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GUIDE FOR THE DESIGN OF THREADED SCREW OR STUD TYPE ELECTRICAL EQUIPMENT TERMINATIONS

CONTENTS

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INTRODUCTION

The standardization and use of electrical wire lug terminals are generally well covered in various government and commercial specifications and practices. The design of the terminations on electrical equipment to which lug terminals are attached, however, is less well covered. This guide, therefore, sets forth design recommendations for equipment terminations that will provide satisfactory connections to lug terminals.

REFERENCES

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Military:

MIL-C-5015 - Electric "AN" Type Connector

MIL-B-5087 (ASG) - Electrical Bonding and Lightning Protection for Aerospace Systems

MIL-W-5088 - Selection and Installation of Aircraft Wiring

MIL-E-5400 - General Specification for Airborne Electronics Equipment

MIL-R-6106 (ASG) - General Specification for Aerospace Electric Relays

MIL-B-6812 - Aircraft Bolts

MIL-T-7099 - Crimp Style Lug Terminals for Aluminum Aircraft Wiring

MIL-S-7742 - General Specification for Standard Screw Threads, Optimum Selected Series

MIL-T-7928 - Copper Crimp-Style Lug and Splice Terminals

MIL-T-15659 - Copper, Solder Type, Lug Terminal

MIL-N-25027 - Self-Locking Nuts

MIL-P-55149 - General Specification for Electrical Binding Posts

MIL-T-55155 - General Specification for Insulated Feed-through Terminals and Noninsulated Stud Terminals

MIL-T-55156 - General Specification for Screw Type Conductor Splices and Lug Terminals

MIL-T-55164 - General Specification for Molded, Barrier, Screw and Stud Type Terminal Boards and Associated Accessories

AFSC DH 1-6 - System Safety, Design Handbook, Series 1-0, General (AFSC and NASA)

NAVAIR 01-1A-505 - Technical Manual, Installation Practices for Aircraft Electric and Electronic Wiring

MIL-STD-454 - General Requirements for Electronic Equipment:

Requirement 1, Safety (personnel hazard)
Requirement 11, Electrical Insulating Materials
Requirement 12, Fastener Hardware
Requirement 16, Dissimilar Metals
Requirement 69, Internal Wiring Practices

MIL-STD-889 - Dissimilar Metals

MIL-STD-1277 - Electrical Splices, Clips, Terminals, Terminal Boards, Binding Posts

MIL-STD-1285 - Marking of Electrical and Electronic Parts

MS17143 - Terminal, Lug, Crimp Style, Copper, Insulated

MS20659 - Terminal, Lug, Crimp Style, Copper, Uninsulated, Ring Tongue, Type I, Class 1

MS21003 and 21004 - Terminal, Lug, Uninsulated, Rectangular Tongue, Crimp Style, Copper, Type I, Class 1

MS21042 - Nut, Self-Locking, 450° F, Reduced Hexagon, Reduced Height, Ring Base, Non-corrosion Resistant Steel

MS21044 - Nut, Self-Locking, Hexagon - Regular Height, 250° F, 125 KSI FTu and 60 KSI FTu

MS21045 - Nut, Self-Locking, Hexagon - Regular Height, 450° F, 125 KSI FTu

MS25036 - Terminal, Lug, Crimp Style, Copper Insulated, Ring Tongue, Bell Mouth, Type II, Class 1

MS25435 - Terminal-Lug, Crimp Style, Straight Type, for Aluminum Aircraft Wire, Class 1

MS25440 - Washers, for Use with Aircraft Aluminum Terminals

MS27212 - Terminal Board, Assembly, Molded-in Stud, Electric

MS35275 - Screw, Machine-Drilled Fillister Head, Slotted, Corrosion Resisting Steel

MS35338 - Washer, Lock-Spring, Helical, Regular (medium) Series

MS35649 - Nut, Plain - Hexagon, Machine Screw, UNC-2B

MS35650 - Nut, Plain - Hexagon, Machine Screw, UNF-2B

AN-960 - Washer, Flat

Federal:

FF-B-575 - Bolts, Hexagon and Square

FF-N-836 - Nut, Square, Hexagon Cap, Slotted, Castle, Knurled, Welding and Single Ball Seat

FF-S-85 - Screw, Cap, Slotted and Hexagon Head

FF-S-92 - Screws, Machine, Slotted, Cross - Recessed or Hexagon Head

FF-W-84 - Washers, Lock (Spring)

FF-W-92 - Washers, Metal, Flat (Plain)

Handbook H28, Part I-- Screw Thread Standards for Federal Services, National Bureau of Standards

SAE:

ARP 506A - High Temperature Insulated Terminal Lugs

ARP 669 - Color Coding of Terminals and Wiring for Flight Equipment

AIR 1263 - Tin Plated Solderless Terminal Lugs and Splices on Nickel Coated High Temperature Wire

Other Useful References

IFI Standard - Fasteners Handbook, Industrial Fasteners Institute

Aluminum Building Wire Reference Book - The Aluminum Association

Aluminum Building Wire Installation Manual - The Aluminum Association

MIL-T-16366 (Ships) - Pressure Grip, Electrical Clamps, Lug Terminals and Conductor Splices

1. SCOPE

To establish design recommendations that will provide a basis for safe and reliable connections to threaded screw- or stud-type electrical equipment terminations. These recommendations are directed primarily, but not solely, to the aerospace and ground support equipment industries.

Since individual design criteria may alter the details as outlined, it is therefore important that this Aerospace Information Report (AIR) not be considered mandatory, but be used only as a design guide.

2. GENERAL

Solderless crimp-type lug terminals are now widely used and accepted as a means to satisfactorily terminate electrical conductors. A high degree of reliability has been achieved through standardization of sizes, dimensions, materials, crimping techniques, and performance specifications. The overall connection reliability, however, is equally dependent on the integrity of the interface contact between the lug terminal tongue and its mating surface. This critical connection has often been overlooked when threaded fasteners are used, probably due to the apparent simplicity of attachment.

There are many design factors to consider in achieving the same degree of reliability at the tongue contact as in the crimp contact to the conductor. Both mechanical and electrical requirements are to be taken into account including such factors as selection of screw size, fastening hardware, materials, insulator design, and consideration for both copper and aluminum wire.

2.1 Lug Terminal Selection: Since the equipment termination is an electrical extension of a lug terminal, proper design must include considerations of the style and characteristics of the lug terminals expected to be used. Preferred copper crimp-type lug terminals are those specified in MIL-T-7928. Several of the more common straight types are detailed in the following associated MS standards, although a variety of other tongue configurations are also standardized:

MS25036 Insulated Ring Tongue
MS17143 Insulated Rectangular Tongue
MS20659 Uninsulated Ring Tongue
MS21003 and 21004 Uninsulated Rectangular Tongue

These range in wire size from No. 26 AWG through 0000 AWG with stud holes from No. 2 (.086 in.) through .875 in. diameter. The temperature rating of tin-plated copper lug terminals is 105°C for the insulated type and 175°C for uninsulated.

2.1 (Continued)

Preferred aluminum crimp-style terminals are those specified in MIL-T-7099 for aluminum aircraft wire. MS25435 details a straight, uninsulated tongue with aluminum wire size from No. 8 AWG through 0000 AWG and stud holes from No. 10 (.190 in.) through .500 in. diameter. Uninsulated aluminum terminals are rated for 105°C conductor temperature.

Recommended military practice is to use pre-insulated terminals or insulate with sleeves after crimping on uninsulated terminals.

Both MIL-T-7099 and MIL-T-7928 provide excellent references for lug terminal performance requirements which could also be applicable, in part, for the stud contact on equipment terminations.

Reference information for higher temperature wire terminals is found in SAE ARP 506A, "Aerospace Recommended Practice for High Temperature Insulated Terminal Lugs." This document establishes design and performance requirements for 200°C and 260°C wire terminals on wire sizes from 26 AWG through 10 AWG.

3. SCREW AND STUD SIZE SELECTION

3.1 Threads: Screws and studs should be of the unified standard form and be selected in accordance with MIL-S-7742, General Specification for Standard Screw Threads, Optimum Selected Series. This specification encourages maximum usage of a limited number of sizes for aircraft, and is based on the National Bureau of Standards, Screw Thread Standards for Federal Services, Handbook H28, Part I. Recommended sizes are listed in Table I.

3.2 Size: Screw or stud size is initially established from wire size and current requirements of the equipment. Table II lists minimum recommended termination screw sizes for various current loads with both copper and aluminum wire. These are based on bundled cable wire ratings from MIL-W-5088, Selection and Installation of Aircraft Wiring. When determining the largest probable wire size to be used, consider one stud size larger. This will assure adequate termination conductivity when voltage drop or circuit protection considerations require larger wires than on the basis of wire current rating alone.

3.3 Length: Length should be sufficient to accommodate at least two, but not more than four lug terminals, plus a flat washer, a split lock-washer, and a nut while maintaining a minimum of 1-1/2 screw threads showing after the assembly is complete. Lug terminals are usually positioned back-to-back as illustrated in Figure 2.

3.4 Strength: In addition to meeting the electrical requirements, screws or studs should have sufficient mechanical strength to resist deformation or damage from tension test loads in any direction. The size and retaining means should meet the equipment physical test requirements and withstand repeated torquing loads from attaching terminated wires. Consideration should be given to tensile, shock, vibration, and thermal cycling loads to meet performance testing and service conditions.

3.4.1 Unless equipment design dictates specific strength criteria, Table I lists recommended minimum static tensile and torque test values to insure satisfactory mechanical and electrical performance.

4. CONTACT DESIGN

4.1 Equipment Leads:

4.1.1 Contact areas of equipment leads should be flat, clean, burrfree, and raised above the surface of the surrounding insulator material. The area should preferably be equal to the mating surface of the tongue of the largest wire terminal expected to be used, or never less than required to permit the current density to exceed 1000 amps per sq in. (155 amps per sq cm.).

4.1.2 It is recommended practice that the lug terminal stud hole be selected to match the stud size for both maximum effective electrical connection and mechanical security. Also, when lug terminals of different tongue sizes are attached to the same stud the largest should be located on the bottom directly against the equipment lead as illustrated in Figure 6.

4.1.3 Current carrying studs should be avoided where possible, however when necessary, the contact area should be an integral part of the stud with a shoulder section as illustrated in Figure 3. Separate spacers or washers should not be used between the integral stud shoulder and the lug terminal tongue. This adds another interface in series with the circuit creating additional contact resistance.

4.2 <u>Contact Supporting Materials:</u> The pressure for electrical contact must not be transmitted through or dependent on materials that shrink or relax with time or at elevated temperatures. Soft metal platings or interfaces such as soft solder are to be avoided. No insulating material should be in compression when the screw or nut is tightened over the lug terminal tongue. Insulating plastic materials may be suitable for retaining studs or captive nuts against repeated torquing or tension loads, but must remain independent of the contact pressure since most are subject to varying degrees of excessive relaxation.

4.3 <u>Contact Materials and Finish:</u>

4.3.1 Current carrying members should be made of copper or high-conductivity copper alloy and be plated with silver, tin, nickel, gold, or other suitable finishes to resist corrosion and maintain low and stable contact resistance. Steel is to be avoided but may be used for low current applications and must be cadmium plated, preferably with a chromate treatment. Stainless steel does not generally require plating. Aluminum equipment leads may be used with special design considerations and must be tin plated, at least at the contact interface.

4.3.2 Screws, studs, and nuts are preferably steel or other suitable high-strength materials. Softer screw or stud materials such as copper or aluminum could result in excessive thread wear and should be avoided. Brass nuts should be considered where greater corrosion resistance or where high wear is anticipated. Current carrying studs of heat treated beryllium copper or high tensile phosphor bronze offer improved thread wear resistance, yet provide good conductivity.

4.3.3 Magnesium equipment leads or termination hardware is to be avoided especially in contact with copper due to the high level of galvanic corrosion potential. Due to chemical incompatability, cadmium plating of termination hardware is not recommended for use in fuel or hydraulic systems.

4.4 <u>Aluminum Considerations:</u>

4.4.1 Special consideration must be given to connecting aluminum equipment leads, aluminum lug terminals, or combinations of copper and aluminum materials Aluminum has different properties from copper which must be taken into account to provide reliable terminations. These differences are related to lower conductivity, oxide formation, galvanic corrosion, creep, and thermal expansion.

4.4.2 Since conductivity is lower, larger cross-sectional areas are used in current carrying members. Lug terminal tongues have larger contact surfaces which must be provided for on equipment leads.

4.4.3 Aluminum oxide is always present on bare aluminum and creates a high-contact resistance barrier to current flow. A plating, such as tin, provides intimate contact to the bare aluminum and presents a low-contact resistance to adjacent members.

4.4.4 Aluminum will corrode and is sacrificial relative to copper in the presence of moisture. Tin plating also greatly reduces the galvanic corrosion rate between aluminum and copper since it falls intermediate in the galvanic series. A moisture seal or protective coating may be applied to aluminum-copper connections to minimize galvanic action as specified in MIL-STD-454, Requirement 16. Table III shows the proper arrangement of dissimilar metals for control of galvanic or electrolytic corrosion. NAVAIR 01-1A-505 is also a useful reference in metal selection.

4.4.5 Aluminum has a high rate of creep or cold flow and will continue to relax when stressed until the stress is equal to its yield strength. This has the effect of significantly reducing the residual contact pressure to the point of possible failure. To compensate for creep, it is common practice to use spring washers under the screw head. The creep problem is compounded with aluminum-copper terminations since aluminum, when heated, expands about 40% more than copper. If the heating is sufficiently high, such that the stresses exceed the elastic limit of the aluminum, then permanent deformation will occur. With repeated heating and cooling, the contact pressure will progressively become less. Application temperature limitations and the use of spring washers will insure long-life reliable copper-aluminum terminations.

5. INSULATOR DESIGN

5.1 Materials: Insulator design first must comply with the equipment requirements. Material selection, however, should include consideration of many characteristics such as:

Arc resistance (non-carbon tracking)
Dielectric strength
Flame resistance
Mechanical strength
Noxious or toxic fume emission
Impact strength
Heat distortion temperature
Temperature endurance
Corrosion resistance to metals
Solvent resistance
Moisture absorbtion
Fungus resistance

In general, a plastic insulation material should combine the more important properties of flame resistance, arc resistance, and low toxicity with good electrical and mechanical properties.

MIL-STD-454, Requirement 1 - Safety (Personnel Hazard) and Requirement 11 - Electrical Insulating Materials, provide good references for safety and establishes criteria for the selection and use of a broad range of insulating materials. Another reference, AF and NASA Series 1-0, General Design Handbook, Safety System, Aerospace Vehicle Safety Design, centers on safety considerations for insulators and terminations.

5.2 Terminal Spacing and Barriers:

5.2.1 Terminal spacings should provide adequate creepage distance to meet the voltage requirements of the equipment. Table IV lists minimum spacings for various voltages and altitudes and is based on MIL-C-5015 for AN connectors. Another spacing reference is MIL-STD-454, Requirement 69, Internal Wiring Practices for electronic equipment from which Table V has been taken.

5.2.2 Barriers increase the creepage path and help prevent accidental shorting between lug terminals. In addition to the electrical requirements, the size of the equipment should be taken advantage of to provide as much space as possible to simplify lug terminal installation with tools and minimize electrical hazards.

5.3 Covers: Covers should be designed to provide electrical and mechanical protection for all equipment terminations and accommodate at least two lug terminals. Covers are usually made of a substantial insulating material, although if metal is required for electrical shielding, care must be taken to afford adequate support against shorting if accidentally crushed. Provision for cover removal is necessary so that when used in an otherwise protected location, such as a junction box, it can be removed to eliminate the weight.

6. FASTENER HARDWARE

Fastener hardware should preferably be selected in accordance with MIL-STD-454, Requirement 12, which establishes such requirements for electronic equipment.

6.1 Screws: Selection of screw and bolt types will vary widely with user preference and equipment requirements, although, head styles should be those with larger diameters. Pan head, binding head, or hexagon head will provide maximum contact area over a washer. Screws may directly be selected from the following specifications:

FF-S-92	Machine Screws
FF-S-85	Cap Screws
FF-B-575	Bolts
MIL-B-6812	Aircraft Bolts (high strength)

6.2 Nuts: Plain nut types are preferred as detailed in MS35649 (coarse) and MS35650 (fine) and specified in FF-N-836. In applications where vibration is of concern, self-locking nuts may be required to insure the integrity of the connection, however, caution is advised in their use. They should not be used on brass studs or where frequent removal is anticipated due to greater thread wear neither should they be used on stainless steel studs since there is a tendency to seize. Self-locking nuts are detailed in MS21042, MS21044, MS21045 and specified in MIL-N-25027.

6.3 Washers: Flat washers and spring split lockwashers must always be used to insure maximum contact reliability. Flat washers distribute pressure over the lug terminal tongue. Spring split lockwashers, in addition to resisting nut loosening, maintain contact pressure when metals relax that are in compression. This follow-up is especially important for aluminum.

Plain flat washers may be selected from FF-W-92 in various materials, although Grade II aeronautical, cadmium-plated steel or tin-plated brass are preferred for use on copper wire terminals and copper equipment leads. These are also detailed in AN-960. Aluminum terminations require a special flat washer as shown in MS25440, Washers for Use with Aircraft Aluminum Terminals. This is an oversize, cadmium-plated, steel washer to match larger aluminum lug terminal tongues.

Spring split helical lockwashers are specified in FF-W-84 and detailed in MS35338. Steel lockwashers should be cadmium plated. Where greater corrosion protection is required phosphor bronze lock washers may be used. Tooth-type lock washers should not be used.

7. HARDWARE ARRANGEMENTS

Preferred hardware arrangements for equipment terminations are shown in Figures 1 through 7. These include typical equipment lead configurations with screws and studs on combinations of copper and aluminum materials. The insulators and equipment leads as illustrated, are schematic only, and not intended to represent any specific detail design.

In general, flat washers must be used directly over all lug terminal tongues, and spring split lock washers used under all screw heads or nuts. Washers should never be placed in the current path. Care must be exercised in the proper selection of base metals and platings for electrolytic corrosion considerations, especially where aluminum is involved.

7.1 Copper-to-Copper Terminations: Figures 1, 2, and 3 show typical arrangements for copper-to-copper connections with screws and studs. Note that lug terminal tongues are always placed directly against the equipment lead and that only standard size washers need be used.

7.2 Aluminum-to-Aluminum Terminations: Figure 4 shows an aluminum equipment lead connection to an aluminum lug terminal. In this case, the special oversize MS25440 washer is used over both the aluminum lug terminal tongue and the equipment lead. Split lockwashers should never be placed directly on any aluminum surface. Figure 5 shows the situation where there may be no equipment lead involved and the current path is directly through two aluminum lug terminals, such as found on a terminal board or binding post. This illustrates that the MS25440 washer preferably be used on both sides of the wire terminals for full bearing pressure.

7.3 Copper-to-Aluminum Terminations: Figure 6 shows the arrangement of both copper and aluminum lug terminals to a copper equipment lead. When the aluminum lug terminal tongue is larger than the copper tongue, it should be placed directly on the equipment lead as shown. If the copper lug terminal is larger than the aluminum, then it should be placed on the equipment lead, in which case a MS25440 washer would be used under the split lockwasher.

Figure 7 shows the case where a copper equipment lead is connected to aluminum lug terminals in which the MS25440 washer is used directly on the aluminum tongue.

8. SPECIAL TOOLS

Selection of hardware and insulator design should be such that no special tools are required and that adequate clearance space be provided for assembly, maintenance, and ready replacement of damaged or worn parts. The design should accommodate standard maintenance tools such as pliers, screwdrivers, socket and spinner wrenches.

TABLE I

RECOMMENDED SCREW SIZES AND
STRENGTH OF SCREW OR STUD TERMINATIONS

SCREW SIZE	MINIMUM STATIC TEST WITHSTAND VALUES			
	Tension		Torque	
	lb.	N	in-lbs.	N·m
No. 2 (.086)-56-UNC-2A	4	17.8	4	.45
No. 4 (.112)-40-UNC-2A	7	31.1	6	.68
No. 6 (.138)-32-UNC-2A	30	133	10	1.1
No. 8 (.164)-32-UNC-2A or 3A	35	156	20	2.3
No. 10 (.190)-32-UNF-2A or 3A	40	178	40	4.5
.250-28-UNF-2A or 3A	50	222	80	9.0
.312-24-UNF-2A or 3A	70	311	160	18.1
.375-24-UNF-2A or 3A	100	445	240	27.1
.500-20-UNF-3A	150	667	400	45.2
.625-18-UNF-3A	200	890	500	56.5

TABLE II

MINIMUM RECOMMENDED TERMINATION SCREW OR STUD SIZES FOR CURRENT AND CONDUCTORS

Based on current carrying capacity of wires in conduit or bundles, MIL-W-5088

CURRENT RATING-CONTINUOUS DUTY AMPERES	WIRE SIZE - AWG		TERMINATION SCREW OR STUD SIZE
	Copper	Aluminum	
	26		No. 2 (.086)-56-UNC
2	24		No. 4 (.112)-40-UNC
5	22		
7.5	20		No. 6 (.138)-32-UNC
10	18		
13	16		No. 8 (.164)-32-UNF
17	14		
23	12		No. 10 (.190)-32-UNF
33	10		
36		8	
46	8		
50		8	
60	6		
66		4	.250-28-UNF
80	4		
82		2	
100	2		
105		1	.312-24-UNF
123		0	
125	1		
145		00	
150	0		
175	00		
162		000	.375-24-UNF
190		0000	
200	000		
210		2(1)	
225	0000		
246		2(0)	
250	2(1)		
290		2(00)	
300	2(0)		
324		2(000)	
350	2(00)		
380		2(0000)	
400	2(000)		

TABLE III

GROUPING OF DISSIMILAR METALS

FOR

ELECTROLYTIC CORROSION PROTECTION

Based on MIL-STD-454, Requirement 16, and MIL-STD-889 - Dissimilar Metals

GROUP I	GROUP II	GROUP III	GROUP IV
Magnesium alloys	Aluminum	Zinc	Copper and its alloys
	Aluminum alloys (all)	Cadmium	Nickel and its alloys
Aluminum alloys 5052, 5056, 5356, 6061, and 6063	Zinc	Steel	Chromium
	Cadmium	Lead	Stainless Steel (passive)
Tin	Tin	Tin	Gold
	Stainless Steel (active)	Stainless Steel (active)	Silver
	Tin Lead (solder)	Nickel and its alloys	
		Tin lead (solder)	
	Titanium	Titanium	Titanium

Metals listed in the same group are similar and considered compatible when in contact and when protected in accordance with MIL-F-7179. Metals listed in different groups are considered dissimilar and incompatible with one another. The tendency toward galvanic corrosion is greater between widely separated groups than between adjacent groups. Metals from different groups may be placed in contact where suitable protection against galvanic action is provided. The method of protection required will be largely dependent on design and usage environments. The surface composition of a part should be considered when determining dissimilarity; a cadmium- or tin-plated copper part is considered similar to aluminum.

TABLE IV

MINIMUM SPACINGS FOR VARIOUS VOLTAGES AND ALTITUDES

Based on MIL-C-5015

Minimum Distance				Voltage at Sea Level		Voltage at 50,000 ft Altitude (15,240 m)		Voltage at 70,000 ft Altitude (21,336 m)	
Air Space		Creepage Distance		Min. flash-over V rms	Test V rms	Min. flash-over V rms	Test V rms	Min. flash-over V rms	Test V rms
in.	mm.	in.	mm.						
*		.046	1.19	800	600	300	225	200	150
*.031	.79	.062	1.59	1,400	1,000	500	375	375	300
.046	1.19	.078	1.98	2,000	1,500	700	525	500	375
.062	1.59	.109	2.78	2,500	1,800	900	675	600	450
.078	1.98	.125	3.18	3,000	2,250	1,050	790	675	500
.093	2.38	.156	3.97	3,600	2,700	1,200	900	750	560
.125	3.18	.187	4.76	4,500	3,300	1,400	1,065	900	675
.187	4.76	.250	6.35	6,100	4,500	1,800	1,350	1,100	825
.250	6.35	.312	7.94	7,300	5,400	2,000	1,500	1,300	975
.312	7.94	.375	9.53	8,500	6,300	2,300	1,725	1,420	1,065

*Contacts should be continuously insulated. There should be no open airspace between any part of the conductors having this mechanical spacing.

The creepage distances apply to dry, clean, smooth surfaces. For installations unprotected from contamination by dust and/or subject to the condensation of moisture by thermal or altitude cycling, it is recommended that the creepage distance be increased. For installations exposed directly to moisture or other conductive contaminants, it is recommended that sealing or other environment-resisting methods be used.