-87, Test Method for Holiday Detection in Pipeline Coatings.

10.2.2 Representative sample coupons are to be conditioned in an air-circulating oven at:

- a) A temperature of 70°C (158°F) for 30, 90, and 180 days; or
- b) A temperature of 60°C (140°F) for 30, 90, 180, and 270 days.

10.2.3 Two groups of samples are to be subjected to 180 and 360 hours, respectively, of light and water exposure in accordance with Method I of the Standard Practice for Operating Light-Exposure Apparatus (Carbon-Arc Type) With or Without Water for Exposure of Nonmetallic Materials, ASTM G23-90, using apparatus designated Type D or DH in ASTM G23-90. during each operating cycle of 120 minutes, the samples are to be exposed to light alone for 102 minutes and to light and water for 18 minutes.

10.2.4 Samples are to be conditioned for 16 hours in a cold box maintained at minus 29°C (minus 20°F).

10.2.5 Each sample is to be clamped between two steel rings having an inside diameter of 4-1/4 inches (108 mm). A 1.18 pound (536 g) steel ball is to be dropped once from a height of 6 feet (1.8 m) to strike the coating.

10.3 Resistance to environmental fluids test

10.3.1 After being immersed as specified in 10.3.2 the coating shall not crack or flake, nor shall the coating dissolve from the surface to the extent that the base steel becomes visible. The coating on the holiday samples shall not disbond more than 1.5 square inches (968 mm²).

10.3.2 Samples are to be immersed vertically in each of the liquids specified in Table 14.2 for 30, 90, 180, and 270 days, respectively, so that the liquid level covers one half of the test sample. Four of the samples are to be prepared with a 1/4 inch (6.4 mm) diameter holiday. The test liquids are to be maintained at 38°C (100°F) during the tests.

10.3.3 The current demand of the undrilled samples is to be measured (both before and after immersion) in accordance with Section 9.13 of ASTM G8-90, Test Method for Cathodic Disbonding of Pipeline Coatings. The current demand shall not exceed 0.04 milliamperes per square foot (0.43 milliamperes/m²).

10.4 Flexibility test

10.4.1 After being loaded as described in 10.4.2, the coating shall not be damaged to the extent that a holiday forms in the coating when the sample is subjected to the holiday test specified in 10.7.1.

Exception: Holidays or other damage to areas in immediate contact with the supports or loading nose shall be disregarded.

10.4.1 revised September 13, 1996

10.4.2 Samples are to be placed in a constant rate of traverse testing machine with a span of 6 inches (152.4 mm). The loading nose and supports are to be aligned such that the axes of the cylindrical surfaces are parallel and the loading nose is midway between the supports. The testing machine is to apply the load at 0.1 inches (2.5 mm) per minute until a deflection is obtained, as determined by the following equation.

$$\text{Deflection} = \frac{9.7 \times 10^{-2}}{6t}$$

where:

t = sample thickness (steel plus coating)

10.5 Abrasion resistance test

10.5.1 After being tested as specified in 10.5.2 the coating shall not be damaged to the extent that holidays form in the coating when the sample is subjected to the holiday test specified in 10.7.1.

10.5.2 Samples are to be subjected to three drops in accordance with ASTM G13-89, Test Method for Impact Resistance of Pipeline Coatings, except that flat plate specimens are to be used instead of pipe samples.

10.6 Cathodic disbondment test

10.6.1 After being subjected to the test specified in 10.6.2 the unperforated samples shall not disbond from the steel surface. The disbonded area of the perforated samples shall not exceed 1.5 square inches (968 mm²).

10.6.2 Samples are to be subjected to Method B of ASTM G8-90, Test Method for Cathodic Disbonding of Pipeline Coatings, except that flat panel specimens are to be used instead of pipe specimens. Half of the samples are to be perforated per ASTM G8-90. The temperature of the electrolyte is to be maintained at $23 \pm 3^\circ\text{C}$ during the test. The samples are to be subjected to the test for 28 days.

10.7 Holiday test

10.7.1 Samples are to be tested in accordance with ASTM G62-87, Test Methods for Holiday Detection in Pipeline Coatings.

11 Tests for Insulating Devices (Bushings and Gaskets)

11.1 General

11.1.1 Insulating devices for use with underground storage tank systems shall be made of nonconductive material to electrically insulate the underground tank from the piping system. Threaded bushings shall accept a standard threaded pipe in accordance with the Standard for Welded and Seamless Wrought Steel Pipe, ANSI/ASME B36.10M-1985. Insulating devices that form part of a bolted and gasketed flanged connection are acceptable.

11.1.1 revised September 13, 1996

11.2 Leakage test

11.2.1 An insulating device shall not leak when subjected to the Leakage Test described in 11.2.2 – 11.2.5.

11.2.2 Samples are to be installed in the test fixture simulating a tank fitting as specified in the manufacturer's installation instructions. The assembly is to be partially filled with regular unleaded gasoline and sealed by installing:

- a) A threaded pipe plug into a threaded bushing; or
- b) A blind flange onto a flange-type connection.

11.2.3 The assembly is to be inverted so that the gasoline contacts the insulating device and subjected to the following conditioning program: 4 cycles consisting of 16 hours at minus 17.8°C (0°F) followed by 8 hours at 49°C (120°F); 72 hours at 17.8°C (0°F); 8 hours at 49°C (120°F); and 16 hours at 17.8°C (0°F).

11.2.4 The assembly is to be tested for leakage at room temperature prior to and following the conditioning program, and also following each temperature segment of the conditioning program.

11.2.5 The assembly is to be tested for leakage by aerostatically pressurizing the assembly to 5 psig (34 kPa) and brushing the device with a leak-detection solution. Continuous formation of bubbles is evidence of leakage.