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DESIGN FOR CORROSION CONTROL OF AVIATION FUEL STORAGE AND DISTRIBUTION SYSTEMS

Fred Reinhart

Civil Engineering Laboratory

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An exhaustive review was made of the literature on corrosion problems and their control as they pertain to aviation fuel storage and distribution systems. Information obtained is combined and presented in a manner suitable for use by designers responsible for new construction at the various US Air Force bases; it covers the many corrosion-related variables encountered with respect to the different types of fuels storage tanks and the distribution lines essential to supplying uncontaminated fuels to planes. Methods of reducing the corrosion of metals used in these systems are considered by identifying potential causes for corrosion in the soil, other external environments to be encountered and in fuels themselves. Different procedures to anticipate and control corrosion are presented, including the use of protective coatings, cathodic protection, and plastics composites as a substitute for metals. Problem areas such as galvanic corrosion, proper surface preparation and techniques for application of protective coatings are considered. Guidelines are given that combine economic considerations with practical corrosion control procedures that will give the most efficient service life compatible with a projected time-of-use requirement.

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This technical report has been reviewed and is approved for publication.

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CORROSION CONTROL DESIGN FOR AVIATION FUEL STORAGE AND DISTRIBUTION SYSTEMS

CORROSION CONTROL DESIGN FOR AVIATION FUEL STORAGE AND DISTRIBUTION SYSTEMS

SECTION I

Introduction

1. Purpose. This technical report provides the latest design procedures for corrosion control of aviation fuel storage and distribution systems [illegible] Air Force Base construction, to achieve maximum protection per construction dollar against corrosion and to avoid unnecessary corrosion-caused breakdowns and later expenditures for corrosion control.

2. Scope. This technical report covers corrosion control procedures for new construction of aviation fuel storage and distribution systems. It incudes storage facilities, pipeline mains, distribution systems, fittings, manifold systems and portable systems (tank trucks). This manual will primarily concentrate on design procedures for metal but will also consider plastics because they completely eliminate most corrosion problems.

3. Cost of Corrosion. Corrosion costs for the United States have been estimated at 20 to 30 billion dollars per year.* Costs due to corrosion include:

a. Loss of plant equipment
b. Loss of product
c. Contamination of product
d. Repair or replacement of equipment
e. Pollution of environment and attendant clean-up costs and/or fines.
f. Medical expenses due to injuries or loss of life.
g. Service interruptions.
h. Deteriorated public relations.

In the past five to ten years many technical developments in the field of corrosion have occurred. To assess properly these developments and their field applicability, a survey of the literature and of current industrial techniques for combating corrosion has been made. The findings of this survey were used as a basis for the preparation of this report.

SECTION II

Site Selection

Site selection for aviation fuel storage should be based on, among other things, environmental conditions which would lead to minimum corrosion. Such factors as the corrosivity of the soil, the atmosphere, and

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* Jamar, L. G., ''The Forgotten Phenomenon,'' Air Force Civil Engineer, August 1972.

the ground water should be taken into consideration along with the ease of installation and maintenance. These factors are discussed in the sections following.

1. Determination of Corrosivity

a. Corrosion Surveys. A corrosion survey consists of the determination of soil and water composition, resistivity, pH, water table level, and for existing structures, electrical potential measurements.

(1) Soil Corrosivity. The characteristics of the soil at the site of a facility are important because of the necessity for burying many different metal components such as pipelines, tanks, etc. in the soil, usually in order to reduce vulnerability to damage. Therefore, before specifying materials or protective measures for such materials, a complete soil survey is necessary to determine its corrosiveness. One of the most accepted methods for classifying a soil is by measuring its electrical resistivity. If time permits, these electrical resistivity measurements should be made during both wet and dry seasons to determine the variations to be expected in the electrical resistivity of the soil. Conductivity is the reciprocal of resistivity and is influenced by a number of variables which also influence the corrosivity of the soil: water content; salts such as nitrates, chlorides and sulfates; degree of aeration; etc. In general, the lower the resistivity the more corrosive is the soil. Other variables which contribute to the corrosivity of the soil are the pH and the presence of anaerobic bacteria.

(2) Water Corrosivity. Two types of water are to be considered in water corrosivity: one is ground water present at the site; and the other is the water which is present as a contaminant in the fuel. The ground water is indigenous to the site and its chief function is to act as an electrolyte to conduct an electric current through the soil and to contribute to the electrical conductivity of the soil. Its efficiency as an electrolyte is determined by the chemical compounds it dissolves from the soil. The corrosivity of the ground water is a function of many factors such as conductivity, pH (a function of hydrogen ion content), aeration, etc. The corrosivity of the water contaminating the fuel is dependent upon the solids and gases dissolved in it.

(3) Atmospheric Corrosivity. Atmospheres differ from area to area, depending upon the location and the type of activity in the area, such as rural, urban, sea coast, industrial, coastal-industrial, etc. The corrosivity of the atmosphere in any selected area is determined by the pollutants such as sulfur dioxide, sodium chloride, fly ash, etc. present, plus the temperature variations, wind speed and direction, and humidity. Therefore, an atmosphere survey should be made at the selected site to determine its corrosivity so that the design engineer can determine what materials or what protective measures should be employed.

b. Results of Operating Similar Systems in the Area. If there are existing installations of a similar nature in the area, an evaluation of the operation of these installations should be made to determine equipment shutdowns, problems, or maintenance related to corrosion. Plant operating records should be reviewed, where available. Weaknesses in corrosion design should be particularly noted as indicated by unplanned shutdowns or maintenance expenses. Particular attention should be paid to shutdown periods and a determination of the causes of shutdown should be established. If the shutdowns are due to corrosion, then clearly, proper precautions and corrosion control procedures should be taken into consideration. The results of operating similar systems is perhaps the most valuable tool that a corrosion engineer has. It should certainly not be overlooked when consideration is being given in design work to the type and extent of corrosion protection necessary to establish adequate corrosion control.

2. Engineering Considerations. Certain basic engineering design considerations should also be followed:

a. Design for easy cleaning and drainage.
b. Design for easy component replacement where service failure is anticipated, e.g. modular construction design.
c. Avoid high localized stress concentrations.
d. Avoid dissimilar metal contacts.
e. Minimize or exclude air.
f. Avoid heat transfer hot spots.
g. Join by continuous welding rather than riveting.
h. Use smooth wide radius bends in piping systems.
i. Avoid metallic contact with absorptive materials.
j. Avoid high velocities.

3. Operating Considerations. Operating conditions also play a role in corrosion design requirements. Factors such as ambient temperature and frequency of use should be considered. Continuous operations usually result in less corrosion and less maintenance than with intermittent operation where parts are left unattended or in a static condition for long periods of time. Fuel flow through structures aids in the reduction of the amounts of water, corrosion products and deposits which can accumulate in the system under static conditions and lead to accelerated attack. For this reason, flow or continuous use is desirable, rather than static conditions or intermittent use.

4. Economic Considerations. If the operating life required for a given installation is extremely short, then little or no corrosion protection may be required. On the other hand, if the base is to be a permanent installation, it may be economical to expend the necessary funds for design engineering and construction to obtain long-term corrosion-free operation of base fuel systems.

In all construction work economic factors must be taken into consideration, including initial costs of the materials, construction, and follow-on costs of maintenance. Follow-on costs for additional corrosion protection may be high and must be taken into consideration when the original design is considered. For example, adding additional anodes and rectifiers may cost 2 or 3 times as much as the cost of installing the same equipment at the time of original construction.

a. Initial Costs. The initial costs will include the costs of the structure and the cost of corrosion protection established for the structure. The choice of the material and the corrosion protection system will depend on economic factors as well as on the design life of the structure. These in turn will be controlled by monetary funds available, the desired life of the structure, and the nature of the site where the construction is required.

b. Maintenance Cost During Estimated Service Life. In determining what type of structure and corrosion protection should be designed to minimize corrosion, the estimated service life must be considered. Also, anticipated maintenance costs for the various structures, systems, and corrosion protection devices, over the estimated service life should be such that the sum of original cost plus the maintenance costs is minimum per year of required service. For example, if a cathodic protection system is being designed, great care should be exercised in the initial design to be sure that the system will provide the protective current required not only initially but during later stages of operation without major redesign of the system. Protective current requirements usually increase during the life of a system as a result of coating degradation. Additions to a cathodic protection system during the life of the system become very expensive when compared to initial costs. Replacing of anode beds, or replacement of rectifiers with greater capacity is costly, and may be difficult after other adjoining structures are in place. Therefore, it is usually wise to allow for such contingencies in the original design of the cathodic protection equipment. Often a figure of 2 to 3 times the initial current requirement is arbitrarily used for determining the size of the rectifiers and the anodes beds required. The same comments also apply to coating systems. The least expensive original coating system often will become the most expensive coating system in terms of cost per square foot per year. It is therefore important that the engineer designing a cathodic protection or a coating system consider not only initial cost but maintenance costs for the time period it is estimated that the structure will be in use.

c. Direct Loss. Direct loss costs relate to replacement costs of the structure should the structure become inoperative or completely lost due to corrosion. Therefore, it should be borne in mind that these replacement costs can be minimized or eliminated by using the proper materials in the original design. Once a structure is in place and other building or construction has taken place nearby, replacement may be many times the original cost.

d. Indirect Loss. As the title indicates, indirect loss does not relate to the direct loss of the structure and replacement of the equipment involved, but relates to other losses involved in a corrosion failure. Some of these losses are discussed below, along with considerations which should be borne in mind in designing for corrosion control.

(1) Loss of Product. In establishing a design for a corrosion protection system, the cost of the product involved should be considered. If a perforation in a tank or line would involve the loss of product, then appropriate measures for protecting the structure should be employed. Refer to Section II.6. of this report for discussions of the dangers in a tank failure.

(2) Loss of Operating Time. If a base or a production facility's downtime is damaging to overall operation and must be minimized, this fact should be considered in designing and installing an adequate corrosion protection system. On the other hand, if the equipment is not critical in the operation of a base, or if there is auxiliary equipment available which may be used in the event of a breakdown, then failure of the equipment due to corrosion and loss of operating time becomes a less important factor.

5. Maintenance Considerations.

a. Ease of Maintenance.

(1) Open Areas. Whenever there is a design option in the choice of pipeline routing, the routing shall be through open areas. The routing shall be such that damage would be minimized in the event of a rupture. Likewise, storage tanks shall be situated in open areas, away from other structures, so that a rupture would cause no damage to other structures.

(2) Under or Near Other Construction. It is mandatory to avoid placement of pipelines under or near other construction. Cathodic protection interference and maintenance problems can be greatly increased by adjacent pipelines or other structures. Sufficient room shall be specified in original design layouts to allow for easy access for corrosion control measurements and maintenance requirements. Facilities should not be located so close to one another as to preclude ease of maintenance.

b. Frequency of Visits. The condition of protective coatings, cathodic protection systems and the extent of corrosion damage must be monitored at regular intervals. Site layout, design for control panels, readout equipment, etc., shall be such that they will be readily available for frequent visits. If the base is remote, and if visits are infrequent, then additional back-up equipment shall be specified to increase reliability, or to advise personnel of unplanned equipment shutdown.

In corrosion design, it has been found that structures easily maintained will be maintained to a much greater extent and more effectively than structures difficult to maintain. Test leads for potential and current readout from cathodic protection systems, and ladders for inspection and maintenance should be considered in corrosion design. Test leads are very important and should be placed during initial installation at convenient locations for pertinent readouts. Structures should not be crowded together - sufficient working area should be allowed for easy access.

6. Safety Considerations.

a. Department of Transportation Regulations, Title 49, Chapter 1. The book, ''Part 195 - Transportation of Liquids by Pipeline,'' published by the Office of Pipeline Safety in 1973, is the authority for the safe transportation of liquids by pipeline. This document gives requirements for the design, construction, operation and maintenance of pipelines which carry liquid petroleum products. Sections 195.242, 195.244, 195.414 and 195.416 pertaining to cathodic protection; 195.236 on external coating and 195.418 on internal corrosion control are particularly applicable to corrosion control design for aviation fuel distribution systems.

b. Location Relative to Personnel Density. Any fuel storage tank or pipeline should be located when possible so that rupture or catastrophic corrosion failure would not endanger personnel.

c. Nature of Product Being Transported and Safety Requirements. Fuels pose a fire hazard and adequate precautions should be taken to protect personnel and structures should corrosion failures or blowouts occur.

d. Design Specifications. For the above reasons, the design of fuel systems shall take into account the possibility of corrosion; and sufficient allowance should be made to prevent catastrophic failure during the anticipated life of the facilities. The original design will also take into account ease of application of remedial measures required during the life of the structure to minimize corrosion.

e. Property and Personal Liability. When designing corrosion protection systems the liabilities involved should a failure occur must also be taken into consideration. These liabilities include property and personal liabilities. The personal liabilities would have to do with any personnel injuries. Property liability would include equipment loss and could also include ecological damage, such as pollution of the soil or washout damage. The possibilities of such losses due to corrosion failure should be considered in designing for corrosion control.

f. Ecological Damage and Cleanup Expenses. Much emphasis has been placed upon ecological considerations within recent years. For this reason, in any corrosion design, attention should be paid to the ecological factors involved in corrosion failure resulting in spillage of product, either from leaky pipelines, failed tanks, or other defective structures. With respect to tankage the costs involved in repairing washouts should also be considered in corrosion design. Washouts become particularly dangerous when large-volume tankage or high-pressure fuel lines are situated on high ground. The nearby downslopes are susceptible to serious and costly erosion and pollution should failure from corrosion occur.

g. Harmful Effects on Personnel. The concentration of gasoline vapors that can be tolerated by humans is far below that required to produce combustible or explosive mixtures with air, one-tenth of this amount being harmful if inhaled for more than a short time. Moderate amounts will cause dizziness, nausea, and headache; while large amounts act as an anesthetic and cause unconsciousness. All gasolines and hydrocarbon fuels as well as methyl alcohol must be regarded as toxic. Lead poisoning from the inhalation of vapors of gasoline treated with tetraethyl lead, while not to be feared from inhalation of vapors given off from open containers in open areas, will occur if these vapors are inhaled over a long period in an inadequately ventilated enclosure. Some jet-engine fuels such as JP-7 contain sufficient gasoline or naphtha to cause this fuel to be regarded as toxic, but do not contain tetraethyl lead. Gasoline will cause severe burns if allowed to remain in contact with the skin, particularly when the contact is maintained under soaked clothing or gloves. Lead in gasoline is not absorbed through the skin to any important extent. However, methyl alcohol may be absorbed through the skin in sufficient quantities to cause the general effects of inhalation as a vapor. Methyl alcohol also causes irritation of the skin by removing natural skin oils, causing cracking of the skin. This increases the possibilities of infection. The danger to personnel from inhalation of the product's vapors or external contact with the liquid is another reason why design deficiencies of facilities for handling these products that increase the possibilities of spillage or the accumulation of vapors from these products in confined areas must be avoided.

SECTION III

Corrosion and Corrosion Control of External Surfaces

This section is concerned with all external metallic surfaces which are subjected to the corrosive variables of the environment. This includes pipes, tanks, supporting structures and any metals exposed to the atmosphere or buried in the soil. There are two ways of combating corrosion of these external surfaces: use materials which are insensitive to corrosion or use protective systems which if properly maintained will preserve the materials for the required service life.

1. Classification of Environment. In order to design the facility at the selected site for the maximum maintenance-free performance the corrosion-inducing characteristics must be known; that is, identifying the aggressive characteristics of the atmosphere and the soil at the site.

a. Atmosphere. The chemical composition of the components of the atmosphere should be determined. Non-marine rural atmospheres are very seldom polluted and as a general rule are not considered corrosive. The amount of corrosion normally expected from rain, air and sunshine is minimal.

In coastal environments the atmosphere may be laden with sea salts, the degree depending upon the direction of the prevailing winds and the proximity to the ocean. In this case the protective measurements employed should be resistant to sea-salt air.

In industrial atmospheres the type of concentrations of the pollutants should be known to combat their corrosive effects effectively. Some of the more prevalent pollutants are sulfur dioxide (SO_2) gas, sulfide gases, chlorides, and nitrates. In coastal-industrial sites the sea salts in addition to any industrial pollutants contribute to the corrosivity of the atmosphere. In industrial sites the protective measures have to be tailored to combat the particular pollutants.

b. Soil. Soils vary widely in their physical and chemical characteristics which in turn affect their corrosivity towards metals. Soils consist essentially of four types of substances: mineral matter, organic matter, water, and air.

(1) Effect of Moisture. The moisture content of a soil greatly affects its corrosivity because of the decrease in the resistivity with the increase in the moisture content up to a point near saturation. It should be pointed out that it is the ion content of the electrolyte (water) that determines the resistance to the flow of an electric current, which plays a part in underground corrosion.

(2) Effect of Aeration. In well-aerated, usually red or yellow soils, the iron compounds have been oxidized to the ferric state $Fe(OH)_3$ or $Fe_2O_3 \cdot nH_2O$. In poorly aerated soils with their low oxygen content the soils are generally gray in color, indicating the presence of reduced forms of iron. Anaerobic soils, which are often black in color, can contain iron sulfide.

Size of soil particles has a definite relation to aeration and ability of soils to retain moisture. Differences in size of soil particles may cause the formation of concentration cells. Metals in well-aerated soils (larger soil particles, e.g.- loam) will be cathodic to metals in the finer soil particles of poorly aerated soils (e.g.- clay).

Aeration factors are those that affect the access of oxygen and moisture to the metal and thereby affect the corrosion. Oxygen can either be from atmospheric sources or from the reduction of salts or compounds in the soil. This oxygen may tend to stimulate or retard the corrosion process, the quantity available being the controlling factor. Oxygen when present in large quantities will form insoluble compounds at the anodic areas on a structure and thus retard corrosion. Oxygen when present in ordinary quantities will stimulate the corrosion process by being reduced at cathodic areas on a structure to form water or hydroxyl ions ($4H^+ + O_2 + 4e^- \rightarrow 2H_2O$ or $O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$). In ordinary quantities, oxygen may also combine with metal ions which have migrated away from anodic areas on the structure. This combination further increases the rate of corrosion. Oxygen when present in small quantities, or absent, will not affect the corrosion process, and corrosion will proceed at a minimum rate.

Some specific examples will illustrate the effect of well-aerated soils and poorly aerated soils. On large-diameter pipelines, unless proper backfill materials or procedures are used, the upper portion of the pipe often is in soil that is well aerated, whereas the lower portion of the pipe is in soil that is poorly aerated. This causes the bottom of the pipe to corrode due to the formation of a differential oxygen cell with the anode on the bottom. Where pipelines are installed in cross-country areas different types of aeration cells are formed. The soils in the open are more aerated than the portions in compacted areas such as under highway and railroad beds. Pipelines exposed to such conditions will generally corrode more readily under the compacted areas because of the difference in aeration.

c. Classification. Soils are classified according to physical and chemical characteristics rather than from their geologic origin or geographic location. Two general classifications exist in the United States: Those in which lime accumulates in the subsoil and those in which it does not. The soils in which lime accumulates in the subsoil lie west of a line from northwestern Minnesota to a point on the Gulf of Mexico 100 miles north of the U.S.-Mexican border.

(1) Soil Resistivity. Soils can be further classified into resistivity ranges in units of ohm-cm. The simplest criterion for estimating the corrosivity of a given soil is its resistivity, which depends largely upon the nature and amount of dissolved salts in the soil, and is also affected by the temperature and moisture content, compactness of the soil and presence of inert materials, such as stones and gravel. Obviously, the resistance of the electrolyte (in this case, ground water) is one of the factors that affect the flow of the current associated with corrosion. If other factors are constant, there is a relationship between soil resistivity and corrosion. Such a qualitative relationship is shown in the following tabular arrangement for steel products:

Resistivity Range, ohm-cm	Corrosion Classification	Corrosivity Class
<700	Very Corrosive	1
700-2000	Corrosive	2
2000-6000	Moderately corrosive	3
>6000	Mildly to noncorrosive	4

The corrosivity of soils with respect to aluminum alloys is dependent upon resistivity as listed above. However, aluminum alloys are very sensitive to the concentration of chloride ion in the soil, pH and aeration. Where the soil is high in chlorides, has a pH outside the range 5-8, or is poorly aerated aluminum alloys will require coating, cathodic protection or, preferably, both.

Since the resistivity of a soil changes with its water content and degree of aeration, it is recommended that resistivity measurements be made 3 or 4 times a year to obtain the variation with different seasons of the year and different moisture contents.

d. Miscellaneous. There are several other factors or phenomena that are difficult to classify because they are a combination of one or more of the previously mentioned causes of corrosion.

Bacterial action, another factor that influences underground corrosion, is associated with aeration and the formation and presence of soluble salts. Bacteria are not only the simplest but also the most numerous forms of soil life. Certain forms, aerobes, thrive in the presence of oxygen but other forms, anaerobes, function best in the absence or near absence of oxygen. Each type of bacteria produces different chemical products. For example, one type of bacterial action transforms sulfur-containing proteins and other organic combinations to hydrogen sulfide or elemental sulfur; and, if much air is available, these products are subsequently oxidized to the sulfite and sulfate conditions (e.g.- sulfurous or sulfuric acid). However, the bacteria that have received the most attention in studies of underground corrosion are the anaerobic bacteria, spirovibrio desulfuricans, which extract oxygen from the sulfate radical to convert soluble sulfates to iron sulfide. It has been established that sulfate-reducing bacteria occur in practically all soils throughout the world when moisture, sulfates, and assimilable organic and mineral matter are present and oxygen is absent. Anaerobic bacterial action has an effect on the corrosion of metals underground, principally because some of the products of bacterial action (H_2S and FeS) accelerate the normal corrosion process.

2. Corrosion Control by Materials Selection. Generally, it is often more economical to use materials which do not require protection of any type. For example, a material possesses the necessary mechanical properties and also is uncorroded in the required environment, its use is preferred to that of a material which requires protection and can usually be justified if the required life is of sufficient length. Many times, the original cost of a corrodible material plus the cost of protection and maintenance over the required life of the installation, will considerably exceed the original cost of a noncorrodible material.

a. Basis for Materials Selection. Materials selection should be based upon the corrosiveness of the particular environment. Information on the corrosiveness of this environment may be obtained in various ways.

(1) Similar Systems in the Area. At many sites or locations information is available on the performance of materials being used in similar applications. Usually the people in charge of such installations will be glad to furnish performance data on the materials they are using, in addition to any satisfactory methods of protection. In these cases performance data of materials and protective systems will be the most reliable and should be used.

(2) Similar Systems in Similar Environments. Should information be unavailable such as that described above, then the availability of information from similar systems in similar environments should be investigated. In such situations the corrosive characteristics of the

atmosphere, soil, and ground water at the proposed site should be determined. Then, with this basic information, the location of similar environments with similar systems in operation should be investigated. Such available and relatively reliable information should be used as a basis for designing the system in question.

(3) Experimental Tests. If no reliable data are available as described in paragraphs a(1) and (2) above, then the generation of experimental data may be necessary. If time permits, either field or laboratory tests can be conducted to obtain approximate information. If time is not available, then the services of a consultant with wide experience in the field in question should be engaged for guidance.

(a) Field Testing. Experimental data obtained by field testing are often more reliable than laboratory testing because actual operating conditions can more readily be found there. However, it must be emphasized that the actual environmental and operating conditions must be closely duplicated in experimental tests.

(b) Laboratory Testing. If laboratory testing must be done because of the time element, then the designer must be willing to accept the unreliability and disadvantages attendant on such tests. Laboratory tests are usually accelerated in some manner in order to obtain results within a shorter period of time. Some of the conditions which may be used to accelerate the test are elevated temperature, increased humidity, increased velocity of flow, chemical solution to simulate special environments, or increased chemical concentrations of solutions, or combinations of two or more of the above. These factors usually increase the corrosion rates of materials and decrease the time required to obtain results. Also, in such laboratory tests, protective coatings may be caused to fail in shorter periods of time. Unfortunately, such tests very seldom duplicate the relative behavior obtained in service from the same materials or protective coatings. Because of the lack of correlation between laboratory tests with actual service performance, such tests are seldom recommended as a source of reliable information. They are, however, often useful as a ''screening process'' used to eliminate undesirable materials prior to field testing.

(4) Galvanic Corrosion and Its Prevention. Galvanic corrosion is defined as ''corrosion associated with the current resulting from the coupling of dissimilar metals together in an electrolyte.'' When two dissimilar metals are metallically connected in an electrolyte, current will flow (in the electrolyte) from one metal to the other. The metal from which the current is flowing (the anode) will corrode, and the metal to which the current is flowing (the cathode) will tend to be protected from corrosion. In this case the anode will corrode at a faster rate than its uncoupled rate in order to protect the more cathodic metal from corroding.

Dissimilar metal couples exposed to the atmosphere present a less serious galvanic corrosion problem than those exposed to wet soil or ground water because they are active only when wet by an electrolyte. In water or soils such couples will corrode, the severity being dependent upon the conductivity of the electrolyte, the temperature, the metals comprising the couples and the area relationships of the two metals. Some metal combinations which commonly constitute galvanic couples are: cast iron-steel, cast iron-aluminum alloy, steel-aluminum alloy, cast iron-stainless steel, steel-stainless steel, steel-copper alloy, and aluminum alloy-copper alloy. The best way to prevent galvanic corrosion is to design a system which requires the use of only one material or compatible materials. However, in many systems this is impossible so preventive measures must be employed. In practically all cases, galvanic corrosion can be prevented by inserting a dielectric separator between the two metals. For example, plastic bushings, connectors or unions will electrically isolate one section of threaded pipe for another; dielectric gaskets, sleeves and washers can be used to electrically isolate materials at a flanged connection.

(5) Compatibility with Other System Requirements. In many applications, characteristics other than corrosion resistance to a particular environment are important, sometimes more important than corrosion resistance. In any case the mechanical and physical properties of the material must be adequate to fulfill the requirements of the application. If the material with adequate corrosion resistance does not possess the necessary mechanical and physical properties for the application, then a compromise must be made in such a way that all requirements are satisfactory or acceptable.

3. Corrosion Control by Alteration of the Environment. Usually no attempt is made to alter atmospheric conditions to control corrosion except in enclosures such as buildings where the contaminants can be removed and the relative humidity can be controlled. Such measures are rarely applicable for fuel systems. Protective coatings might be considered as an alteration of the environment because they present a barrier between the material surface and the atmosphere. Protective coatings are discussed separately, in Section 3.4.

In many cases, particularly where cathodic protection is used, special backfill materials are used to encase the pipe prior to covering it with the material removed to create the trench. Thus, the pipe is encased with a material of one type which provides a uniform environment with a constant electrical resistivity and degree of aeration. This method of altering the environment is discussed more fully under ''Cathodic Protection,'' Section III.5.

4. Corrosion Control by Protective Coatings. A protective coating, either metallic or nonmetallic, prevents corrosion by forming a barrier between a material surface and the environment to which it is exposed. For exterior surfaces of fuel systems coatings will be the protective coatings of major concern.

a. Selection of Coatings. The coating selected for any installation will depend upon the material to be protected and its environment. Different paint coatings have been formulated for different materials for use in different environments. For example, a paint coating formulated for use on steel in a mild environment such as a rural atmosphere would probably not protect satisfactorily or economically the same steel in a very corrosive atmosphere such as a heavy industrial or a chemical environment. The best paints often prove to be the most economical for the longest periods of time since labor costs usually constitute a large portion of the total coating cost.

There are specifications applicable to practically all general and specific applications of materials. For economy, steel is used for most applications in the liquid fuel industry; therefore, specifications for painting it are of major concern. The Steel Structures Painting Council has formulated specifications and recommendations for steel in practically any application. In addition, Air Force Manual AFM 85-3 contains all government specifications for painting materials and should be used if possible. Also, Section 5 of NACE Standard RP-01-69 is a useful source for coatings.

Different types of coatings are required for different atmospheres. In general, alkyds are very satisfactory for non-marine rural atmospheres. For more corrosive atmospheres vinyls, vinyl-alkyds, silicone-alkyds, urethane, epoxy, chlorinated rubber and zinc-rich primer systems are used. Still different types are best suited for application to materials underground. Bituminous and coal-tar-epoxy systems are used for such application.

Actual field experience on the performance of a coating is the most informative and reliable information that can be used for design and recommendation. When it is possible to obtain information on an actual field application of a similar nature in a similar area and the specifics with regard to material, surface preparation and method of coating application are available, performance information regarding such applications should be seriously considered for design purposes.

b. Design Factors. The performance of a protective coating can be enhanced or negated by consideration or lack of consideration of various design factors. Some of these more important factors are discussed below.

(1) Accessibility. Every effort should be made during designing that portion of the system to be protected be made as accessible as possible. A poorly applied protective coating will not provide satisfactory protection. If portions of a system are not accessible for the proper application of the protective coating, satisfactory performance will not be obtained.

(2) Sharp Corners. It is well known that protective coatings fail at sharp corners and edges first because the thickness of cover is often much less at these areas than elsewhere. For this reason all corners

and edges should be rounded in order to obtain a more uniform thickness of the protective coating. The rounding of corners and edges can be specified during design and can be more easily and economically accomplished during fabrication than afterwards.

(3) Condensation. Most protective coatings and paints will not adhere to material surfaces, especially metals, if moisture has condensed on the surfaces to be painted. Painting should not be done when the relative humidity exceeds 60% or the temperature of the metal is lower than 50°F. Sometimes the relative humidity and temperature are such that the volatile solvents in the paint will cause moisture condensation when they evaporate. Under such circumstances painting should be suspended until the weather conditions change.

c. Surface Preparation. Because of the more stringent air pollution regulations today and the limitations imposed upon field sandblasting, procedures of shop blasting and shop priming are becoming more widely used in many applications and can be expected to become more widely used in fuel storage and distribution systems.

In designing for corrosion protection the proper choice of a painting system and the surface preparation required will be controlled by the environmental conditions and the life requirements of the installation. Methods of preparing the surfaces to be painted are discussed below.

(1) Mechanical. The Steel Structures Painting Council (SSPC) has established specifications for several methods of mechanical cleaning of steel prior to painting.

Hand Cleaning. (SSPC-SP 2) Hand cleaning will remove only loose or loosely adhering surface contaminants. Before cleaning, the surface must be free of oil, grease, dirt and chemicals. Hand cleaning is recommended only for spot cleaning in areas where corrosion is not a serious factor.

Power Tool Cleaning. (SSPC-SP 3) Power tool cleaning methods provide faster and more adequate surface preparation than hand tool methods. Power hand tools are satisfactory for removing small amounts of tightly adhering contaminants, but they are uneconomical and time consuming. Power tool cleaning should be preceded by solvent or chemical treatment.

Flame Cleaning. (SSPC-SP 4) Flame Cleaning is a method of passing high-velocity, oxy-acetylene flames over a metal surface. Oil and grease must be removed prior to flame cleaning.

Blast Cleaning. Blast cleaning abrades and cleans through the high-velocity impact of sand, metal shot, metal or synthetic grit, or other abrasive particles on the surface. It is most often used on metal structures in the field. It is by far, the most thorough of all mechanical treatments. There are four degrees of blast cleaning as established by the Steel Structures Painting Council (SSPC) and the National Association of Corrosion Engineers (NACE).

White Metal Blast (SSPC-SP5 or NACE-1). Blast cleaning to white metal is the ultimate in blast cleaning. It is used for coatings which must withstand exposure to very corrosive atmospheres (chemical, heavy industrial, or marine) where a high cost of surface preparation is considered to be warranted. This will contribute to maximum performance of the paint system. This level of blast cleaning is required when zinc-rich coatings are used.

Near-White Metal Blast (SSPC-SP10 or NACE-2). In this procedure the blasted surface will show shadows, streaks and/or discolorations, but they will appear across the general surface area and not be concentrated in spots. It has proven to be sufficiently adequate for many of the special coatings developed for long-term protection in moderately severe environments.

Commercial Blast (SSPC-SP6 or NACE-3). With this blast all loose scale, rust and other surface contaminants are removed. This method of surface preparation will result in a high degree of cleaning and is generally considered adequate to the long life of the majority of paint systems under normal exposure conditions.

Brush-Off Blasting (SSPC-SP7 or NACE-4). This is a relatively low-cost method of cleaning to remove old finishes in poor condition, loose rust and loose mill scale. Brush-off blasting is not intended for use where severe corrosion is prevalent but is, instead, intended to supplant hand tool and power tool cleaning where blast cleaning equipment is available. All blast cleaned surfaces require that prime painting be completed on the same day to prevent new corrosion products from forming, since such blast cleaned surfaces are subject to rapid corrosion if not coated.

Vacuum Blasting. Vacuum blasting is a relatively new method, which minimizes the dust hazard and in which the blast abrasive is reclaimed. This procedure, also known as dry honing, allows practically no dust to escape and contaminate the atmosphere. It is very efficient and economical for cleaning repetitive, small-scale surfaces in a shop.

Wet Blasting. This method reduces to a minimum the dust associated with blasting, but is not suitable for all types of work. Wet sand and other blast residues become trapped on upturned angles and horizontal girders creating difficult clean-up work. These residues must be removed by rinsing, brushing or using compressed air; and the wet blasted surfaces will rust if not dried and primed immediately.

Centrifugal Blasting. This is a shop blasting method in which the abrasive grit is dropped into a spinning vaned wheel at a controlled rate. The grit is thus impinged against the material moving beneath it at a predetermined rate. This results in a controlled, uniformly cleaned surface. This type of surface preparation can be performed at a minimum cost, the abrasive can be reused and dust is virtually eliminated.

(2) Chemical Treatment. (SSPC-SP1). Chemical and solvent cleaning methods are seldom if ever used in the field. They are usually restricted to shop and tank immersion operations. They consist of solvent wiping, alkali cleaning, steam cleaning, and acid cleaning.

Chemical methods of surface cleaning are usually more suited to paint shop application, while mechanical methods are generally more practical in field work. On the basis of overall effectiveness and efficiency, chemical cleaning is superior to mechanical methods, with the exception of blast cleaning. The paint or paint system selected for any given surface and environment is of primary importance. The coating and environment, then, determine the degree of surface cleaning required. The existing surface conditions, job location, equipment availability and economic factors will serve as a guide to the cleaning method required.

d. Methods of Application. The most common methods of applying paint are by brush, roller and spraying. Dip and flow coat methods are also used but the mechanics of operation limit their use to shop work. Of the three for field use, brushing is the slowest, rolling is much faster and spraying is usually the fastest of all. The choice of method is based on many additional factors such as environment, type of substrate, type of coating to be applied, appearance of finish desired and skill of personnel involved in the operation.

Environment. General surroundings may prohibit the use of spray application because of fire hazards or potential damage from overspray. Adjacent areas not to be coated must be masked during spraying. This results in loss of time and, if extensive, may offset the advantage of the rapidity of spraying.

Type of Surface. Roller coating is the most efficient on large flat surfaces. Corners, edges, and odd shapes, however, must be brushed. Spraying is also most suitable for large surfaces, except that it can also be used for round or irregular shapes. Brushing is ideal for small surfaces or for cutting in corners and edges.

Type of Coating. Rapid drying, lacquer-type products, e.g., vinyls, should be sprayed. Application of such products by brush or roller may be extremely difficult especially in warm weather or outdoors on breezy days.

Appearance of Finish. Coatings applied by brush may leave brush marks in the dried film; rolling leaves a stippled effect while spraying yields the smoothest finish, if done properly.

e. Basic Application Procedures. To obtain optimum performance from a coating, there are certain basic application procedures which must be followed, regardless of the type of equipment selected for applying the paint. Cleaned, pretreated surfaces must be first-coated within specific time limits established in order to minimize re-contamination. It is essential that surface and ambient temperatures are between 50°F and 90°F for water-thinned coatings and 45°F to 95°F for other coatings, unless the manufacturer specifies otherwise. The paint material should be maintained at a temperature of 65°F to 85°F at all times. Paint should not be applied when the temperature is expected to drop to freezing before the paint has dried. Wind velocity should be below 15 miles per hour and relative humidity below 80 percent. Masonry surfaces that are damp (not wet) may be painted with latex or cementitious paints; otherwise, the surface must be completely dry before painting. When successive coats of the same paint are used, each coat should be tinted differently to aid in determining proper application and to assure complete coverage.

Brush. Rapid drying, lacquer-type products (e.g., vinyls) are very difficult to apply with brushes. Most other types of paints can be applied with brushes but if not done properly brush marks can be left in the dried film. Brush application is the slowest method of application but for trim, corners, door and window frames and areas difficult of access no other method is satisfactory. Brush application is the only method of applying high viscosity coatings.

Roller. Roller application of paint is rapid and large surfaces areas can be covered in a short period of time.

There are recent advances in rollers by which paint is fed to the inside of a roller by pressure so that it is not necessary to keep reloading the roller periodically. By this method the speed of application is considerably increased.

Spray. Spray equipment is available in three general types.

Conventional Spray. The coating material is placed in a closed container. Pressurized air from a compressor forces the material through a hose to the spray gun. The gun is also connected to a separate air hose. At the gun, the material is atomized by the air supplied through the central openings in the air cap. This is the most inexpensive and most common spray technique but it tends to create excessive overspray because of the high ratio of air to paint used.

Airless Spray. In this method, coatings are sprayed by the use of hydraulic pressure alone. The equipment is similar to conventional spray except that the compressor operates a hydraulic pump. The material is atomized by forcing the material through a specially shaped orifice at a pressure of between 1,500 and 3,000 pounds per square inch. Airless spraying usually permits the use of products with a higher viscosity. Considerable caution must be exercised because of the high pressures required.

Hot Spray. The hot spray technique can be adapted to either conventional or airless spray painting. The paint temperature is raised to 130 to 180°F to lower the viscosity and reduce the quantity of solvent needed. The resultant coating has higher solids and will produce greater film thickness per coat. Considerable caution must be exercised because of the personnel and fire hazards due to the high temperatures required.

Paint Mitt. The paint mitt is a mitten made of lambskin with the wool exposed and lined to prevent paint leaking through to the user's hand. It is excellent for applying paint to small pipes, railings and similar surfaces.

b. Wrappings and Other Types of Coatings. In many underground installations impregnated wrapping materials are used to increase the thickness of the coating in order to better resist mechanical damage from rocks, etc., in the soil. Some of the wrapping materials are discussed below.

Mill-coated Pipe. In recent years the use of mill-coated pipe has been steadily increasing. Wrapping materials are applied over hot applied enamels under the most favorable conditions and, hence, the coatings are freer of defects.

Plastic Tapes. Pressure-sensitive plastic tapes for wrapping underground pipe or other structures such as tanks are essentially plastic protective wraps with an adhesive on one side to cause it to adhere to the pipe when applied to it under pressure. Polyvinyl chloride tapes are supplied in thicknesses of 10 and 20 mils. Polyethylene tapes are supplied in 12- , 14- , and 20-mil thicknesses.

Laminated Tapes With Primers. The major tape of this type available today consists of uncured butyl rubber laminated to polyvinyl chloride. Although it has no adhesive qualities it is applied to an adhesive primer while still wet.

Coal-Tar Tapes. Coal-tar tapes may be either hot-applied or cold-applied. They generally consist of a layer of specified thickness of coal-tar pitch applied to a coal-tar-saturated fabric, plus a thinner coal-tar coating on top, with a separator (paper or plastic film) on top of the outer layer.

Extruded Plastic Coatings. One of the most recent methods of pipe protection underground is the extruded polyethylene coating. This coating is applied at the mill to small-diameter pipe.

Asbestos Wrappers. The asbestos felt wrapper is saturated with either asphalt or coal-tar enamel before application. This wrapper is applied directly over hot enamel as it is flooded or sprayed on the pipe.

Glass Outer Wrap. Glass outer wrap is a thick film of glass fibers held together with a binder. This wrap may or may not be furnished saturated with tar or asphalt cutback before application. It is also applied directly over the hot enamel as it is flooded or sprayed on the pipe.

Glass Inner Wrap. Glass in the form of single filaments laid down in random form and bonded together with a tough, flexible binder, is formed into a wrapper that is used with hot enamel applications.

g. Coating Maintenance. Paint systems deteriorate and will lose their protective ability unless the film remains intact.

Inspection. All coated structures above ground should be inspected at definite intervals. They should be inspected at 6-month intervals in exterior or corrosive environments and at yearly intervals in other environments. Buried structures should be inspected whenever exposed for any reason, especially if exposed for the repair of leaks. The condition of the structures with reference to type and stage of deterioration should be determined and recommendations made for the type of maintenance to be performed after each inspection.

Recoating. Recoating can be considered, roughly, in two categories. Data from the Inspection Records will determine the necessity for spot painting or complete painting.

Spot or Touch-up. Spot painting should be performed when there are only local areas of failure such as at sharp edges, seams, pinholes and holidays, with the greater portion of the coating in satisfactory condition. Spot painting prolongs the time required before complete repainting because it stops the spread of deterioration and decreases the cost of surface preparation.

Total Recoating. If a protective coating is permitted to deteriorate excessively, then it becomes necessary to completely recoat the structure. Complete recoating necessitates the complete removal of the old coating, a completely new surface preparation, and the application of a completely new coating system. Such extensive maintenance procedures are expensive, and relatively more frequent maintenance procedures should be adopted to maintain structural integrity of the system.

5. *Corrosion Control* by Cathodic Protection. Cathodic protection is very simply, the use of direct-current electricity from an external source to oppose the discharge of corrosion current from anodic areas. When a cathodic protection system is installed, for maximum effect all portions of the protected structure collect current from the surrounding electrolyte and the entire exposed surface becomes a single cathodic area - hence the name. In all cases of underground corrosion, anodic areas and cathodic areas are present on a metallic structure (e.g., steel). At the anodic areas, where corrosion occurs, current flows from the anode into the surrounding electrolyte (soil or water). Likewise, where current flows from the electrolyte onto the structure, the surface of the structure is cathodic and does not corrode.

Hence, if every bit of exposed metal on the surface of a structure could be made to collect current, it would not corrode because the entire surface then would be cathodic. This is exactly what cathodic protection does. Direct current is forced to flow from a source external to the structure onto all surfaces of the structure. When the amount of this current flowing is adjusted properly, it will counteract corrosion current discharging from all anodic areas on the structure; and there will be a net current flow onto the structure surface at these points. The entire surface then will be cathodic and the protection complete. It should be noted that only the exposed metal surface requires or utilizes a significant amount of current. Therefore the current required to protect a coated structure is less than that to protect an uncoated structure of the same size in the same environment. Complete and detailed application and design data on cathodic protection is contained in Section 7, Chapter 4, Air Force Manual AFM 88-9, Corrosion Control.

a. General Requirements. The two methods of applying cathodic protection are the sacrificial anode method and the impressed current method. Both types of systems have certain essential features: (a) a source of electrons, called an anode, (b) a metallic electrical path to carry the electrons from the anode to the structure and (c) a continuous electrolyte such as water or moist soil between the structure and the anode to complete the electrical circuit.

Sacrificial Anode Systems. In the sacrificial anode method the structure to be placed under cathodic protection is metallically coupled to a metal less noble (more negative) than itself. For example, zinc is less noble than steel and can be used to cathodically protect steel structures. A galvanic cell is thereby established in which the protected structure becomes the cathode and the less noble metal, the sacrificial anode. Current flows through the electrolyte from the anode to the cathode. The system is designed so that sufficient current will flow from the anode to suppress all local action currents on the surface of the protected structure.

Impressed Current Systems. In the impressed current method of cathodic protection, the consumption of the anode material is not used to supply the required current. Any available source of direct current may be used provided it is continuous. A.C. rectifiers are generally used for this purpose. However, motor-generator sets, gasoline engine generators, and wind-driven generators have been used. The direct current enters the electrolyte from the anodes, flows to the protected structure, and is drained back to the current source through a metallic circuit.

Where Applicable. Cathodic protection can be used to protect any metallic structure from corrosion whose surfaces are contacted by an electrolyte (a current conducting liquid) which may be either soil or water.

Field Surveys. Before a cathodic protection system is designed, it is necessary to conduct a field survey of the intended site to determine and obtain information on the characteristics of the environment.

Other Cathodic Systems. It is necessary to know whether any cathodic protection systems exist in the area. If so, it must be determined whether there will be any interference between the two: whether either system will interfere with the other's operation.

Soil Survey. Soil characteristics, the most important of which are resistivity, pH, and degree of aeration, must be determined. The characteristics of the soil which will be in contact with the structure are very important to the design of the system.

b. Determination of Protective Requirements. Cathodic protection is used almost universally in conjunction with a protective coating system of some kind. The use of such combinations reduces the current required to achieve complete protection. Protective coating systems never form a completely perfect or impervious barrier against intrusion of the environment to the metal surface. Also, such coatings tend to deteriorate with time. Cathodic protection furnishes protection against such defects; thus, such a combination affords complete protection against corrosion.

c. Cathodic Protection System Design. The information obtained from the field surveys and from the protective requirements should provide a basis for the design of the cathodic protection system. One of the most important things to be realized in designing a cathodic protection system is that it should be over designed: usually, from two to three times the initial current requirements are designed into the system. The reasons for this is that: (a) the protective coating will deteriorate with age, necessitating an increase in required current; and (b) usually, sometime during the life of the system, additions will be made to the system, thus increasing the requirement for additional current.

Impressed Current vs. Sacrificial Galvanic Anodes. The use of galvanic anodes for cathodic protection is limited to areas where the soil conductivity is high enough to permit sufficient current to flow to achieve the desired protection with a reasonable number of anodes. This is due to the relatively low driving potential between the sacrificial anodes and the structure, usually less than one volt. If electrical power is available locally, it is usually less expensive to use an impressed current cathodic protection system, especially if it will be in operation five or more years. If power will not be available or the system will be needed only temporarily, it is usually more economical to use sacrificial galvanic anodes such as zinc, magnesium, or aluminum. Galvanic anodes have the advantage of providing only a given known potential, without fluctuations that may occur with an impressed current system.

Selection of Anodes.

Impressed Current Anodes. Impressed current anodes are made of graphite, high silicon cast iron (Duriron), steel, platinum, platinized titanium, scrap steel, old rails and pipe, and lead. Availability, cost, life expectancy and type of environment (soil or water) determine which type of anode to use. Where large amounts of current are required, impressed current systems are usually more economical.

Sacrificial Galvanic Anodes. Sacrificial galvanic anodes are made from special aluminum, magnesium or zinc alloys. The selection of a specific sacrificial anode should be based upon the required driving potential, soil characteristics, availability, cost, weight and durability. In soils application they are generally used where relatively small increments of current are required and where the soil resistivity is low enough to permit obtaining the desired current with a reasonable number of anodes.

Anode Placement. The placement of either impressed or sacrificial anodes depends upon the geometry of the system, the current required, the desired system lifetime, the environmental characteristics (such as type of electrolyte), and resistivity. The configuration of the system also dictates the placement of anodes because it is important that no portion of the structure be shielded from the currents traveling to it through the electrolyte.

Testing. When a cathodic protection system is installed, test points and alarm signals should be installed so that the condition and operation can be checked periodically. Testing of cathodic protection systems is very well described in Air Force Manuals AFM-88-9, Chapter 4, Section VIII, Corrosion Control, and in AFM-85-5, Maintenance and Operation of Cathodic Protection Systems.

Automatic Control and Alarm Systems. Where soil resistivity fluctuates or where periodic inspection is impractical, the installation of automatic controls on an impressed cathodic protection system, available from a number of cathodic protection companies, should be considered.

In remote areas or even critical portions of local systems it might be advantageous to have alarm systems to alert personnel when a system or portion of one is damaged or rendered inoperative. Again, such systems are available from many commercial companies.

Nonautomatic Test Systems. Tests which are made periodically to monitor the operation of a cathodic protection system are described below.

Potential Measurements. Structure-to-soil potentials should be measured to determine the effectiveness of the cathodic protection being furnished.

Current Measurements. The measurement of current output is used to determine the operating condition of anodes and/or rectifiers and to insure that sufficient current is being applied to the protected structure.

Resistance (Resistivity) Measurements. The ability of soil or water to conduct electricity is closely related to the rate at which buried or immersed structures will corrode: the lower the resistance to current flow the higher the rate of corrosion. The practical measure of the ability of a material to resist the flow of electricity is known as resistivity. The greater the soil resistivity the lower its corrosivity.

SECTION IV

Corrosion and Corrosion Control of Internal Surfaces

In order to properly design aviation fuel storage and distribution systems from the standpoint of corrosion control it is first necessary to define the corrosive environment. Then, corrosion-control methods can be selected to insure that the lifetime of the fuel system will be commensurate with the projected lifetime of the overall facility.

1. Classification of Environment. Materials in fuel distribution systems are exposed to many different environmental conditions. Proper definition of these conditions is essential in the design of effective corrosion control methods for these systems.

a. Total Immersion. Many portions of aviation fuel supply systems such as pipelines and valves are normally completely filled with fuel at all times. This constitutes total immersion. Short periods of atmospheric exposure due to equipment failure or periodic maintenance will not significantly change the behavior of most materials from their behavior during constant total immersion. The behavior and protection of materials in conditions of total immersion is dependent primarily upon the fuel, contaminants, temperature, and velocity.

Fuel Classes. Aviation fuels are designated as classes according to their source.

Liquid Hydrocarbons. Liquid hydrocarbons are the fuels derived from petroleum.

Aviation Gasolines. Low flashpoint but a flammable mixture is always present in the vicinity of leaks or where spillage has occurred.

Blended Gasoline, kerosene and light distillates (JP-4 Jet-Engine Fuel). High fire hazard because of extremely low flashpoint (-20°F), and low volatility. Can be ignited by discharge of static electricity generated by the flow of the fuel in pipes.

Kerosene and kerosene-type jet-engine fuels. These are low-volatility, high flashpoint fuels.

JP-5 Fuel. Flashpoint is 140°F.

JP-7 Fuel. Flashpoint is 150°F. JP-7 fuel is highly refined, clear, colorless, thermally stable to withstand high temperatures in jet-engine fuel systems at flight speed. Special materials such as aluminum alloys, stainless steel and non-metallics are required for handling JP-7 fuel.

Methyl Alcohols. Methyl alcohol—water mixtures are used for power augmentation during take-off for certain piston-type engines and gas-turbine jet aircraft.

Contaminants. The successful performance of aircraft engines depends upon the availability of high-quality fuel. The introduction of any form of contaminant will lower the quality of the fuel and seriously impair its efficiency or make it entirely unsuitable for use. The use of contaminated fuels can be the cause of serious damage to the engine and, in many cases, results in complete engine failure. Aircraft engine fuels can be contaminated by the intermixing of petroleum products, by the introduction of foreign matter such as water or solids, or by chemical reaction of the fuel with some component of the fuel handling system.

Intermixing of Products. For example a very small amount of jet-engine fuel or diesel oil will contaminate a high-antiknock gasoline to such an extent that the gasoline loses its ability to resist knocking and loss of power results. Also, mixing can effect deterioration of the fuel handling systems, e.g. a system designed to handle JP-5 will be severely deteriorated if methyl alcohol-water mixture is introduced.

Water. Liquid hydrocarbon fuels are all lighter in weight than water and will separate sharply from entrained water in stationary containers (storage tanks), after sufficient time has elapsed for the water to settle to the bottom. The solubility of water in liquid hydrocarbons is quite low and decreases with the temperature. Thus, lowering of the fuel's temperature tends to release small amounts of dissolved water. This tendency of the fuel to release dissolved water during lowering temperatures, until the dissolved water is released in the form of ice crystals at extremely low temperatures, has complicated the handling of these fuels and caused clogging of line strainers, filters and filter/separators when such temperatures are encountered. At temperatures below that at which water will freeze, the passage of fuel to aircraft engines can be blocked by ice in the aircraft's fuel-system. For this reason, it is of critical importance to prevent delivery of fuel containing free water to any aircraft.

Foreign Solids. Solid contaminants such as foreign debris, or normal rust particles from steel tanks and piping systems, must be prevented from entering the fuel systems of all types of aircraft, as they will cause clogging of the filters on the engine-fuel feed lines and scoring of close precision-fit moving engine parts is passed through the filter. Also, metal ions such as Fe^{++}, Zn^{++}, Cu^{++} can degrade the thermal stability of JP-7 fuel.

Contaminants Picked Up From Contact With Components of the Fuel-Handling System. Two of the minor components that may be present in aircraft engine fuels are mercaptans and naphthenic acids. Mercaptans are sulfur compounds which are limited by current specifications for jet-engine fuels to a maximum concentration of 0.005 percent. Mercaptan sulfur will cause corrosion of cadmium, and zinc if present in the system, and the corrosion is greater if water is present. Napthenic acids are organic acids which can be present in high-boiling jet-engine fuels. However, their concentration is not limited in present aviation fuel specifications. Zinc is rapidly attacked by the naphthenic acids to produce zinc naphthenates, which are soluble in the fuel. Minute amounts of zinc have been found to be highly detrimental to hot parts of aircraft engines; zinc penetrates along the grain boundaries causing embrittlement of the parts. For this reason, zinc-containing coatings, zinc coated and galvanized materials will not be permitted in storage tanks or any other parts of the fuel handling system that come in contact with the fuel. In addition, cadmium-plated steel, copper and copper alloys, because of their susceptibility to corrosion attack by the fuels, shall not be used for components of the aircraft/engine fuel handling system. Steel, black iron stainless steels and some aluminum alloys are less susceptible to corrosion by the fuels, hence their use is permitted. Methyl alcohol is corrosive to aluminum alloys, therefore its use in such a system is prohibited but the use of carbon steel and nonferrous alloys other than aluminum are permitted.

Harmful Effects on Materials. One characteristic of all gasolines, and to some degree their vapors, is their ability to dissolve petroleum oils and portions of grease. This must be taken into consideration in the specifications for lubricants for pump shafts and valves for gasoline service. Some pipe-thread joint pastes that are immune to solution in lower grades of gasoline are partially dissolved by the high-antiknock-value aviation gasoline containing aromatic hydrocarbons, and form a tacky mass, that will plug strainers and filters. High-antiknock-value aromatic aviation gasolines have the ability to soften and deteriorate natural rubber and some types of synthetic rubbers, and these cannot be used in hoses, gaskets, packings, or other seals that come in contact with the gasoline. Jet-aircraft engine fuels contain sufficient gasoline and aromatics to be capable of these same actions. In addition, the characteristics of a penetrating oil develop in jet-engine fuels and cause possibilities for leaks to occur where gasoline will not get through. These characteristics also cause these fuels to loosen rust and scale that have adhered to pipe and tank interiors of systems previously used for aviation gasoline. Methyl alcohol, and to some degree its vapors, will dissolve shellac, gums, dyes, and certain oils, but is not harmful to rubber, asbestos, cork, and most valve packing. The alcohol will dissolve or leach the asphalt in a pavement if allowed to drip or to spill without prompt removal by washing with a hose stream, or by absorbing it with sand, earth, or other inert material. Because of its lower rate of evaporation, jet-engine fuel is particularly harmful to such pavement. For this reason, rigid concrete pavement will be provided for the parking of truck tanks at unloading positions or at truck-fill stands. All pavement-joint sealers will be a jet-fuel-resistant type.

Microorganisms. With the advent of jet aircraft using kerosene-type fuel, the presence of microorganisms in the fuel tanks, especially at the fuel/water interface became a serious problem. Large deposits of sludge and bacterial growth in tanks caused widespread corrosion, fouling of fuel filters and screens. General good housekeeping practices are necessary to clean out accumulating sludge from time to time. Elimination or removal of residual water, protective coatings and chemical additives are the usual methods employed for combating the bacterial growth problem.

Temperature. Because of the volatilization characteristics of all aviation fuels, temperature is an important factor. As temperature increases the volatilization rate increases which can cause an increase in pressure in an unvented system. Therefore, the system must be either adequately vented or constructed of alloys capable of withstanding increases in pressure resulting from increases in temperature.

b. Partial Immersion. Portions of aviation fuel systems such as tank walls, particularly at the tops of the tanks and roofs usually are not in contact with the fuels. Condensation occurring on these portions can cause corrosion; therefore, corrosion-control methods must be considered for these conditions.

c. Alternate Immersion. Portions of aviation-fuel systems such as storage tanks, tank trucks, etc., usually are subject to alternate immersion as the result of emptying and refilling. The conditions of alternate immersion (alternate exposure to the fuel and the air) must be considered in the selection of corrosion-control methods for such applications.

2. Corrosion Control by Materials Selection. The selection of materials which are compatible with the fuel to which they will be exposed is one of the most effective methods of corrosion control. This selection should be based upon the behavior of similar systems, previous performance, results of experimental tests, and the application of basic corrosion behavior. The materials selected must also be compatible with other system requirements such as strength, weight, etc.

a. Basis for Materials Selection.

Behavior of Similar Systems (Previous Performance). If there are aviation-fuel systems in use in which the materials have shown acceptable levels of corrosion resistance these same materials will normally behave in a similar manner in a new system. The longer the time of performance of the existing system the more reliable is the basis for the materials selection.

Results of Experimental Tests. When the information required to select materials on the basis given in Section IV.1 is not available, other selection criteria must be used. Experimental tests, especially long-term tests, are often used as a basis for materials selection for aviation fuel systems. However, such test results must be applied judiciously because seldom, if ever, do such tests duplicate all the variables encountered in an actual installation.

Field Testing. In field testing, specimens of materials are included in actual operating systems. With proper monitoring of operating environments and application of accepted material exposure techniques, the results of these tests are useful in the design of systems using the same or similar fuels. These tests are, however, expensive and time-consuming. Such testing is justified only when the information used for the selection criteria given above is not available. Field testing is useful, however, in predicting actual system lifetimes and in establishing realistic inspection and maintenance schedules for existing fuel systems.

Laboratory Testing. Corrosion testing under laboratory conditions is useful in understanding the basic mechanisms of corrosion and determining the effect of environmental variables on metal behavior. They are normally, however, of rather short duration and usually do not simulate actual operating conditions. Laboratory corrosion testing is not, therefore, normally recommended as a basis for materials selection for fuel systems.

Galvanic Corrosion and Its Prevention. Galvanic corrosion of internal surfaces is attributable to the mechanism described earlier in this report. The basic methods of control of galvanic corrosion of internal surfaces are the same as outlined in that section: use same material throughout the system, use compatible materials throughout the system, or electrically isolate dissimilar materials. The compatibility of dissimilar metals with one another is usually based upon a galvanic series which is experimentally derived for a given environment.

Compatibility With Other System Requirements. As stated in Section III.2 of this report the selection of materials for use in aviation-fuel systems must be based on many factors other than corrosion. Compatibility of the material with the fuel which it must contain or transport is only one factor in materials selection. The selection criteria are for materials which are commonly used in fuel systems and, therefore, meet many of the other selection criteria.

3. Corrosion Control by Protective Coatings. Protective coatings are widely used to protect the interior surfaces of aviation-fuel systems. Their use is often limited by inaccessibility to interior surfaces; however, when protective coatings are properly selected and applied they can give low-cost alternatives to the use of expensive construction materials.

a. Limitations of Coatings for Protection of Interior Surfaces. The major limitation in the use of protective coatings on interior surfaces is the inaccessibility to the surfaces. The interior surfaces of large fuel tanks are readily accessible. The relative accessibility of the surfaces affects the initial application of the coating as well as the inspection and maintenance of the coated surfaces.

Initial Application. The methods used for surface preparation and coating of internal surfaces prior to the application of protective coatings are the same as those stated elsewhere in this report. Tanks larger than 5000 gallons capacity are normally coated on site after fabrication. Smaller tanks are normally shop-coated during manufacture. Many of the surface preparation and coating application methods described in this report have been adapted to the shop coating of internal surfaces of small tanks. This equipment is normally automated. Sandblasting is the normally used surface preparation method. Coatings are usually applied by spraying.

Inspection and Maintenance. When the internal surfaces are accessible, such as in large storage tanks, the inspection and maintenance of the internal coating are readily accomplished when the tank is empty. Inspections should be made at each opportunity, especially when the tanks are being cleaned.

b. Selection of Coatings. Coatings for internal surfaces of aviation-fuel systems, in addition to providing protection to the underlying material, must be compatible with the end use of the fuel. They must not contaminate the fuel with material which adversely affects its quality. The selection of coatings for internal surfaces is based primarily upon accepted industrial standards, although in many applications successful field experience is used.

Based on Specifications for Specific Applications. The Technical Manual on ''Interior Coating Systems for Surfaces in Contact with Petroleum Fuels'' is an excellent guide to the selection of coatings for such applications. Coating systems for specific applications are given in Section V of this report under the appropriate system subheading.

Based on Field Experience. If standard coating systems specified for internal surface coatings have been unsatisfactory in fuel supply systems or are unavailable in the area and nonstandard coatings have been used with satisfactory results then such nonstandard coating systems can be used. However, the use of such nonstandard coatings is recommended only when it has been proven that the coating does not adversely affect the fuel quality, does not produce toxic effects and is approved by the cognizant AF office.

Surface Preparation. The applicability of any commonly used surface preparation methods to the preparation of internal surfaces for coating may be limited by accessibility. However, most of the surface preparations are adaptable to the preparation of all but the most inaccessible areas. The internal surface of large tanks can be cleaned using many of the mechanical methods outlined in Section III.4 of this report. Since air pollution can be controlled in the cleaning of the internal portions of such tanks it is normally the preferred method of on-site surface preparation.

d. Methods of Application. When the surfaces are readily accessible, such as in large tanks, any method of application described in Section III.4 of this report can be used. Spraying is normally the most cost-effective method of applying many coatings, although heavy coatings are often applied using dauber techniques.

e. Coating Maintenance. Coating maintenance is normally not applicable to inaccessible portions of fuel systems. When the surfaces are accessible then the maintenance of the coatings should be accomplished according to the guidelines given in Section III.4 of this report.

4. Corrosion Control by Cathodic Protection. The corrosion control of internal surfaces of aviation fuel storage and distribution systems is considered to be impractical at this time. However, under certain exceptional circumstances it might be considered although the presence of such potential ignition sources in a fuel storage tank will limit their application.

SECTION V

Specific Applications

1. Fuel Storage Facilities. Storage tanks for aviation fuels at installations within the continental limits of the United States should be above ground to reduce the problems of external corrosion, inspection and maintenance unless underground tanks are specifically authorized. Storage of methyl alcohol and water-alcohol blends, and operating storage of aircraft-engine fuels at Air Force bases will normally be in underground horizontal tanks. Each fuel storage tank will be used for only one product and will be so marked. The bottoms of all tanks must have a 5-degree slope to the drainage sump to facilitate the removal of any water and sludge.

a. Materials Selection. Materials for construction of aviation fuel storage tanks must be compatible with the fuel to be stored or they must be protected from corrosion. Steel is the normal material of construction, but aluminum alloy, stainless steel or fiberglass-reinforced plastic storage tanks are used for special fuels. Since fuel storage tanks are usually large, material costs are an important part of the material-selection process.

Steel Storage Tanks. Due to its high strength, toughness, and relatively low cost, steel is usually the material of choice for large fuel storage tanks. Steel tanks are used for storage of all aviation fuels except methyl alcohol, water-methyl alcohol blends and thermally stable (JP-7) aviation fuel. However, tanks used to hold JP-7 fuel must be internally coated to prevent fuel contamination.

Corrosion Resistance. Steel does not resist corrosion by either the atmosphere or the aviation fuels when moisture if present; and for these reasons, protective measures must be employed to prevent corrosion. Bare steel tanks shall not be used.

Methods of Protection. The most commonly accepted methods for protection of steel aviation fuel tanks are coatings and cathodic protection.

Exterior Protection, Above Ground. Protection of undersides of flat-bottomed tanks is seldom critical. If the tank is placed on a well-drained sand pad it will be practically free from corrosion. However, if because of other special considerations additional corrosion protection is desired, the bottom may be painted, or oiled. The paint usually used is an asphalt varnish applied in one coat in accordance with Federal Specification TT-V-51A. Additionally, weld seams are usually protected by 6-inch wide, 1/8-inch-thick asbestos strips which have been saturated with a high-melting-point, corrosion-inhibitive wax. Proper surface preparation and coating procedures as described in Section III of this report should be followed to insure desired coating performance.

For exposed surfaces of steel aviation fuel storage their surfaces should be prepared and coatings applied according to the procedures given in this report. Alkyds are the most widely used paint systems but should only be used in non-marine rural or other mildly corrosive environments. Alkyds may be applied over a commercially blasted steel surface with good results. Two- or three-coat systems of six to eight mils total dry film thickness are recommended. The first coat should be a primer and must be a minimum of two mils thick. If a high-build, two-coat system is being used, the primer may be three mils thick (dry film thickness). Topcoats are available in widely varying colors but are usually chosen to match the surrounding environmental coloration. Greens, browns, tans and white are used most frequently. For application of the exterior paint system the weather should be warm and dry. The minimum temperature usually acceptable for painting is 50°F and the maximum relative humidity is 60%. During painting there must be no tendency for condensation to occur on the steel surface from solvent evaporation. For exterior systems exposed in areas along the coast, or under marine atmospheric conditions which are generally aggressive, or for storage tanks which are exposed in highly corrosive industrial areas, additional corrosion protection is recommended. This may be obtained from a thicker alkyd system, for example an 8- to 10-mil alkyd system, or by going to other paint systems. Some of the other paint systems which have been used are vinyl alkyds, vinyl acrylics, vinyls, PVA latex or an acrylic latex, silicone alkyds, and zinc-rich primer systems. A zinc-rich primed coating system has a number of distinct advantages. Zinc produces a white corrosion product rather than the usual red or reddish-brown steel corrosion product. For this reason rust stains are not produced on zinc-rich primed tanks. The zinc has excellent resistance against abrasion from rocks, etc., and generally protects the steel from abrasive damage of this type. Further, if a rupture occurs in the zinc-rich primer, it affords a degree of cathodic protection in the area adjacent to the break. Both organic and inorganic zinc-rich primers are used with success for exterior priming of fuel tanks. If appearance is not a factor, the zinc-rich primer may be used by itself as a coating system. It has excellent resistance against atmospheric corrosion. However, it is subject to attack in industrial environments if they are either highly acidic or alkaline in nature. Under such corrosive industrial conditions it must be top-coated with a suitably resistant topcoat system; vinyls or vinyl acrylics are frequently used for this purpose. If appearance is a factor, some of the better weathering topcoats include the acrylics, silicone alkyds, and vinyl acrylics.

Exterior Protection, Below Ground. Steel storage tanks and other steel facilities underground are usually protected by a combination of a coating system and a cathodic protection system. Such combinations reduce the current required to achieve complete protection. Protective coating systems alone never form a completely perfect or impervious barrier against intrusion of the environment to the metal surface. Also, such coatings tend to deteriorate with time. Cathodic protection furnishes protection at such defects; thus, a combination affords complete protection against corrosion. Coatings as described in AFM 85-3 should be used in conjunction with a cathodic protection system installed in accordance with AFM 88-9, chapter 4, section VII, August 1962.

Interior Protection. The entire interior surfaces of all steel fuel storage tanks must be coated; this includes the interior surfaces of roofs as well as both surfaces of floating roofs. Tanks will be coated with an epoxy or urethane coating system as described in Department of Defense Manual AD 666969 ''Interior Coating Systems for Surfaces in Contact with Petroleum Fuels.'' The tank surfaces shall be prepared for coating in accordance with the requirements of paragraph 3-50g, AFM 88-15, 11 Feb 1969.

Stainless Steel Storage Tanks. Stainless steel storage tanks shall be of welded construction of AISI Type 316L stainless steel. This type of tank shall be used for storing methyl alcohol, water-alcohol blends, or thermally stable (JP-7) supersonic aircraft fuels.

Corrosion Resistance. Type 316L stainless steel normally is resistant to corrosion in most atmospheres. However, in heavy industrial or severe marine atmospheres light pitting can occur after a considerable period of exposure. Type 316L stainless steel is completely resistant to any chemical attack by the fuels listed above.

Methods of Protection.

Exterior Protection. Usually, no exterior protection is required except for an occasional washing. It is a good practice to wash such tanks occasionally to remove accumulated dirt, especially in severe marine and heavy industrial atmospheres, to prevent the possibility of pitting or crevice corrosion.

Interior Protection. Type 316L stainless steel is used because it is immune to attack by the fuels stored in it; therefore, no interior protection is required. However, any water or sludge which might accumulate in the bottom should be removed during the regular inspections.

Aluminum Alloy Storage Tanks. Aluminum-alloy storage tanks shall be of welded construction using alloys such as 5052, 5454, 5456, 5083, 5086, 6061, 6063, 214 or 356. This type of tank shall be used only for storing thermally stable (JP-7), supersonic aircraft fuels.

Corrosion Resistance. Aluminum alloys, such as those listed above are completely resistant to any chemical action of thermally stable aircraft fuels (JP-7).

Methods of Protection.

Exterior Protection. Except in severely corrosive atmospheres (heavy industrial and severe marine atmospheres), aluminum alloys require no protective coatings unless coatings are desired for decorative or camouflage purposes. Such coatings are specified in AFM 85-3, Jan 1969. Protective coatings for heavy industrial and severe marine atmospheres are also specified in AFM 85-3, Jan 1969.

Interior Protection. To prevent contamination of the JP-7 fuel a coating should be used to coat the interior surfaces of the aluminum alloy storage tanks.

Fiberglass-Reinforced Plastic Storage Tanks. Fiberglass reinforced plastic storage tanks should conform to specification MIL-P-22245. This type of tank is used for storage of methyl alcohol, alcohol-water blends, and thermally stable (JP-7) aircraft fuel.

Corrosion Resistance. These tanks must be completely resistant to attack from any of the fuels intended for storage therein.

Methods of Protection.

Exterior Protection. This type of plastic is sufficiently resistant to degradation in the atmosphere that no protective coatings are required.

Interior Protection. The type of plastic for this application is chosen because it is completely immune to degradation by the aviation fuels given in this report. Therefore, interior protection is neither needed nor permitted.

2. Distribution Systems. Distribution systems are the means by which the aviation fuels are transported from the storage tanks to the point of delivery to the aircraft. This system may be either above ground or buried or both. Corrosion control for such systems is important because of their high replacement cost, the potential for property damage, the possible fire hazard from leakage, and the dependence of the consumer on an uninterrupted fuel supply. This corrosion control is accomplished by proper material selection, system design, protective coatings and cathodic protection.

a. Material Selection. Material selection for distribution systems should be based upon the criteria stated in this report. Distribution system components are exposed to the aviation fuel on the inside and to either soil or atmosphere on the outside. The materials selected must be resistant to both environments or must be protected. The application of several commonly used distribution system materials is given below.

Of the materials discussed below (steel, stainless steel, aluminum alloys, and fiberglass-reinforced plastic), only two can be used unrestrictedly for all fuels downstream of the final filter-separator in the distribution system: stainless steel and fiberglass-reinforced plastic. Steel may not be used at all, and aluminum alloys may not be used with methyl alcohol or water-methyl alcohol blends.

Steel. Steel piping has excellent strength and ductility, is easily fabricated and has a low overall cost. Steel is satisfactorily resistant to internal corrosion by aviation fuels and is used for all fuel distribution systems except methyl alcohol, water-alcohol blends and thermally stable (JP–7) fuel systems. The use of steel, as noted above, is not permitted downstream of the final filter-separator in the distribution system.

The external protection of steel piping above ground is achieved by coating. Coating systems should be selected and the basis of criteria given in Section III.4. Zinc rich coatings are normally recommended for this application and may be topcoated for cosmetic purposes. Other coating systems such as normal alkyd, bitumastic, and tar are also commonly applied to above ground piping.

The external protection of steel piping underground is achieved by coating, and, if required, by coating and cathodic protection. If the soil is aggressive or if a long system life is desired, cathodic protection is recommended in addition to coating. The selection and design of such cathodic protection systems is discussed in Section III.5.

Stainless Steel. AISI Type 316L stainless steel is used for distribution systems for methyl alcohol, water-methyl alcohol blends, and thermally stable (JP-7) aviation fuel because it is immune to corrosion by these fuels. It is one of the required materials for all aviation-fuel systems downstream of the final filter-separator.

Stainless steel requires no internal protection and usually requires no external protection in the atmosphere.

External protection underground may be required under particularly aggressive conditions. In such cases the most satisfactory protective measures would be cathodic protection outlined above.

Aluminum Alloys. Aluminum alloys such as 5052, 5454, 5456, 5083, 5086, 6061 or 6063 are used for the distribution systems for thermally stable (JP-7) aviation fuels. They may be used for all aviation fuel systems except methyl alcohol and water-methyl alcohol blends downstream of the final filter-separator.

Aluminum alloys require no internal protection and usually require no external protection in the atmosphere.

External protection underground may be required under certain circumstances as described in Section III of this report. If protection is required, it can be achieved by coating or cathodic protection or both.

Fiberglass-Reinforced Plastic. Fiberglass-reinforced plastic conforming to specification MIL-P-2245 is suitable for distribution systems for methyl alcohol, water-methyl alcohol blends, and thermally stable (JP-7) aviations fuels. It is one of the materials to be used for all aviation-fuel systems downstream of the final filter-separator. Before such reinforced plastic is specified, its compatibility with the particular fuel in question should be checked.

In general plastics require no protection, neither internal nor external.

b. Design. In order to insure the maximum reliability of aviation fuel distribution systems good design practices must be followed. Design criteria and standards as specified in Chapter 14, AFM 88-15 and Chapter ?, AFM 88-12 should be followed. To ensure maximum corrosion resistance other design factors are also important.

Couplings and Fittings. In order to minimize galvanic corrosion as described above in this report, galvanically compatible materials should be used for couplings and fittings used on metallic aviation-fuel distribution systems. If the piping materials are not suitable for the fabrication of couplings or fittings then materials more noble than the pipe should be used. This will prevent rapid corrosion of the couplings and fittings due to an unfavorable anode-to-cathode area relationship. If more noble couplings and fittings cannot be used, electrical isolation from the pipe must be achieved. Insulating couplings and bushings are available for such isolation. The materials of construction must be immune from attack by the aviation fuel. Also, smooth-faced couplings are suggested. If the couplings do not present a smooth face toward the internal flow, then severe turbulence can be generated and protecting corrosion products can be removed by this turbulence. If the protective corrosion products are removed, extensive corrosion can result, usually just downstream from the rough-faced couplings. This corrosion is a combination of cavitation corrosion and erosion corrosion.

Working Pressure. Normal working pressures of aviation-fuel distribution systems have little or no effect on corrosion. However, deterioration of the system must be taken into account in the determination of safe working pressures. If significant deterioration is expected or discovered, working pressures should be reduced accordingly to avoid catastrophic failures.

Stray Currents. Aviation-fuel distribution systems are susceptible to corrosion by stray currents (electrical currents which flow through paths other than the intended circuit). Direct currents sources are of primary importance. Alternating currents have little effect on aviation-fuel distribution system materials. Stray current sources are commonly grounded direct current power supplies, electric welding equipment, cathodic protection systems, and electroplating plants, etc. Any grounded direct current source can cause stray current corrosion. Stray-current corrosion occurs where the current leaves the structure and can cause rapid failure. Stray-current corrosion can be minimized by connecting the current source directly to the distribution system at the point where current would leave the structure. Stray-current corrosion can also be minimized by the application of cathodic protection or the placement of an intentional anode of scrap iron which is connected to the distribution system at the point where current leaves the distribution system. In many cases the installation of insulating couplings in the system can make it a less favorable path for stray currents; however, if large potential gradients are present this practice may cause accelerated attack at the insulating joint. Stray-current corrosion can usually be detected by measuring the pipe-to-soil potential over a long period of time (24 hours). Since the direct current source usually fluctuates in power level while other sources (galvanic or cathodic protection currents) remain steady, fluctuations in pipe-to-soil potential will reveal the presence of stray currents. A potential direct current source with a similar power fluctuation pattern can be located, and thus the stray-current source can often be determined.

Long-Line Currents. Long-line currents are similar to stray currents in effect but are caused by variations in soil type along a pipeline. Long-line currents are, therefore, a type of concentration cell-caused current. Passage of distribution systems through soils with dissimilar characteristics (salinity, resistivity, pH, etc.) should be avoided. If such routing is not possible, insulating couplings should be installed in the system near the discontinuity between different soil conditions. Externally coated piping is less susceptible to long-line current attack than is uncoated piping. Also, since these currents are usually low, cathodic protection can usually eliminate attack from long-line currents and should be utilized whenever long-line currents are a potential problem.

c. Piping.

Steel. Bare carbon-steel pipe conforming to ASTM specifications, except cross-country or other pipelines over a mile in length, shall conform to API standards for line pipe. Steel pipe shall be used for aviation fuel systems except downstream of the final filter/separator and for special fuels (methyl alcohol, water-methyl alcohol blends and thermally stable (JP-7) aviation fuel).

Stainless Steel. Stainless steel (type 316L) piping shall be used downstream of the final filter/separator of all aviation-fuel systems and for the complete distribution systems for methyl alcohol, water-methyl alcohol blends, and thermally stable (JP-7) aviation fuels.

Aluminum Alloys. Aluminum alloys piping shall be used downstream of the final filter/separator for all aviation-fuel systems except the methyl alcohol and water-alcohol blend systems. It shall be used for the entire distribution system for thermally stable (JP-7) aviation fuel.

Fiberglass-Reinforced Plastic. Fiberglass-reinforced plastic piping shall be used downstream of the final filter/separator of all aviation fuel systems and for the complete distribution systems for methyl alcohol, water-alcohol blends and thermally stable (JP-7) aviation fuel systems.

d. Fittings. Fittings for all piping should be fabricated from the same material as the pipe wherever possible; the use of dissimilar materials will result in galvanic corrosion. This attack can be minimized by the resistivity of the electrolyte (water when present), small differences in galvanic potential, favorable anode-to-cathode area relationships, large distances between anodes and cathodes, and high resistivity in the metallic current paths. Should the use of dissimilar metals be necessary, galvanic corrosion should be minimized by application of these measures. Complete electrical isolation between dissimilar components is often accomplished by utilization of insulating couplings or flanges; they should be included in the design of the aviation-fuel distribution system where galvanic corrosion is a potential problem. Fittings should be designed to present a smooth surface to the internal flow to reduce friction losses in the system and to reduce turbulence which can cause cavitation corrosion, erosion corrosion or impingement attack.

e. Tank Trucks. Tanks for trucks used for transporting aviation fuels from any point downstream of the final filter/separator to planes shall be AISI type 316L stainless steel or an aluminum alloy such as specified above in this section. However, aluminum alloy tanks shall not be used for transporting methyl alcohol or water-methyl alcohol blends.

SECTION VI

APPENDIX — GLOSSARY OF TERMS

Abrasive -- The agent used for abrasive blast cleaning; for example, sand, grit, steel shot, etc.

ABS plastic -- Acrilonitrile-butadiene-styrene plastic.

Absorption -- Process of soaking up, or assimilation of one substance by another.

Active -- Referring to the negative direction of electrode potential, Antonym; noble.

Adhesion -- Bonding strength, the attraction of a coating to the surface to which it is applied.

Adhesive -- A substance capable of holding materials together by surface attachment.

Air drying -- Drying by oxidation or evaporation by simple exposure to air.

Airless spraying -- Spraying using hydraulic pressure to atomize the paint.

Air volume -- Quantity of air in cubic feet (usually per minute) at atmospheric pressure.

Alcohol -- a flammable solvent; alcohols commonly used in painting are ethyl alcohol (ethanol) and methyl alcohol (Methanol, wood alcohol).

Alkali -- Caustic, such as sodium hydroxide, lye, etc.

Alkyd plastics -- Plastics based on resins composed principally of polymeric esters, in which the recurring ester groups are an integral part of the main polymer chain, and in which ester groups occur in most cross-links that may be present between chains.

Alligatoring -- Surface imperfections of paint having the appearance of alligator hide.

Amide -- Curing agent combined with epoxy resins.

Amine -- Curing agent combined with epoxy resins.

Anaerobic -- Free of air or uncombined oxygen.

Anode -- An electrode of an electrolytic cell at which a net oxidation reaction occurs. In corrosion processes, the anode is the electrode that has the greater tendency to go into solution. Antonym: Cathode. Synonym: See inert anodes, sacrificial anodes, and auxiliary electrodes.

Anodic protection -- A technique to reduce corrosion of a metal surface under some conditions by passing sufficient anodic current to it to cause its electrode potential to enter and remain in the passive region.

Asphalt -- Residue from petroleum refining; also a natural complex hydrocarbon.

Auxiliary electrode -- An electrode commonly used in polarization studies to pass current to or from a test electrode. It is usually made out of a noncorroding material.

Barrier coating -- Shielding or blocking coating or film.

Bell end -- An enlarged portion of a pipe that resembles the socket portion of a fitting and that is intended to be used to make a joint by inserting a piece of pipe into it. Joining may be accomplished by solvent cements, adhesives, or mechanical techniques.

Binder -- In a reinforced plastic, the continuous phase which holds together the reinforcement.

Bituminous coating -- Coal tar or asphalt based coating.

Blast cleaning -- Cleaning with propelled abrasives.

Blisters -- Bubbles in dry or partially dry paint film.

Bright blast -- White blast.

Brush-off blast -- Lowest blast cleaning standard, a light blast.

Caking -- Hard settling of pigment from paint.

Catalyst -- Accelerator; curing agent; promoter.

Cathode -- The electrode of an electrolytic cell at which net reduction occurs. In corrosion processes, usually the area which is not attacked. Typical cathodic processes are cations taking up electrons and being discharged, (e.g., $2H^+ \rightarrow H_2$) oxygen being reduced, and the reduction from a higher to a lower valence state.

Cathodic protection -- A technique to reduce corrosion of a metal surface by passing sufficient cathodic current to it to cause its anodic dissolution rate to become negligible.

Caustic embrittlement -- That form of stress corrosion cracking occurring in steel exposed to alkaline solutions. (See stress corrosion cracking.)

Cavitation -- Damage of a material associated with collapse of cavities in the liquid at a solid-liquid interface.

Cell -- A system consisting of an anode and a cathode immersed in an electrolyte. The anode and a cathode may be separate metals or dissimilar areas on the same metal. When the electrodes are in electrical contact with each other, their difference in potential causes current to flow and produces corrosion at the anode.

Chalking -- The development of loose removable powder at or just beneath an organic-coating surface.

Checking -- The development of slight breaks in an organic coating which do not penetrate to the underlying surface. Checking may be described as visible (as seen by the naked eye) or as microscopic (as seen under magnification of 10 diameters).

Chemical conversion coating -- A thin integral protective or decorative film produced in situ by chemical reaction of a metal with a chosen environment.

Chlorinated rubber -- A particular film former used as a binder, made by chlorinating natural rubber.

Coal tar-epoxy paint -- Paint in which binder or vehicle is a combination of coal tar with epoxy resin.

Coatings -- Surface coverings; paints; barriers.

Coat of paint -- Layer of dry paint resulting from a single wet application.

Cohesion -- Property of holding self together as in a paint film.

Composition -- Analysis; make-up.

Cooling water -- Any water that removes heat from a point or area of higher temperature and delivers it to a point or area of lower temperature.

Corrosion -- Oxidation; deterioration due to interaction with environment.

Corrosion fatigue limit -- The maximum stress endured by a metal without failure in a stated number of stress applications under defined conditions of corrosion and stressing.

Corrosion potential (E_{corr}) -- The potential of a corroding surface in an electrolyte, relative to a reference electrode. Synonym: rest potential, open circuit potential, freely corroding potential.

Couple -- See galvanic corrosion.

Cracking -- Splitting, disintegration of paint by breaks through a film to substrate.

Crazing -- A network of checks or cracks appearing on a paint or plastic surface.

Cross-spray -- Spraying first in one direction and then at right angles.

Cure -- To change the properties of a polymeric system into a final, more stable, usable condition by heat, radiation, or reaction with chemical additives.

Curing agent -- A catalytic or reactive material which is required for curing.

Decomposition potential (or voltage) -- The potential of a metal surface necessary to decompose the electrolyte of a cell or a substance thereof.

Degreaser -- Chemical solution (compound) for grease removal.

Depolarization -- The removal of factors resisting the flow of current in a cell.

Deposit -- A foreign substance, which comes from the environment, adhering to a surface of a material.

Descaling -- Removing scale.

Detergent -- Cleaning agent.

Dew point -- Temperature at which moisture condenses.

Dezincification -- A corrosion phenomenon resulting in the parting of zinc from copper-zinc alloys (see parting).

Diffusion -- The movement of material, such as a gas or liquid, in material. If the gas or liquid is absorbed on one side of a piece of material and given off on the other side, the phenomenon is called permeability. Diffusion and permeability are not due to holes or pores but are caused and controlled by chemical mechanisms.

Dilutents -- See thinners.

Dispersion -- Suspension of one substance in another.

Dry spray -- Overspray or bounce back; sand finish due to spray particles being partially dried before reaching the surface.

Drying time -- Time interval between application and a specified condition of dryness.

Dry to touch -- Time interval between application and ability to be touched lightly (tack-free time).

Electrochemical cell -- See cell.

Electrochemical equivalent -- The weight of an element or group of elements oxidized or reduced at 100% efficiency by the passage of a unit quantity of electricity.

Electrolysis -- The chemical change in an electrolyte resulting from the passage of electricity.

Electrolyte -- A chemical substance or mixture, usually liquid, containing ions which migrate in an electric field.

Embrittlement -- Severe loss of ductility of metal or alloy.

Emulsion paint -- Water-thinned paint with an emulsified oil and/or resin or latex vehicle.

Enamel -- A paint which is characterized by an ability to form an especially smooth film, often an alkyd.

Environment -- The surroundings or conditions (physical, chemical, mechanical) in which a material exists.

Epoxy plastics -- Thermoplastic or thermosetting plastics containing ether or hydroxy alkyl repeating units, or both, resulting from the ring-opening reactions of lower molecular weight polyfunctional oxirane resins, or compounds, with catalysts or with various polyfunctional acidic or basic coreactants.

Erosion corrosion -- A corrosion reaction accelerated by abrasion by solid particles carried by a liquid or gas.

Extrusion -- A process whereby heated or unheated plastic forced through a shaping orifice become one continuously formed piece.

Ferrous -- Iron containing.

Filiform corrosion -- Corrosion which occurs under films in the form of randomly distributed hairlines.

Filler -- A relatively inert material added to a plastic to modify its strength, permanence, working properties, or other qualities, or to lower costs. (See also reinforced plastic.)

Fluorocarbon plastics -- Plastics based on resins made by the polymerization of monomers composed of fluorine and carbon only.

Film thickness -- Depth of applied coating, expressed in mils (1/1000 in.).

Fretting corrosion -- Deterioration at the interface between two contacting surfaces accelerated by relative motion between them.

Galvanic corrosion -- Corrosion associated with the current resulting from the coupling of dissimilar electrodes in an electrolyte. Also known as couple action.

Galvanic series -- A list of metals and alloys arranged according to their relative corrosion potentials in a given environment.

Galvanized steel -- Steel coated with a thin layer of metallic zinc applied by a hot dip or electrolytic process.

Gel -- A jelly-like substance.

Gelling (gelation) -- Conversion of a liquid to a gel state.

General corrosion -- A form of deterioration that is distributed more or less uniformly over a surface.

Gloss -- Shininess; lustre; ability to reflect in mirror direction.

Graphitic corrosion -- Deterioration of gray cast iron in which the metallic constituents are selectively leached or converted to corrosion products leaving the graphite intact. (See parting.)

High build -- Producing thick dry films per coat.

Holiday -- Pinhole, skip, discontinuity, void in a paint film.

Holiday detector -- Device for detection of pinholes or holidays of a non-conductive film over a conductive substrate.

Humidity -- Measure of moisture content; relative humidity is the ratio of the quantity of water vapor in the air compared to the greatest amount possible at the given temperature. Saturated air is said to have a relative humidity of 100 percent.

Hydrogen embrittlement -- Embrittlement caused by entrance of hydrogen into the metal. (As for example, through pickling or cathodic polarization.)

Hydrogen overvoltage -- Overvoltage associated with the liberation of hydrogen gas. (See overvoltage.)

Hydrostatic design stress -- The estimated maximum tensile stress in the wall of the pipe in the circumferential orientation due to internal hydrostatic pressure that can be applied continuously with a high degree of certainty that failure of the pipe will not occur.

Immunity -- A state of resistance to corrosion or anodic dissolution caused by the fact that the electrode potential of the surface in question is below the equilibrium potential for anodic dissolution.

Incompatibility -- Inability to mix with or adhere to another material.

Inert anode or electrode -- An electrode which does not corrode or react under an impressed anodic potential.

Inert pigment -- A non-reactive pigment.

Inhibitive pigment -- One which retards the corrosion process.

Inhibitor -- A chemical substance or combination of substances, which when present in the proper concentration in the environment, prevents or reduces corrosion by a physical, physico-chemical or chemical action.

Intercrystalline corrosion -- See intergranular corrosion.

Intergranular corrosion -- Preferential corrosion at grain boundaries of a metal or alloy. Also called intercrystalline corrosion.

Ion -- An electrically charged atom or group of atoms.

Iron rot -- Deterioration of wood in contact with iron.

Langlier index -- A calculated saturation index for calcium carbonate that is useful in predicting scaling behavior of natural water.

Latex -- Rubber like; a common binder for emulsion (water) paints; there are natural and synthetic latexes.

Leveling -- Flowing out to films of uniform thickness; tendency of brush marks to disappear.

Lifting -- Softening and raising of an undercoat by application of a top coat.

Long-line current -- Current flowing through the earth from an anodic to a cathodic area which returns along an underground metallic structure (generally applied only where the areas are separated by considerable distance and where current results from concentration cell action).

Mastic -- A heavy bodied high build coating.

(MEK) methyl ethyl ketone -- A strong flammable organic solvent.

(MIBK) methyl isobutyl ketone -- A strong flammable organic solvent.

Micron μ -- 1 x 10^{-6} meters.

Mil -- One one-thousandth of an inch.

Mill scale -- The heavy oxide layer formed during hot fabrication or heat treatment of metals and alloys.

Mixed potential -- A potential resulting from two or more electrochemical reactions occurring simultaneously on one metal surface.

MVT (moisture vapor transmission) -- Moisture vapor transmission rate through a known membrane.

Noble -- Referring to positive direction of electrode potential, thus resembling noble metals such as gold and platinum. Antonym: active.

Noble potential -- A potential more cathodic (positive) than the standard hydrogen potential.

Non-ferrous -- Containing no iron.

Nylon plastics -- Plastics based on resins composed principally of a long-chain synthetic polymeric amide which has recurring amide groups as an integral part of the main polymer chain.

Olefin plastics -- Plastics based on resins made by the polymerization of olefins or copolymerization of olefins with other unsaturated compounds, the olefins being in greatest amount by weight. Polyethylene, polypropylene and polybutylene are the most common olefin plastics encountered in pipe.

Open circuit potential -- See corrosion potential.

Orange peel -- Dimpled appearance of dry film; resembling an orange peel.

Overcoat -- Second coat; top coat.

Overspray -- Sprayed paint which did not hit target; waste.

Overvoltage -- The change of an electrode potential from its reversible equilibrium value due to polarization. (See hydrogen overvoltage and polarization.)

Oxidation -- Loss of electrons by a constituent of a chemical reaction.

Oxygen concentration cell -- A galvanic cell resulting from difference in oxygen concentration between two locations.

Paint system -- The complete number and type of coats comprising a paint job. In a broader sense, surface preparation, pre-treatments, dry film thickness, and manner of application are included in the definition of a paint system.

Parting -- The selective attack of one or more components of a solid solution alloy.

Pass (spray) -- Motion of the spray gun in one direction only.

Passivation -- A reduction of the anodic reaction rate of an electrode involved in electrochemical action such as corrosion.

Passive-active cell -- A cell, the emf of which is due to the potential difference between a metal in an active state and the same metal in a passive state.

Patina -- The green coating which forms on the surface of copper and copper alloys exposed to the atmosphere.

Permeability -- See diffusion.

pH value -- Measure of acidity or alkalinity; pH 7 is neutral; the pH values of acids are less than 7, and of alkalis (bases) greater than 7.

Phenolic plastics -- Plastics based on resins made by the condensation of phenols, such as phenol and cresol, with aldehydes.

Pin-holing -- Formation of small holes through the coating.

Pits -- Corrosion of a metal surface, confined to a point or small area which takes the form of cavities.

Pitting Factor -- The ratio of the depth of the deepest pit resulting from corrosion divided by the average penetration as calculated from weight loss.

Plasticizer -- A paint ingredient which imparts flexibility.

-- A material incorporated in a plastic to increase its workability and its flexibility or distensibility.

Polarization -- The deviation from the open circuit potential of an electrode resulting from the passage of current, as for example achieving a protected potential of -0.9V with respect to $Cu/CuSO_4$ electrode for a steel structure.

Polyester plastics -- Synonymous with alkyd plastics.

Polyethylene plastics -- Plastics based on polymers made with ethylene as essentially the sole monomer.

Polymerization -- A chemical reaction in which the molecules of a monomer are linked together to form large molecules whose molecular weight is a multiple of that of the original substance. When two or more monomers are involved, the process is called copolymerization or heteropolymerization.

Polypropylene plastics -- Plastics based on polymers made with propylene as essentially the sole monomer.

Poly(vinyl chloride) -- A resin prepared by the polymerization of vinyl chloride alone.

Porosity -- Degree of integrity or continuity of a paint film.

Pot-life -- Time interval after mixing of reactive components of a paint during which liquid material can be properly applied.

Pre-treatment -- Treatment given a surface prior to applying a primer or first coat of paint. For example an acidified wash.

Profile -- Surface contour of a blast-cleaned surface as viewed from the edge; cross section of the surface.

Protective life -- Interval of time during which a paint system protects substrate from deterioration.

Reinforced plastic -- A plastic with some strength properties greatly superior to those of the base resin, resulting from the presence of high strength fillers imbedded in the composition (see also filler).

Resin -- A material, natural or synthetic, contained in varnishes, lacquers and paints; the film former.

-- *A solid, semisolid, or pseudosolid organic material which has* an indefinite and often high molecular weight, exhibits a tendency to flow when subjected to stress, usually has a softening or melting range, and usually fractures conchoidally.

Rest potential -- See corrosion potential.

Rigid plastic -- For purposes of general classification, a plastic that has a modulus of elasticity either in flexure or in tension greater than 7000 kgf/cm^2 (100,000 psi) at 23°C and 50% relative humidity when tested in accordance with ASTM Methods D747, Test for Stiffness of Plastics by Means of a Cantilever Beam, ASTM Method D790, Test for Flexural Properties of Plastics, ASTM Method D638, Test for Tensile Properties of Plastics, or ASTM Methods D882, Test for Tensile Properties of Thin Plastic Sheeting.

Runs -- Curtains or sags in a paint film.

Rust -- Corroded iron; red iron-oxide deposited on metal; also other metal oxides formed by corrosion of iron or steel.

Sacrificial anode -- An anode which corrodes and sacrifices itself, providing protection to an adjoining metallic component.

Sacrificial protection -- Reduction or prevention of corrosion of a metal in an electrolyte by galvanically coupling it to a more anodic metal.

Sandblast -- Blast cleaning using sand as an abrasive.

Saran plastics -- Plastics based on resins made by the polymerization of vinylidene chloride or copolymerization of vinylidene chloride with other unsaturated compounds, the vinylidene chloride being in greatest amount by weight.

Scale -- Rust or other deposits adhering or occurring in thin layers.

Scaling - Process of removing scale. (See descaling).

Season cracking -- A term usually applied to stress corrosion cracking of brass.

Semirigid plastic -- For purposes of general classification, a plastic that has a modulus of elasticity either in flexure or in tension of between 700 and 7000 kgf/cm^2 (10,000 and 100,000 psi) at 23^oC and 50% relative humidity when tested in accordance with ASTM Method D747, Test for Stiffness of Plastics by Means of a Cantilever Beam, ASTM Method D790, Test for Flexural Properties of Plastics, ASTM Method D638, Test for Tensile Properties of Plastics, or ASTM Method D882, Test for Tensile Properties of Thin Plastic Sheeting.

Shelf-life -- Maximum interval in which a material may be stored and still be in usable condition.

Shot blasting -- Blast cleaning using steel shot as the abrasive.

Silicone plastics -- Plastics based on resins in which the main polymer chain consists of alternating silicone and oxygen atoms, with carbon-containing side groups.

Solids -- Non-volatile portion of paint.

Solvent -- A liquid in which another substance may be dissolved.

Spalling -- The chipping, fragmentation, or separation of a surface or surface coating.

Spark tester -- A high voltage holiday detector which sparks at holidays. (See holiday detector.)

Standard electrode potential -- The reversible potential for an electrode process when all products and reactions are at unit activity on a scale in which the potential for the standard hydrogen half cell is zero.

Standard thermoplastic pipe materials designation code -- A means for easily identifying a thermoplastic pipe material by means of three elements. The first element is the abbreviation for the chemical type of the plastic in accordance with ASTM D1600. The second is the type and grade (based on properties in accordance with the ASTM materials specification); in the case of ASTM specifications which have no types and grades or those in the cell structure system, two digit numbers are assigned by the PPI that are used in place of the larger numbers. The third is the recommended hydrostatic design stress (RHDS) for water at 23°C (73°F) in pounds per square inch divided by 100 and with decimals dropped; e.g., PVC 1120 indicates that the plastic is poly-(vinyl chloride), Type I Grade 1 according to ASTM D1784 with a RHDS of 2000 psi for water at 73°F. PE 3306 indicates that the plastic is polyethylene, Type III Grade 3 according to ASTM D1248 with a RHDS of 630 psi for water at 73°F. PP 1208 is polypropylene, Class I-19509 in accordance with ASTM D2146 with a RHDS of 800 psi for water at 73°F; the designation of PP12 for polypropylene Class I-19509 will be covered in the ASTM and Product Standards for polypropylene pipe when they are issued.

Stray current corrosion -- Corrosion resulting from direct current flow through paths other than the intended circuit. For example, by any extraneous current in the earth.

Stress accelerated corrosion -- The increased corrosion caused by applied tensile stresses.

Stress corrosion cracking -- Premature cracking of metals produced by the combined action of corrosion and surface tensile stress (residual or applied).

Styrene-rubber plastics -- Compositions based on rubbers and styrene plastics, the styrene plastics being in greatest amount by weight.

Surface preparation -- All operations necessary to prepare a surface to receive a coating of paint.

Tarnish -- Surface discoloration of a metal resulting from the formation of a thin film of corrosion product.

Thermogalvanic corrosion -- Corrosion resulting from a galvanic cell caused by a thermal gradient.

Thermoplastic -- Capable of being repeatedly softened by heating and hardened by cooling through a temperature range characteristic of the plastic, and that in the softened state can be shaped by flow into articles by molding or extrusion.

Thermoset -- A plastic which, when cured by application of heat or chemical means, changes into a substantially infusible and insoluble product.

Thinners -- Volatile organic liquids for reducing viscosity; solvents.

Tie coat -- Intermediate coat used to bond different types of paint coats.

Tooth -- Profile; mechanical anchorage; surface roughness.

Toxic -- Poisonous.

Toxicity -- Degree of poisonousness or harmfulness.

Throwing power -- The relationship between the current density at a point on the specimen and its distance from the counter electrode. The greater the ratio of the surface resistivity shown by the electrode reaction to the volume of resistivity of the electrolyte the better is the throwing power of the process.

Tuberculation -- The formation of localized corrosion products scattered over the surface in the form of knoblike mounds.

Urethane plastics -- Plastics based on resins made by the condensation of organic isocyanates with compounds or resins that contain hydroxol groups.

Vinyl plastics -- Plastics based on resins made from monomers containing the vinyl group $CH_2 = CH -$.

Vinylidene chloride plastics -- See saran plastics.

Viscosity -- A measure of fluidity.

Viscosity cup -- A device for measuring viscosity.

Voids -- A term generally applied to paints to describe holidays, holes, and skips in the film.

Volatiles -- fluids which evaporate rapidly from a paint film.

Wash primer -- A thin inhibiting paint usually chromate pigmented with a polyvinyl butyral binder.

Weld decay -- Localized corrosion of weld metal.

White blast -- Blast cleaning to white metal.

SECTION VII

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