FACILITY AND INFRASTRUCTURE CORROSION PREVENTION AND CONTROL

SUSTAINMENT (MAINTENANCE AND REPAIR)

Training Objectives

Training Objectives:

- Identify corrosion prevention and control (CPC) impacts and opportunities during facility sustainment
- Identify the importance of preventive maintenance with respect to corrosion prevention and control
- Introduce key project and environmental factors that affect the rate of corrosion and component service life
- Discuss cathodic protection as a corrosion control strategy
- Identify paints and coatings tools and resources
- Identify resources, training , and sustainment feedback opportunities for CPC

Importance of Corrosion Prevention and Control During Maintenance & Sustainment

- Corrosion
  - Adds nearly $2B in annual facility sustainment costs across the DoD and may be as much as 40% of an asset's life cycle cost
  - Affects mission readiness – facility capacity & downtime, personnel productivity, and asset employment
  - Affects safety, health, and quality of life

The DoD is required by law[1] and policy[2] to investigate corrosion prevention and mitigation strategies for enhancing the sustainability of existing facilities and ensuring the integration of corrosion prevention and mitigation technologies in newly constructed facilities and infrastructure

[1] 10 USC Sec 2228 and the House Armed Service Committee Report accompanying H.R. 1540, The National Defense Authorization Act (NDAA) for Fiscal Year 2012 (H.R. Rep. No 112-78, p. 293)
[2] DoDI 5000.67, February 2010, Prevention and Mitigation of Corrosion on DoD Military Equipment and Infrastructure

Definition of corrosion *– 10 USC Sec. 2228*

CORROSION

The deterioration of a material or its properties because of a reaction of that material with its chemical environment.

Traditionally thought of as deterioration of metal (e.g., rusting of steel) but includes:

- Degradation of non-metallic materials
  - Wood rot
  - Concrete carbonation and alkali silica reaction
  - Composite material degradation
  - Mold and mildew destruction of fabrics and organics

- Degradation from
  - Fluid flow, i.e. erosion corrosion
  - Stressed induced, i.e. stress corrosion cracking
  - Embrittlement
  - Biological processes
  - Solar exposure

High Sustainment Cost Systems and Components

Components and systems with high sustainment costs associated with corrosion:

- Building envelope - Exterior doors, windows, and roofing
- Exterior attachments- Stairways, gutters/down spouts, lighting fixtures, electrical panels, and mechanical louvers
- Interior spaces with high humidity, plumbing, and fixtures
- Interior spaces routinely open to the exterior and non conditioned spaces that are vented.
- HVAC systems
- Pavements
- Utilities and buried structures
- Waterfront and coastal structures
- Wastewater plants

Sustainment

Sustainment:

The maintenance and repair activities necessary to keep an inventory of facilities in good working order. It also includes major repairs or replacement of facility components (usually accomplished by contract) that are expected to occur periodically throughout the life cycle of facilities.

From a corrosion prevention and control perspective it is best to group the maintenance activities as follows:

- <u>Preventive Maintenance </u>– maintenance tasks including inspection, monitoring, routine maintenance, and correction of incipient failures either before they occur or before they develop into major defects or fail.

- <u>Corrective Maintenance </u>- maintenance and repair activities which is carried out after failure detection and is aimed at restoring an asset to a condition in which it can perform its intended function

Maintenance Timing

In general, preventive maintenance is more cost effective than corrective maintenance. Corrective maintenance is also referred to as "reactive maintenance" and can affect DoD readiness. Waiting for the component to fail or be near failure results in:

- Emergency repair procedures
- Downtime and lost productivity
- Labor and material cost for component removal and replacement
- Shortened service life of the component

The importance of preventive corrosion maintenance:

Typically, materials degrade at a higher rate once rust forms and chemical deterioration of the material begins.

Predictive Maintenance

Predictive maintenance is a higher form of preventive maintenance based on the periodic inspection and monitoring of corrosion damage and component condition. This form of maintenance can be valuable in controlling corrosion and optimizing maintenance budgets.

The chart below contains a typical component service-life curve which identifies the economic "sweet spot" for maintenance investment based on the asset condition index

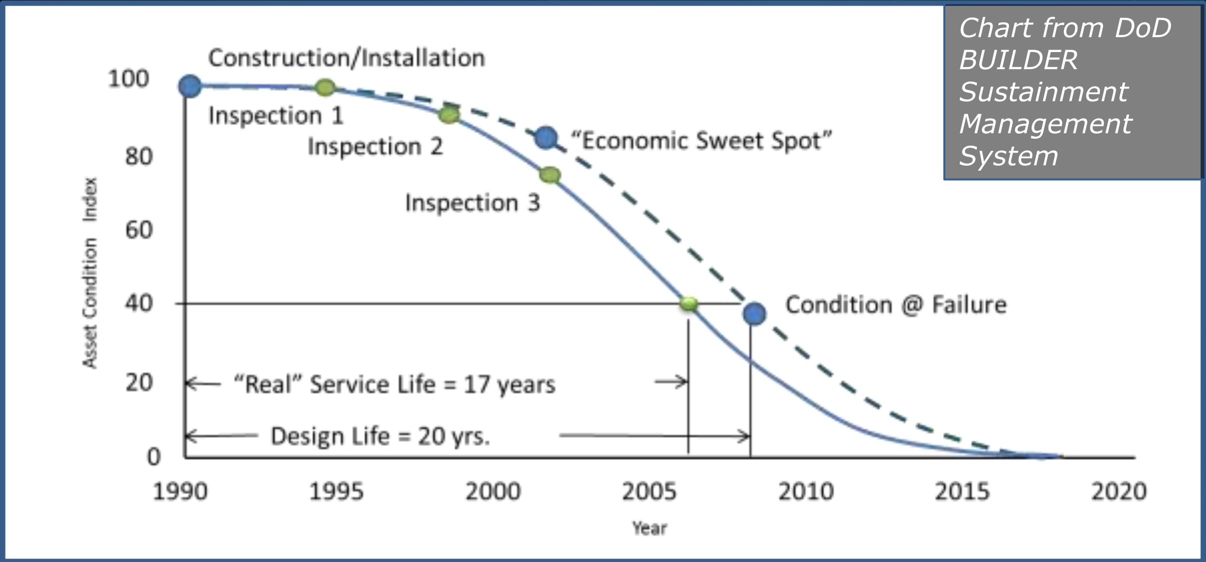
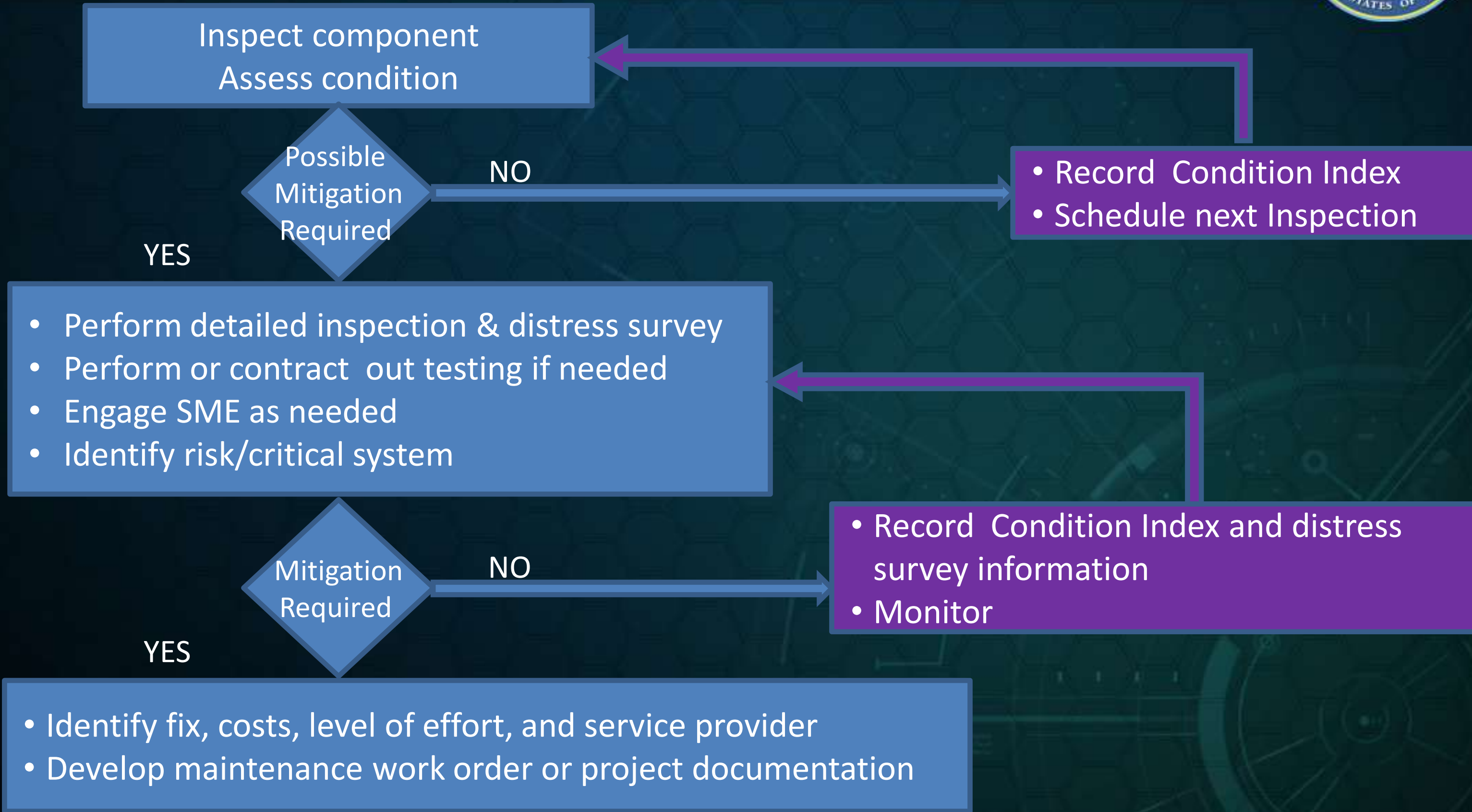


Chart from DoD BUILDER Sustainment Management System

Predictive Maintenance – General Process



Corrosion Inspection and Analysis

Key information:

- Corrosive Environmental Severity
- Type and Extent of Corrosion
- Component Age & Material
- Design Characteristics
- Construction Impacts

Corrosive Environmental Severity

Environmental Severity must be considered when evaluating the effects of corrosion and in developing a maintenance and repair strategy. Environmental factors include:

- Airborne salinity
- Time of wetness
- Temperature
- Humidity
- Pollution
- Prevailing winds
- Insects & fungi (mold & mildew)
- Erosive forces – wind, wave action, fluid flow
- UV/Solar exposure
- Subsurface conditions
    - Submerged (e.g. water conditions)
    - Buried (e.g. soil corrosiveness)

Example:
The SSPC Painting Manual Vol. 2 contains useful tables to help select coatings and painting systems for different environmental zones and special service conditions

http://www.sspc.org

Environmental Severity – Metals and Alloys

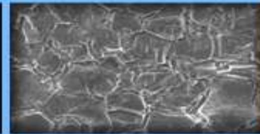
Airborne salinity, time of wetness, humidity, temperature, pollution, and soil PH and resistivity are the major environmental factors affecting the corrosion of metals and alloys:

- Environmental severity can vary significantly across an installation based on proximity to salt water, exposure to prevailing winds, and exposure to industrial pollutants
- Localized corrosion effects can be more important and destructive than general attack

Additional information on the environmental corrosive effects on metals and alloys can be found in the following International Organization for Standardization (ISO) standards:

- ISO 9223 Corrosivity of Atmospheres — Classification, determination and estimation
- ISO 9224 Corrosivity of Atmospheres — Guiding values for the corrosivity categories
- ISO 9225 Corrosivity of Atmospheres — Measurement of environmental parameters affecting corrosivity of atmospheres
- ISO 11303 Guidelines for selection of protection methods against atmospheric corrosion
- ISO 11844-(1,2,3) - Classification of low corrosivity of indoor atmospheres

Identifying the Major Types of Corrosion

	Uniform (general)		Intergranular
	Pitting		Selective Leaching/Dealloying
	Crevice		Stress Corrosion Cracking
	Galvanic		Solar Ultraviolet degradation
	Erosion Corrosion		Other less common types and combinations

Most materials of construction have susceptible environments that may induce early and rapid degradation.

Component Age & Material Identification

In addition to establishing the type and extent of corrosion, it is important to identify the age of the facility/component in question as well as the type of component materials and coatings.

This information will help in determining the rate of corrosion, the corrosion susceptibility of the component materials and coatings, and will help in the development of mitigation strategies. Suggested resources include:

- Component maintenance and replacement history
- As-built engineering drawings and contract specifications
- Design-build request for proposal (RFP) and the accompanying performance technical specifications
- Operation and Maintenance Support Information (OMSI) manual and associated electronic data
- Construction submittals
- Contracting officer technical representatives and subject matter experts
- Architect/Engineer of record
- Unified Facility Criteria (UFC) & Unified Facility Guide Specifications (UFGS)

Design Characteristics and Defects

Improper material selection and poor design detailing will accelerate deterioration of building components and interfere with their protection by coatings. Identifying the following design defects are important when developing a maintenance plan and mitigation strategy:

- Water Traps and Crevices
- Rough and Sharp Surfaces
- Incompatible Environments
- Contact of Dissimilar Metals
- Lack-of Coating or Improper Coating Selection
- Building Envelope Integrity
- Insufficient concrete cover or mix design

Design Characteristics - Water Traps & Crevices

Water Traps and Crevices

Since water greatly accelerates deterioration, structures should be designed so that water is not trapped. Most coatings are designed for atmospheric exposure and not immersion.

Examples include:

- Angle shapes and other configurations that are oriented upward
- Skip welds
- Missing or insufficient sized weep holes
- Condensate water from air conditioners allowed to run or drip on surfaces
- Steam or other vapors impinging on surfaces
- Improper or missing flashing
- Pipe support details that trap water

Design Characteristics and Defects (cont)

- Rough and Sharp Surfaces

- Contact of Dissimilar Metals

- Incompatible Environments and Materials
- Lack-of a Coating or Improper Coating Selection

- Insufficient concrete cover or inadequate concrete mix design

Design Characteristics – Building Envelope

The building envelope is designed to control the transfer of heat, air, moisture, light/radiation, and noise. In order to prevent interior corrosion and mold, it is important to have the following elements which make up the building envelope, continuous and sealed:

- Rain screen or water deflection layer
- Insulation or thermal barrier
- Air barrier
- Water drainage plane
- Waterproof barrier
- Fenestrations & penetrations (Doors, windows, vents, etc.)

Cursor here for additional information

Infrared thermography is useful in determining areas of the building envelope that have thermal leakage which often translates into barrier integrity issues. Blower door tests can help identify the amount and rate of leakage.

Construction Impacts

Construction practices that affect corrosion include:

- Field modifications and material substitutions
- Improper storage of materials
- Damage to coatings
- Improper concrete placement
- Field cuts and cut edge corrosion
- Improper welding
- Improper insulation and leakage or HVAC ducts and utility piping
- Building envelope penetrations

Corrosion of Underground Utilities

Most pipeline and tank leaks are caused by interior or exterior corrosion.
(Less frequent causes of leaks include cracked welds, split seams and joints, separation at collars, buried flanges, and threaded pipe.)

Generally, buried metal pipelines and tanks suffer from corrosion because of one or more of the following soil conditions:

- Low Resistivity values
- High moisture content
- Low pH values (Acidity)
- Presence of chlorides, sulphides, and bacteria
- Differences in soil composition

In addition, the corrosion potential can be increased due to:

- Dissimilar materials, including new and old adjacent materials
- Surface scratches and irregularities
- Presence of stray currents

Resistivity and Moisture

Generally soil resistivity has the greatest impact on corrosion with respect to soil properties and environmental conditions. Soils with the poorest drainage (clays) and highest moisture content are generally the most corrosive and lower resistivity values. Conversely well drained soils (sands and gravels) have higher resistivity and are considered the least corrosive. Backfilling pipe trenches and excavations with sand or gravel improves the long-term protection in corrosive poorly draining soils.

Soil Type	Resistivity (Ω · cm) (ohm · cm)
Gravel	20,000 to 400,000
Sand	10,000 to 500,000
Loam	3,000 to 20,000
Silt	1,000 to 2,000
Clay	500 to 2,000

Corrosivity	Resistivity (Ω · cm)
Not likely	Over 30,000
Mild	10,000 to 30,000
Moderate	2,000 to 10,000
Severe	0 to 2,000

Corrosion of Underground Utilities & Structures

Acidity of the Soil (pH)

Soils usually have a pH range of 4.5 – 8.0. More acidic soils (pH 0 - 4.5) may represent a serious risk to common construction materials and metal. Soils acidity is produced by mineral leaching, decomposition of acidic plants, industrial wastes, acid rain and certain forms of micro-biological activity.

Chlorides, Sulphides, and Bacteria

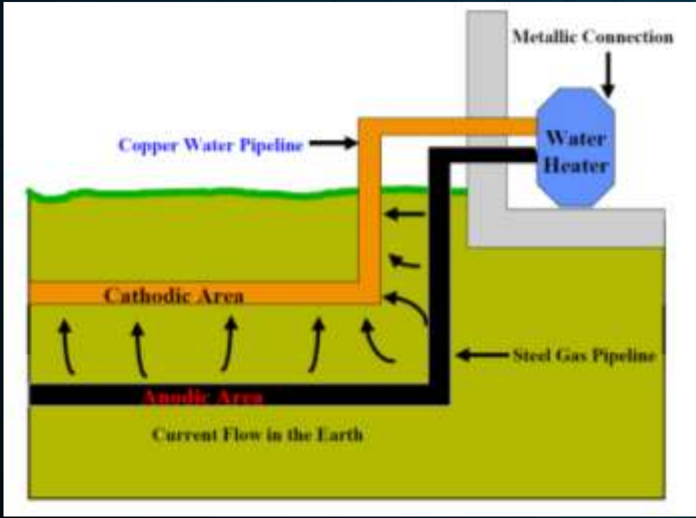
Chloride ions are harmful, as they participate directly in pitting initiation of metals and their presence tends to decrease the soil resistivity. They may be found naturally in soils as result of brackish groundwater and historical geological sea beds or from external sources such as de-icing salts. Sulphates are generally considered to be less aggressive, however sulphates can be converted to highly corrosive sulphides by anaerobic sulphate reducing bacteria. These microorganisms normally operate in temperatures from 20 to 30 °C, pH from 6 to 8, and soil resistivities from 500 to 20,000 $\Omega \cdot$ cm

Note : AWW/ANSI C105/A21.5 Standard contains a 10 point soil evaluation test method for evaluating corrosivity of soils on cast iron pipes.

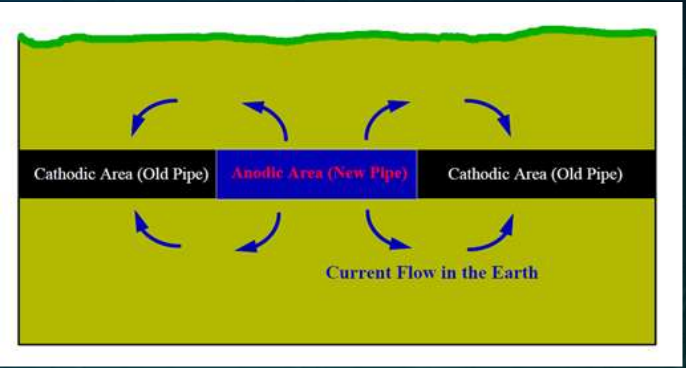
Corrosion of Underground Utilities

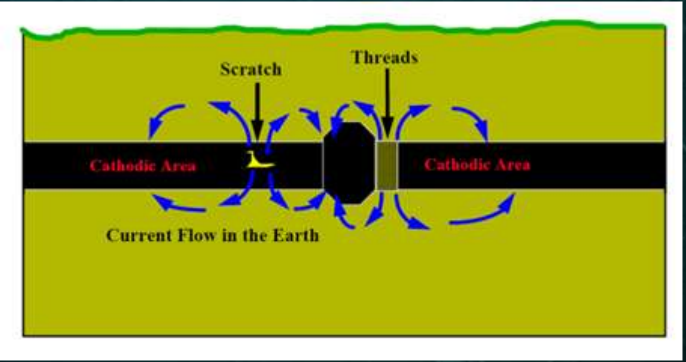
Increasing the corrosion potential

Dissimilar Metal Corrosion Cell



Old-to-New Syndrome





Marred, Scratched, and Irregular Surfaces

Corrosion of Underground Utilities & Structures

Stray Currents

Stray currents flow into pipe systems and other buried structures from direct-current (DC) and to a smaller degree alternating-current (AC) producing systems such as:

- Distribution lines
- Substations
- Street and underground railway systems (metros, trams, or trolley bus systems)
- DC welding systems
- Other DC power supply systems.

The corrosion resulting from stray currents is similar to that from galvanic cells; specifically, the corroding metal is again considered to be the anode from which current leaves to flow to the cathode. Soil and water characteristics affect the corrosion rate in the same manner as with galvanic-type corrosion.

The development of stray current can be suppressed with a proper electrical insulation of the pipe (coatings or wrappings) and / or cathodic protection. The most common types for cathodic protection are impressed current cathodic protection and sacrificial anode cathodic protection.

Cathodic Protection (CP)

For buried utilities and structures, there are typically two choices:

1. Periodically replace the utility when the leak failure rate becomes an operational or financial burden

2. Provide and maintain a cathodic protection system in conjunction with a protective coating

Properly installed and maintained cathodic protection systems can:

- Reduce life cycle costs by indefinitely extending a utility's lifetime.
- Reduce the government's potential liability from premature failure of utilities, such as gas line explosions and jet fuel leaks.
- Avoid costs associated with the leak such as fines, environmental cleanup, remediation and disposal of contaminated soil, and monitoring requirements

Cathodic Protection

Systems that may employ cathodic protection (CP) in a corrosion control program:

(* buried/submerged metallic structures and systems that usually <u>require</u> both CP and protective coatings regardless of soil or water corrosivity)

- *Natural gas piping.
- *Liquid fuel piping.
- *Oxygen piping.
- *Underground storage tank (UST) systems.
- *Underground fire protection piping.
- *Ductile iron pressurized piping under floor (slab on grade).
- *Underground heat distribution and chill water piping in metallic conduit.
- *Systems with hazardous products
- *Elevated and ground level tanks
- Potable water distribution systems.
- Natural gas distribution systems.
- Compressed air distribution systems.
- Fire mains
- Sewage lift stations.
- Steel sheet pile seawalls, pier support/fender piles, and other submerged steel structures.
- Concrete reinforcing steel.

Cathodic Protection Inspection and Maintenance

UFC 3-570-06 O&M: Cathodic Protection Systems

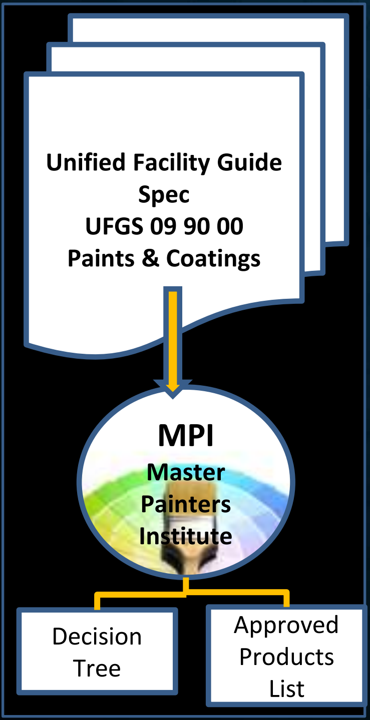
System performance can be monitored by measuring the supplied current, by measuring the potential of the structure, or (preferably) by a combination of the two methods. Scheduled maintenance may include inspection and adjustment of equipment items, such as current rectifiers or anodes; unscheduled maintenance may include troubleshooting and repair of items identified as defective during scheduled inspections, such as anode beds or electrical conductors. Periodic documented cathodic protection surveys should be accomplished.

Other applicable standards:

- National Association of corrosion Engineers (NACE)
  - SP0169, Corrosion Control of External Corrosion on Underground or Submerged Metallic Piping Systems
  - SP0285, Corrosion Control of Underground Storage Tanks By Cathodic Protection
  - RP0388, Impressed Current Cathodic Protection of Internal Submerged Surfaces of Steel Water Storage Tanks
  - RP0193, External Cathodic Protection of On-Grade Metallic Storage Tank Bottoms
  - SP0196, Galvanic Anode Cathodic Protection of Internal Submerged Surfaces of Steel Water Storage Tanks

- UFC 3-570-01 Cathodic Protection (Soon to be published as a result of update and unification of UFC 3-570-02A Cathodic Protection & UFC 3-570-02N Electrical Engineering Cathodic Protection

Paints and Coatings Resources



Architectural Painting Specification Decision Tree
http://www.wbdg.org/tools/apsdt.php?c=5

UFC 3-190-06 Protective Coatings and Paints
http://www.wbdg.org/ccb/DOD/UFC/ufc_3_190_06.pdf

UFGS http://www.wbdg.org/ccb/browse_cat.php?c=3

SSPC Painting Manual Volume 2 (Cursor Over)
http://www.sspc.org

- Coating Condition Inspections and Testing Options:
  - SSPC-PA 2 Procedures for Determining Conformance to dry coating thickness Requirements
  - SSPC-VIS2 Standard Method of Evaluating Degree of Rusting on Painted Steel Surfaces
  - ISO 4628-3 Evaluation of Degradation of Coatings
  - ASTM D610 Standard Test Method for Evaluating Degree of Rusting on Painted Steel Surfaces
  - Other ISO and ASTM Standards are available for evaluating Blistering, Cracking, Flaking, Chalking, and Delamination of Coatings
  - Other tests include Cure Tests, Adhesion Tests, Low Voltage (Wet Sponge) Holiday Testing, and High Voltage Holiday Testing

Mold Response, Assessment, and Remediation

In addition to causing a variety of negative health impacts, mold can degrade and destroy building materials and fabrics

Mold assessment, investigation, and remediation usually result from conditions associated with the following:

- Catastrophic Event – Water damage from a catastrophic event such as hurricane, storm, flood, or internal building system rupture or discharge. Stop initial water infiltration and begin clean up immediately. An immediate response (within 24 to 48 hours) and thorough clean up, drying, and/or removal of water damaged materials will prevent or limit mold growth.

- Chronic moisture intrusion and high humidity levels (greater than 60%) can lead to indoor air quality issues and mold growth both visible and hidden. These conditions can result from many causes such as:
    - Inadequate ventilation
    - Damage to building elements and systems
    - Defective design of building envelope and systems
    - Inadequate commissioning, testing, and balancing of the HVAC system
    - Inadequate maintenance and repair of the building elements and equipment
    - Improper or unplanned use of ventilation system and operable windows

Mold Remediation

- As adapted by the New York City Department of Health, Guidelines on Assessment and Remediation of Fungi in Indoor Environments and EPA Guidelines, response actions may be broken down into separate and distinct categories:
  - Level 1 Small Isolated Areas 10 sq. feet or less
  - Level 2 Mid Size Isolated Areas 10 – 100 sq. feet
  - Level 3 Extensive Contamination Greater than 100 contiguous sq. ft. in an area
  - Level 4 Contaminated HVAC

  Requirements for each level vary with respect to remediation response, personnel training, personal protective equipment (PPE), work area occupancy and isolation, ventilation, dust suppression, and material disposal.

- Resources:
  - Unified Facilities Guide Specification UFGS 02 85 00.00 20 Mold Remediation
  - Unified Facilities Guide Specification UFGS 01 35 29.13, Health, Safety, and Emergency Response Procedures for Contaminated Sites
  - U. S. Army Corps of Engineers Safety and Health Manual, EM 385-1-1
  - Interim Technical Guidance ITG FY03-04 NAVFAC Mold Response Manual
  - Certified Industrial Hygienist and/or the Occupational Safety and Health Manager or designated representative
  - WBDG resource pages (Cursor Over)

Additional CPC Maintenance and Design Resources

- UFC 3-460-03 O&M: Maintenance of Petroleum Systems
- UFC 3-460-01 Design: Petroleum Fuel Facilities (Chapter 12 Major Rehabilitation)
- API 653 Tank Inspection, Repair, Alteration, and Reconstruction
- UFC 3-430-07 Operations and Maintenance: Inspection and Certification of Boilers and Unfired Pressure Vessels

- For Concrete and Pavements:
  - UFC 3-250-06 Repair of Rigid Pavements Using Epoxy Resin Grouts, Mortars and Concretes
  - UFC 3-250-08FA Standard Practice for Sealing Joints and Cracks in Rigid and Flexible Pavements
  - UFC 3-260-16FA Airfield Pavement Condition Survey Procedures Pavements
  - UFC 3-270-03 Concrete Crack and Partial-Depth Spall Repair
  - UFC 3-270-04 Concrete Repair
  - UFC 3-270-05 Paver Concrete Surfaced Airfields Pavement Condition Index (PCI)
  - UFC 3-270-07 O&M: Airfield Damage Repair
  - UFC 3-270-08 Pavement Maintenance Management

Unified Facility Criteria (UFC) found on www.wbdg.org

Training and Certification

It is valuable to have a sustainment staff and support contractors trained and certified in the inspection and maintenance associated with material corrosion and degradation of facilities, components, and coatings. Some available training and certification programs:

- NACE International (The Corrosion Society)
  http://www.nace.org/Training-Education/

- SSPC (The Society for Protective Coatings)
  http://www.sspc.org/training/SSPC_Training_Programs_from_A_Z/

- Steel Tank Institute
  http://www.steeltank.com/Education/EducationandTraining/tabid/481/Default.aspx
  - STI SP001 Aboveground Tank System Inspector Training
  - STI Cathodic Protection Course and Certification

Feedback from Sustainment Activities

The maintenance and sustainment activities in the military department's maintenance databases and sustainment management systems offer the greatest opportunity to obtain true performance and reliability data. Feedback opportunities:

- In computerized sustainment and maintenance management systems, identify the sustainment performed on the facility down to the subcomponent or equipment level. Identify the condition (usually a condition index rating) for the subcomponent. Where possible, identify the corrosion specifics, distressed elements, and design/construction defects.
- For criteria issues, use the Criteria Change Request (CCR) feature located adjacent to each UFC or UFGS on the Whole Building Design Guide
- Contact the Corrosion SME, Contracting Officer, or Project Technical Lead

Resources – DoD Subject Matter Experts

DoD Subject Matter Experts:

- CorrDefense https://www.corrdefense.org
- US Army Corps of Engineers, Engineer Research Development Center (ERDC) http://www.erdc.usace.army.mil/
  - Construction Engineering Research Lab (CERL), Champaign, IL http://www.erdc.usace.army.mil/Locations/ConstructionEngineeringResearchLaboratory.aspx
  - Geotechnical and Structures Laboratory (GSL), Vicksburg, MS http://www.erdc.usace.army.mil/Locations/GeotechnicalandStructuresLaboratory.aspx
- Naval Facilities Engineering Command
  - Engineering and Expeditionary Warfare Center (EXWC) Port Hueneme, CA https://www.navfac.navy.mil/navfac_worldwide/specialty_centers/exwc/products_and_services/capital_improvements.html
  - Engineering Criteria and Programs Office. NAVFAC Atlantic, Norfolk, VA
- US Air Force Civil Engineering Center (AFCEC), Operations Directorate, Engineering Division http://www.afcec.af.mil/facilityengineering/index.asp

Other Resources

DoD Facility Criteria - Whole Building Design Guide http://www.wbdg.org

- CPC Source Page http://www.wbdg.org/resources/cpcsource.php
- Unified Facility Criteria http://www.wbdg.org/ccb/browse_cat.php?c=4
- Unified Facility Guide Specifications http://www.wbdg.org/ccb/browse_cat.php?c=3
- NAVFAC Design-Build Performance Technical Specifications (PTS) http://ndbm.wbdg.org/system/html/6/
- Engineering and Construction Bulletins (ECB) http://www.wbdg.org/ccb/browse_cat.php?c=268

Industry:

- Master Painters Institute (MPI) http://www.mpi.net/
- NACE International (The Corrosion Society) http://www.nace.org
- SSPC (The Society for Protective Coatings) http://www.sspc.org
- STI (Steel Tank Institute) http://www.steeltank.com

Training Sponsor

This training is provided by the

Office of the Under Secretary of Defense (AT&L),
Corrosion Policy and Oversight