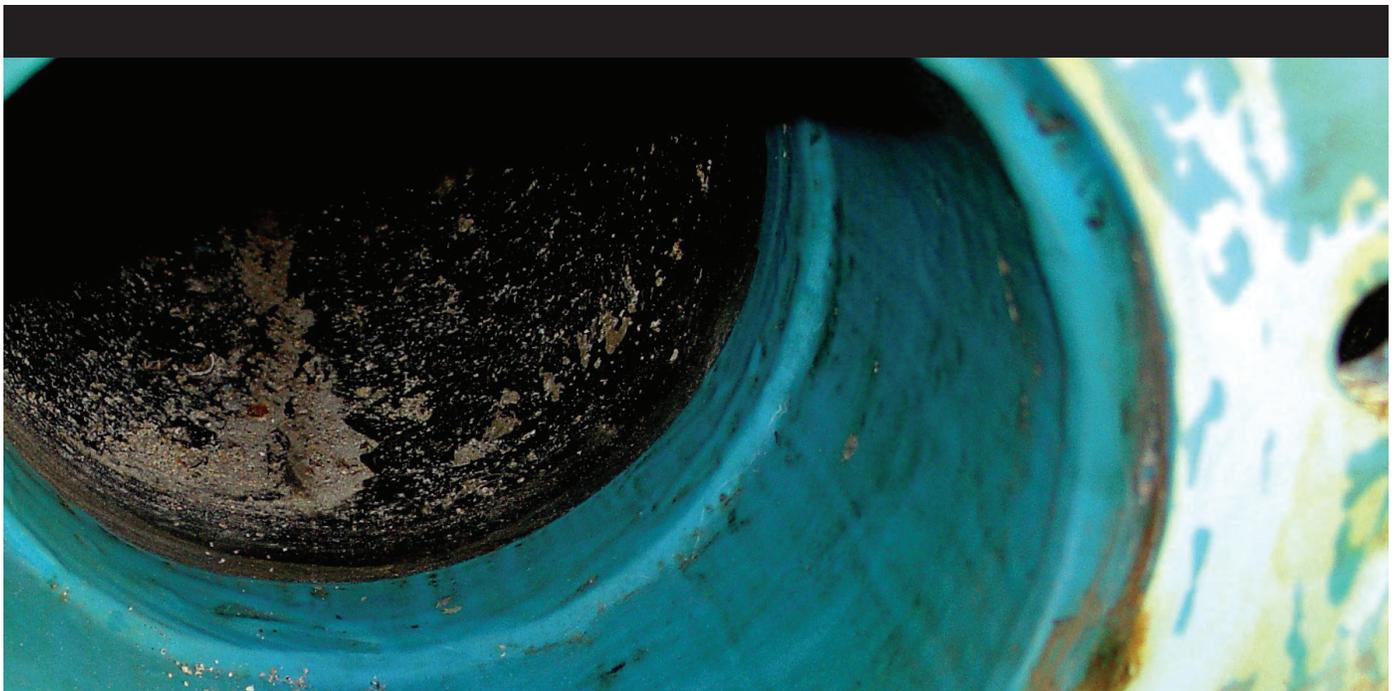


# PROTECTIVE COATINGS FOR POWER PLANTS

**Maintaining the First Line of Defense**





A field guide illustrated with dozens of color photos will improve plant engineers' understanding of coating degradation mechanisms, condition assessment, and mitigation options, providing the foundation for effective coating maintenance programs. This white paper summarizes EPRI report 1025323, *Field Guide: Coatings Assessment*.

Protective coatings and linings are used throughout power plants as a first line of defense against corrosion, cracking, erosion and other types of degradation that can damage components ranging from nuclear reactor containments and concrete structures to buried piping and tanks. With age and exposure, coatings may degrade, compromising their protective function. Effective maintenance of coatings, therefore, is essential in ensuring continued safe, reliable, and economical plant operation.

An effective coatings and linings maintenance program is based on an understanding of coating fundamentals, degradation mechanisms, condition assessment methods, and repair or mitigation options. Armed with this knowledge, plant engineers can:

- Evaluate the integrity of protective coatings and linings in the plant
- Recognize coating and lining degradation
- Identify the stressors contributing to degradation and identify locations where degradation could occur
- Identify appropriate actions to mitigate the stressors contributing to degradation
- Correct damage that has occurred

Recognizing that such knowledge was not readily accessible to power plant maintenance engineers, the Electric Power Research Institute (EPRI) developed a practical field guide to support coating and lining condition assessment, *Field Guide: Coatings Assessment* (EPRI Product 1025323). EPRI also offers a comprehensive coatings training course to equip coatings specialists with the foundation to develop or augment effective coating maintenance programs.

## Coating Fundamentals

Although the terms *paint* and *protective coating* are often used interchangeably, the terms are not equivalent. Paint is a liquid that, after application to a suitable substrate, will form a solid, continuous film to provide a weather-resistant decorative surface. A protective coating is a material that, after application to a suitable substrate, will develop a continuous film that resists industrial or marine environments and also resists breakdown of its basic structure under the influence of abrasion or imperfections.

Coatings are used throughout nuclear power plants, including inside the primary containment, in safety-related applications outside of primary containment, and in the balance of plant (BOP), including buried pipe and tanks. Coatings are not specific to nuclear power plants, of course; they are also used in fossil plants and throughout the power industry to protect structures and equipment from corrosion.

Coatings are most often applied to provide corrosion protection to metal surfaces and to prevent degradation of concrete surfaces. Inside a nuclear plant's primary containment, for example, coatings protect carbon steel components including the containment liner, drywell head and shell, cable trays and supports. Coatings and linings also protect concrete structures and surfaces including the reactor cavity, bioshield wall, pressurizer and steam generator shield walls, and floors and equipment pedestals.

In general, coatings provide protection through three fundamental mechanisms: barrier, corrosion inhibition, and cathodic protection.

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A barrier coating is most often used in immersion service (that is, exposed to continuous or intermittent submerged conditions) to isolate steel surfaces from water or chemical solution. Examples include linings applied to internal surfaces of tanks and piping. Barrier coatings also are used to waterproof concrete structures and as secondary containment liners in chemical handling areas. An effective barrier coating exhibits a very low rate of moisture vapor transmission through the coating and is resistant to the fluid into which it is immersed. On metal surfaces, the effective barrier coating performance depends on a clean surface with an even surface texture and a strong adhesive bond to the metal surface. On concrete surfaces, coating performance is enhanced by the ability to soak into the surface texture and form an adhesive bond with no voids.

Corrosion inhibiting pigments are used as the primer coat on metal (typically steel) surfaces in atmospheric service. When moisture vapor permeates the coating, the inhibitive pigments will react with the steel in the presence of moisture to form a passive layer that retards the corrosion process. Historically, lead and hexavalent chrome primers were used as corrosion inhibitive pigments. Although these materials are no longer available due to environmental and health concerns, they may still be encountered in when maintaining older existing coatings. Alternative corrosion inhibiting pigment formulations have been developed to replace the lead and hexavalent chrome as well as heavy metals, including phosphates (zinc, calcium), phosphosilicate compounds (calcium, barium), and borosilicate compounds (calcium, barium).

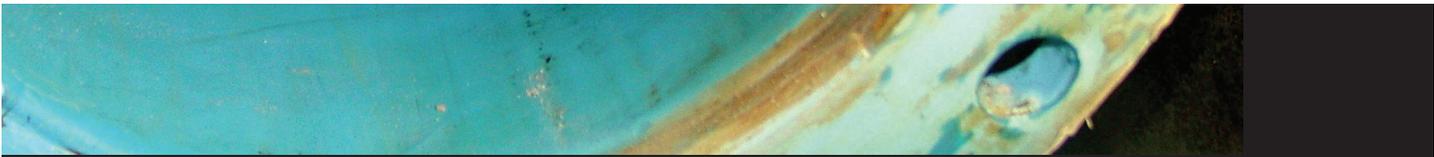
Cathodic protection is provided via liquid-applied coatings that typically include metallic zinc powder. If the coating is mechanically damaged to expose the steel surface, or if moisture vapor permeates the coating, the zinc, in the presence of moisture, forms a galvanic corrosion cell with the steel in which the zinc becomes a sacrificial anode and corrodes instead of the steel substrate. In a non-immersion environment, the exposed zinc surface of galvanized carbon steel reacts with moisture in the air to form zinc hydroxide, a soluble corrosion product. With continued exposure, the zinc hydroxide corrosion product reacts with carbon dioxide to form a dense, hard zinc carbonate layer. This layer serves as a passivation layer that protects the zinc, thereby significantly reducing the zinc's corrosion rate. The combination of the zinc's cathodic protection of the carbon steel and the reduced corrosion rate of the zinc significantly extends the life of the carbon steel component.

## Coating Degradation

Coatings degrade or fail due to many factors, including chemical exposure, temperature extremes, and mechanical forces. In addition, some surface features and configurations are conducive to premature coating failure. Other factors that may contribute to poor performance and early failure are improper coating selection, inadequate surface preparation, and deviation from the manufacturer's instructions for mixing, thinning, application, and cure of the coating material.



*Example of a barrier coating in immersion service: a multifunctional epoxy coating repair to polyvinyl chloride (PVC) lining in cooling water pipe.*



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The common degradation mechanisms associated with coating failure in power plants are listed below. Detailed descriptions and color photographs of each degradation mechanism are presented in the field guide, and three of the more common mechanisms are further described below.

- Checking
- Cracking
- Mudcracking
- Blistering
- Chalking
- Flaking
- Intercoat delamination
- Oxidation
- Pinpoint rusting
- Zinc depletion

**Mudcracking** is an irregular broken network of cracks in the film with the appearance of dried mud. Corrosion of the exposed substrate may be present. Contributing causes and stressors include coating material formulated with a high pigment loading, excess dry film thickness, application on a warm surface that force-dried the coating too quickly, and use of a non-UV inhibiting coating in an outdoor environment.

**Blistering**, the most common form of coating failure, is caused by degradation of the adhesive bond between the coating and the underlying surface—either the substrate or the previously applied coating.



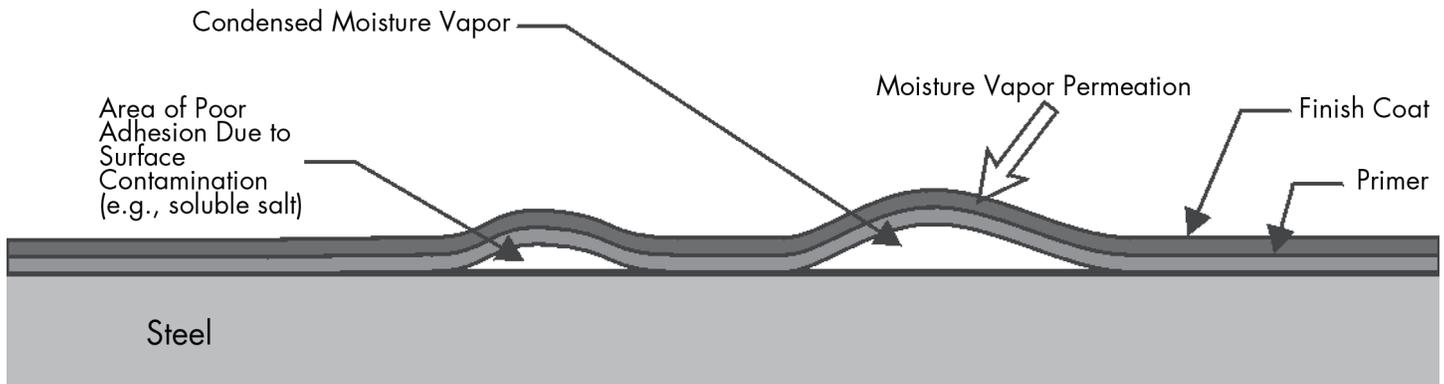
*A mudcracked epoxy phenolic coating.*



*A barrier coating with blisters*

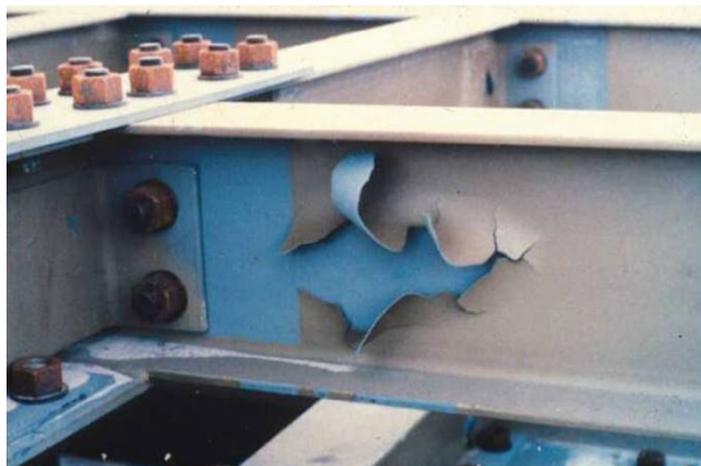
The appearance of the blisters can provide clues to the cause of failure. Hemispherical bubbles in the coating may be caused by osmosis or solvent entrapment, while elongated bubbles may be caused by a significant air space pressure change (such as from containment pressure testing).

## Surface Contamination



Formation of osmotic blisters in a coating on a metal surface. Soluble contaminants on the metal surface serve as condensation sites for moisture vapor permeating through the coating.

**Intercoat delamination**, also referred to as peeling, is the loss of adhesion between two coats. The delamination may occur at the interface between any two coats—intermediate coat to primer coat, or top coat to intermediate coat. The residue of the underlying coat may be present on the bottom side of the delaminating coat. Causes include contamination on the surface of the underlying coat (such as dirt, grease, and moisture) and incompatibility of top coat with underlying coat (such as solvent incompatibility or moisture cured coating incompatibility). Intercoat delamination can also occur when too much time elapses between successive coats without additional surface preparation.



Intercoat delamination between top coat and primer.

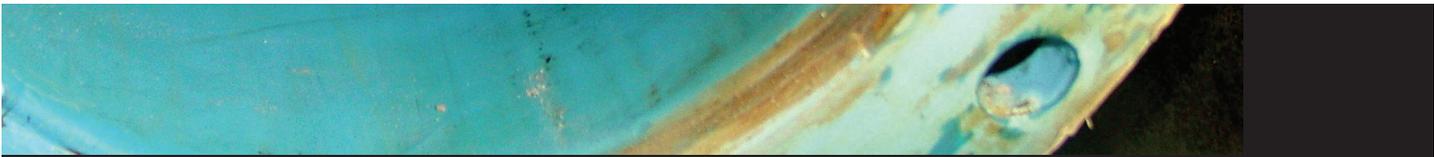
## Coating Condition Assessment

A methodical approach to coating condition assessment involves planning, performance, documentation, and evaluation. Throughout the process, applicable plant procedures must be followed.

Planning is necessary to allow proper access, adequate time to conduct the assessment, and proper safety and security protocols. Planning also ensures a thorough understanding of the coating condition history as a basis for determining the scope of the assessment.

Performing a coating condition assessment involves completing the inspections identified in the planning stage. Inspections are usually visual, but may include dry film thickness measurement, adhesion testing, and the collection of coating samples for detailed examination. The visual inspection is intended to identify indicators and causes of degradation, determine the apparent degradation mechanism, identify the severity of degradation, and quantify its extent. Visual inspections should consider a variety of factors:

- Is the coating damage caused by substrate action (concrete cracking, metal bending, rubbing surfaces, etc.)?
- Is blistering located between the coating and the substrate or between two layers of coating (osmotic or solvent entrapment)?
- Where blisters have broken open, is rust staining present (corrosion of the substrate)?



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- Where the coating has changed color, is there physical degradation of the coating (softening, cracking, dissolution, textured surface, peeling, blistering)?
- Where the coating has changed color, is there similar damage on surfaces below (suggesting chemical spillage)?
- Is there a gradual transition from damaged to non-damaged areas of the coating (suggesting a temperature profile)?

Documentation of observed conditions is critical to an accurate coating condition assessment. Worksheets should be prepared for use during performance of a condition assessment to record the observed conditions (see sample summary sheet).

The documentation also should include a map of the areas being evaluated. Radiation maps can be used for radiological areas, equipment arrangement drawings can be used for other areas, and manufacturer's drawings may be useful for single components. In other areas, a hand-drawn sketch can be useful. The maps can be annotated to indicate the location number for each data record and to indicate the area involved. Each photograph number can be noted on the map along with the respective direction of view.

The data evaluation process should:

- Compare the current condition to the conditions determined in previous assessments
- Identify areas exhibiting a negative trend in condition
- Recommend actions for each location, which may include:
  - No action required, continue periodic monitoring
  - Plan for coating repair during next outage
  - Plan for total coating replacement during next outage
  - Repair coating prior to returning to service
  - Repair observed substrate degradation and repair or replace coating prior to return to service

- Assign priority rankings to the recommended actions to resolve the observed conditions. For example:
  - Priority 1 – coating failure and substrate degradation requiring immediate substrate evaluation; repair substrate and coating as needed prior to return to service
  - Priority 2 – peeling coating that exposes the substrate with no active substrate degradation; remove damaged coating and repair coating prior to return to service
  - Priority 3 – widespread (e.g., approximately 25% of surface) coating degradation with no peeling and no active substrate degradation; plan for coating replacement at next outage
  - Priority 4 – degraded coating with no peeling and no active substrate degradation; plan for coating repair at next outage



*Deep cracking that exposes the substrate.*



## Repair and Mitigation

Coating repair and mitigation options depend on the type of coating and degradation mechanism. Examples of mitigation and repair measures include:

- Sand the component to remove areas of damaged coating and apply replacement coating material
- Replace with a more flexible coating material at proper dry film thickness
- Minimize thermal cycles
- Ensure more stringent surface preparation
- Select the appropriate non-oil type coatings for application to galvanized surfaces

- Use compatible coatings in multiple coat system
- Control ambient conditions and surface preparation prior to coating application
- Adhere to manufacturer’s application instructions for the “dry to recoat time,” which is the drying time required between the application of successive coats of paint or varnish.

Education and training (see sidebar) can help plant personnel identify the optimal mitigation and repair measures to correct damage and ensure that coatings continue to perform their protective function.

### Condition Assessment Data Collection Summary Report

Reference No: \_\_\_\_\_ (Condition Report, Work Order, Engineering Document, etc.)

Structure or Component:			Substrate:			Date:		Sheet ____ of ____			
Surfaces (check applicable): Internal External			Service (check applicable): Dry Immersion Fuel oil immersion Wet, non-immersion Chemical Buried in soil				Team Members:				
Location in Plant:			Coating System Primer (metals): Surfacer (concrete): Intermediate: Finish:								
Location Number	Elevation / Azimuth	Component Type	Location	Description	Nearest Component	Damage	Description	Size of Damaged Area	Photo Number	Photo Description	

## **Protective Coatings Education and Training**

EPRI has developed training courses to equip coating managers with the knowledge to develop and maintain effective coating maintenance programs.

The Comprehensive Coatings Course includes 16 training modules covering all aspects of protective coatings for nuclear power plants. Course modules include Basic Corrosion Control, Coating Composition, Curing Mechanisms, Surface Preparation, Coating Calculations, Nuclear Coatings Qualification, Specification and Procurement, Condition Assessment, and Failure Analysis. In a series of hands-on workshops, students learn how to apply information from manufacturer product data sheets to select coatings for different plant applications; use test coupons and instrumentation to measure dry film thickness and assess coating condition; and specify different coatings depending on safety function.

EPRI also provides a Buried Pipe Inspector Course that includes buried pipe coating repairs. The computer-based training course uses interactive features, review questions, and graphics to illustrate key concepts and enhance training.

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