ASTM INTERNATIONAL
Manual

Maintenance Coatings for Nuclear Power Plants 2nd Edition

ASTM INTERNATIONAL

Compiled by ASTM Subcommittee D33.10 on Protective Coatings Maintenance Work for Power Generation Facilities

Maintenance Coatings for Nuclear Power Plants—2nd Edition

ASTM Stock Number: MNL8-2ND
DOI: 10.1520/MNL8-2ND-EB

ASTM International
100 Barr Harbor Drive
PO Box C700
West Conshohocken, PA 19428-2959
www.astm.org

Printed in the U.S.A.

Library of Congress Cataloging-in-Publication Data
Manual on maintenance coatings for nuclear power plants
Maintenance coatings for nuclear power plants : compiled by ASTM Subcommittee D33.10 on Protective Coatings Maintenance Work for Power Generation Facilities. – 2nd edition.
pages cm
Revised edition of: Manual on maintenance coatings for nuclear power plants. 1990.
"ASTM Stock Number: MNL8-2ND."
Includes bibliographical references.
ISBN 978-0-8031-7070-4
1. Nuclear power plants–Maintenance and repair–Handbooks, manuals, etc. 2. Nuclear power plants–Painting–Handbooks, manuals, etc. 3. Nuclear power plants–Equipment and supplies–Protection–Handbooks, manuals, etc. 4. Nuclear reactors–Containment–Painting–Handbooks, manuals, etc. I. Title.
TK1078.M254 2015
621.48'30288–dc23 **2015029334**

Publisher:
ASTM International
100 Barr Harbor Drive
PO Box C700
West Conshohocken, PA 19428-2959
Phone: (610) 832-9585 Fax: (610) 832-9555
ISBN 978-0-8031-7070-4
ASTM Stock Number: MNL8-2ND
DOI: 10.1520/MNL8-2ND-EB

Printed in Baltimore, MD
May, 2016

Foreword

THIS PUBLICATION WAS sponsored by ASTM Committee D33 on Protective Coating and Lining Work for Power Generation Facilities. Its creation and maintenance is the responsibility of Subcommittee D33.10 on Protective Coatings Maintenance Work for Power Generation Facilities. This subcommittee is composed of representatives from various organizations involved with manufacturing, specifying, applying, and using protective coatings to control corrosion and erosion issues in nuclear power facilities. Subcommittee members include individuals from utilities, architects/engineers/constructors, coating inspection service providers, and other interested parties. The first edition was originally published in December 1990.

In the 1990s and early 2000s, numerous changes evolved with regard to nuclear power coatings. Operating experience, lessons learned, and regulatory changes have resulted in many changes to the way nuclear power plant coatings are selected, evaluated, applied, monitored, and repaired. Due to the magnitude of these changes, Subcommittee D33.10 felt it was prudent to revise this publication to reflect those changes. The information presented herein reflects a consensus of the subcommittee members of D33.10 as of 22 May 2015.

This manual was prepared to address a need perceived by ASTM Committee D33 for guidance in selecting and applying maintenance coatings in nuclear plants but is not to be considered a standard. In addition to serving as that source of guidance, this document has the equally necessary role of acting as a focal point for a rapidly changing technology. While Subcommittee D33.10 considers the information contained in this manual to be state of the art, the book offers limited historical data upon which to establish detailed requirements or methodologies. Accordingly, the user will find this edition rather general. The details of these practices are found in the various cited standards and standard guides referenced throughout and listed in the appendix. ASTM Standard D4538, "Standard Terminology Relating to Protective Coating and Lining Work for Power Generation Facilities," contains the definitions of the terms used in this publication.

This manual does not purport to address all the safety concerns, if any, associated with the use of the referenced standards. It is the responsibility of the user of this manual to establish appropriate safety and health practices and to determine the applicability of regulatory limitations prior to use.

Daniel L. Cox
Structural Integrity Associates
2321 Calle Almirante
San Clemente, CA 92673

Contributors

Paul Abate, Williams Specialty Services
Gary D. Alkire, Exelon Corporation
Timothy S. Andreychek, Westinghouse Electric Co.
Andy Baer, Carboline Co.
Peter Blattner, Baker Concrete
Jon R. Cavallo, PE, Jon R. Cavallo, PE LLC
Judy Cheng, Pacific Gas and Electric Co.
Daniel L. Cox, Structural Integrity Associates
Michael Damiano, Society for Protective Coatings
John F. De Barba, PPG Protective & Marine Coatings
Bruce Dullum, Carboline Co. (retired)
Michael E. Fraley, Luminant
John O. Kloepper, Carboline Co.
Steve L. Liebhart, Carboline Co.
Richard L. Martin, Altran Solutions
Keith A. Miller, Sargent & Lundy LLC
Bryan M. Monteon, Sherwin-Williams
Christopher Palen, PPG Protective & Marine Coatings
Timothy B. Ridlon, First Energy Corp.
Timothy Shugart, Alliant Energy
Carol J. Uraine, Arizona Public Service
Charles Vallance, UESI

Acronyms

3M	Minnesota Mining and Manufacturing
ABWR	Advanced boiling water reactor
ALARA	As low as reasonably achievable
ANSI	American National Standards Institute
ASTM	ASTM International (formerly American Society for Testing and Materials)
BWR	Boiling water reactor
CFR	Code of Federal Regulations
CSL I	Coatings Service Level I
CSL II	Coatings Service Level II
CSL III	Coatings Service Level III
DBA	Design basis accident
DSC	Digital still camera
ECCS	Emergency core cooling system
EPA	Environmental Protection Agency
EPRI	Electric Power Research Institute
ESS	Engineered safety system
FME	Foreign material exclusion
FSAR	Final safety analysis report
GC	Gas chromatograph
HEPA	High efficiency particulate air
HP	Health physics
HPWC	High pressure water cleaning
HVAC	Heating, ventilation, and air conditioning
LOCA	Loss of coolant accident
LOTO	Lockout/tagout
LPWC	Low pressure water cleaning
MOS	Maximum operating speed
MP	Magnetic particle testing
NACE	NACE International (formerly National Association of Corrosion Engineers)
NFPA	National Fire Protection Association
NIOSH	National Institute of Occupational Safety and Health
NIST	National Institute of Standards and Technology
NPP	Nuclear power plant
NRC	Nuclear Regulatory Commission

OSHA	Occupational Safety and Health Administration
PA	Protected area
PC	Protective clothing
PT	Penetrant (dye) testing
PWR	Pressurized water reactor
QA	Quality assurance
QC	Quality control
RCA	Radiological controlled area
Reg. Guide	Regulatory guide
RHR	Residual heat removal
ROS	Recommended operating speed
RT	Radiographic testing
SAR	Safety analysis report
SSC	System, structure, or component
SSPC	The Society for Protective Coatings (formerly Steel Structures Painting Council)
TTP	Time temperature pressure
UHPWC	Ultra-high pressure water cleaning
UT	Ultrasonic test
VOC	Volatile organic compound
WJ	Water jetting

Contents

Chapter 1 | Protecting Surfaces in a Nuclear Plant

Andy Baer[1] and Bruce Dullum[1]

This chapter acquaints the reader of this manual with background information on the use and maintenance of coatings in the nuclear power facility. The following subjects will be briefly discussed:

1. The classification of the coating service based upon nuclear safety significance
2. The reasons for the initial coating work, including that done in the primary containment structure
3. The relationship between the coating work accomplished during the construction phase and the concerns of the emergency coolant system/engineered safety systems (ESS) of light-water nuclear power plants
4. Maintenance painting during the life of the nuclear power plant
5. Proposed "new generation" nuclear power plants as well as existing nuclear power plants

Various Levels of Coating within a Nuclear Power Plant

COATING SERVICE LEVEL I (CSL I)

This area is exclusively related to surfaces within the reactor containment structure. The primary *containment structure* is a very large building that contains the nuclear reactor and associated equipment. During operations, the containment interior may experience varied humidity conditions as high as 100%. Equipment, walls, and appurtenances can be constantly subjected to condensation, radiation, and contamination by radioactive particles. Most coatings used in CSL I areas require a complex prequalification design basis accident (DBA) testing using approved ANSI or ASTM nuclear coating standards, or both. The application of the coatings in the CSL I areas also requires strict adherence to accepted standards. The purpose of the prequalification testing is to ensure that the coating will remain intact and adherent to the surface (e.g., sumps and strainers) in the event of a DBA and will not become debris that could adversely affect the ability of nuclear safety-related equipment to perform the respective intended safety function.

[1] Carboline Company, 2150 Schuetz Rd., St. Louis, MO 63146

DOI: 10.1520/MNL820130034

Purpose for Coating the Primary Containment Structure

The Nuclear Regulatory Commission (NRC) does not require an item or surface in a nuclear plant to be coated. However, it would be impractical to allow corrosion to occur if it can be prevented by the application of an acceptable coating or coating system.

Corrosion protection of carbon steel, concrete, and other components within containment with a coating or coating system may be a direct safety-related function. Impairment of this protection is of vital concern because operational and outage surveillance may be quite difficult. A protective coating/coating system used in the primary containment structure is designed to protect surfaces from corrosion, enhance lighting within the containment vessel, and to provide an easily decontaminable substrate.

During the course of construction and during the service life of the containment vessel, many small "off-the-shelf" items coated with the manufacturers' standard unqualified coating system will be placed within the primary containment structure. Examples of these off-the-shelf items are small motors, pumps, valves, and so on. Such surfaces are of particular concern for several reasons: First, the unqualified coating may not be capable of withstanding the environment of the containment for more than a year or two; second, if in excess of the allowable quantity established during the construction phase, the safe shutdown of the facility could be affected. Unqualified coatings must be considered as solid debris under DBA conditions.

Coating Service Level I Requirements (New Construction)

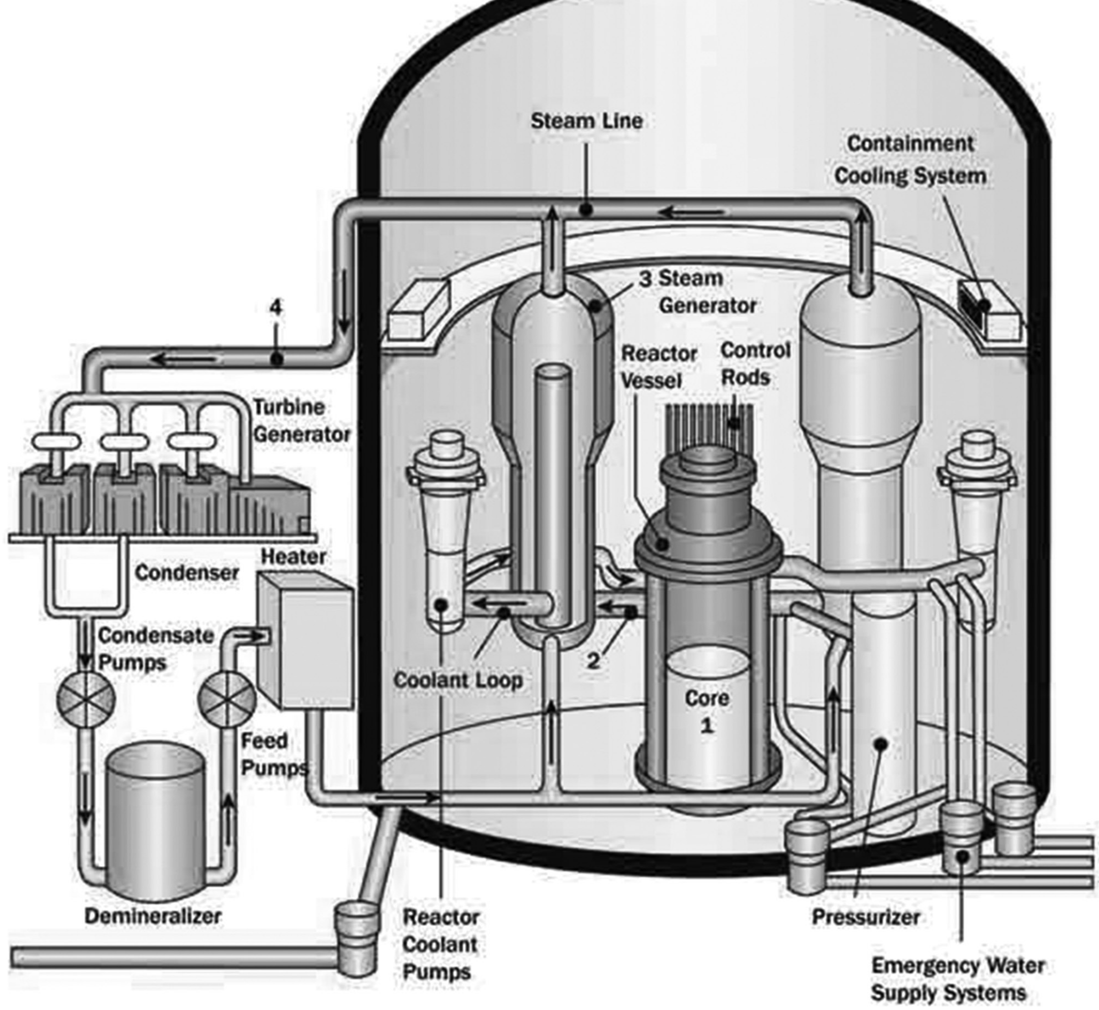
Most all coating systems used in CSL I areas are qualified in accordance with accepted and approved nuclear coating standards. Many of the coating systems used in existing pressurized water reactor (PWR) and boiling water reactor (BWR) nuclear power plants are qualified in accordance with ANSI N5.12, ANSI N101.2, and ANSI N101.4. The construction of new generation nuclear power plants (NPP) will adhere to ASTM standards and may be affected by local regulations (such as in the United States, where they can be impacted by NRC Reg. Guide 1.54 Rev. 1 or Rev. 2

depending on their licensing agreement). The important criteria include but are not limited to:

1. A design basis accident (DBA) test must be successfully completed with a temperature curve of approximately 307°F (153°C) for a PWR or a temperature curve of approximately 340°F (171°C) for a BWR. In either case, the DBA curve against which the coating systems are tested must envelope the individual nuclear power plant design criteria for a DBA—typically, loss of coolant accident (LOCA) conditions.

   The CSL I coating systems must be easily decontaminated. The type of coatings currently qualified for CSL I service do provide a surface that is easily decontaminated. Inorganic zinc coatings based upon an ethyl silicate binder can be top-coated with an epoxy-type coating to attain an additional degree of decontamination. An ASTM standard used to test the ease of decontaminating a coating, ASTM D4256, *Test Method for Determination of the Decontaminability of Coatings Used in Light-Water Nuclear Power Plants* [1], was withdrawn by ASTM in 1995 because it was considered to be ineffective. In spite of this, the standard remains part of the original licensing basis of many plants and still finds its way into many specifications to this day.
2. The CSL I coating system also must be tested for radiation resistance based on the individual plant's requirements. The required radiation resistance typically ranges from 2×10^8 RAD for a PWR to 1×10^9 RAD for a BWR. The radiation resistance of a coating is determined in accordance with ASTM D4082, *Standard Test Method for Effects of Gamma Radiation on Coatings for Use in Light-Water Nuclear Power Plants* [2].
3. Construction must meet a flame spread rating of 50 or below per ASTM E84, *Standard Test Method for Surface Burning Characteristics of Building Materials* [3].
4. The plant must meet pull-off adhesion of greater than 200 psi (1379 kPa) for steel and concrete surfaces in accordance with ASTM D4541, *Standard Method for Pull-Off Strength of Coatings Using Portable Adhesion-Testers* (Test Method B—Fixed Alignment Adhesion Tester Type II) [4].

FIG. 1.1 Diagram of a pressurized-water reactor (courtesy of NRC).



Coating Service Level I Requirements (Maintenance)

The coatings requirements for new construction also are applicable for maintenance painting. In some instances, the original manufacturer's coating (paint) is used for coating repairs; in those cases, the manufacturer must have documented evidence that the performance of its repair coating systems meets these original aforementioned requirements. This is also the case when another manufacturer's products are used for the intended repairs. Surface preparation requirements and the combination of coatings from each manufacturer must also then be considered for DBA testing.

Coating Service Level II and III Requirements

Coating Service Level II (CSL II) requirements generally pertain to areas that may be radioactively contaminated where the coatings should exhibit radiation resistance and ease of decontamination. The CSL II areas do not require DBA testing. The CSL II coatings may be selected, tested, and installed at the discretion of the plant engineer or owner.

Coating Service Level III requirements pertain to areas or safety-related structures, systems, or components located outside of reactor containment and may impact the safe operation or shutdown of the NPP. These coatings may require chemical resistance, abrasion resistance, and adhesion testing. The CSL III coatings may be selected, tested, and installed at the discretion of the plant engineer or owner.

Types of Commercially Operated BWR and PWR Nuclear Reactors

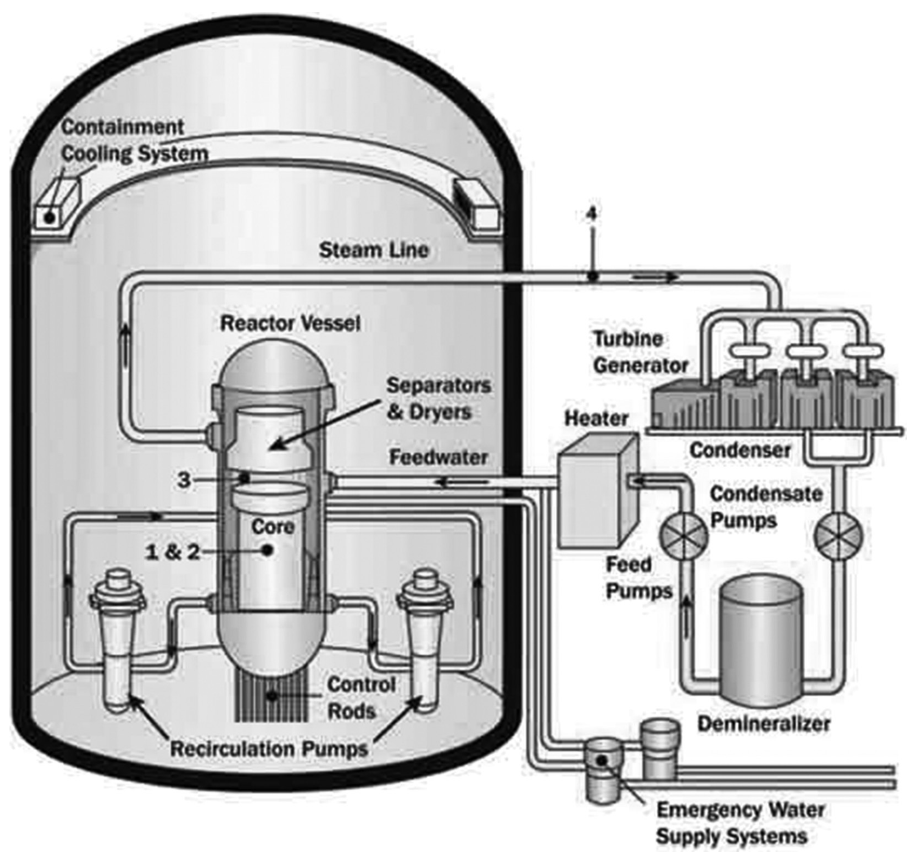
The PWR concept (Fig. 1.1) utilizes a closed coolant loop to circulate high-pressure liquid water at more than 2,200 psi (15,160 kPa) and 650°F (343°C) through the reactor vessel to pick up heat. This heat is then transferred to steam generators (a type of heat exchanger) that furnish steam to conventional turbine generators to produce electric power.

The BWR concept (Fig. 1.2) utilizes a high-pressure water feed to produce steam within the reactor vessel at about 1,000 psi (6,895 kPa) and 550°F (288°C). This steam is then piped directly to the turbine generator to produce electric power.

The steam condensate from the turbine is piped to a processing facility for decontamination and impurity cleanup (not shown in Fig. 1.1) prior to recirculation in the main coolant loop.

At the time of this writing, there are numerous "third generation" nuclear reactors in the design or construction phase. These reactors are based on PWR and BWR design criteria. The most common of the PWR reactors are the Westinghouse AP 1000 and

FIG. 1.2 Diagram of a boiling-water reactor (courtesy of NRC).



the AREVA EPR. The most common BWRs are the GE advanced boiling water reactor (ABWR) and the GE economic simplified boiling water reactor (ESBWR). These third generation nuclear reactors have been called safer, more easily constructible, and more economical to operate and maintain than the original reactors.

Relationship of Coating Work to the Engineered Safety Systems

It is suggested that the following guidelines, adhered to by most architects/engineers/constructors during the construction phase, be adhered to during the maintenance of a nuclear power plant. If the item cannot be removed and is not insulated, the item should be coated with a qualified coating system (i.e., liner plate, structural steel, polar crane, tanks, etc.). If the item is a small, removable component, subject to periodic maintenance, an unqualified coating system may be considered (i.e., a motor, pump, instrument, etc.). Some original components such as electrical panels may also remain with unqualified coatings. ASTM D7491 provides guidance for management of nonconforming coatings [5].

The function of an item being coated must be considered (i.e., is it a safety-related item, are there thermodynamic scenarios to be considered, does the item receive frequent decontamination, etc.). In the primary containment structure, the critical relationship of the coating system to the engineered safety system is that the coating system remains in place and intact in the event of a DBA in order not to compromise the function of the ESS. This critical relationship exists during and after the time required for the ESS to stabilize and maintain cooling of the nuclear fuel core.

There are three principal scenarios in which the failure of a coating system can affect the ESS following a DBA:

1. Coatings subject to flaking, peeling, or delamination may detach from the surface and clog strainers, flow lines, pumps, spray nozzles, and core coolant channels. These conditions can jeopardize the residual heat removal capability of the core or can reduce the pressure suppression and iodine-removal effectiveness of the containment spray system and result in undue risk to public health and safety.
2. By-products from coating or exposed metal surfaces reacting with containment spray solutions may plate out within the residual heat removal (RHR) system or on the nuclear fuel in the core. Plating out in either of these areas could reduce the effectiveness of core cooling after an accident.
3. There has been concern over a coating generating hydrogen gas during contact with steam (particularly inorganic zinc-rich coating systems during a DBA). This concern may be satisfied with the use of hydrogen recombiners. However, the use of recombiners should not give license to undue use of coating materials or reactive metal that would generate gases capable of producing explosive mixtures within the primary containment structure.

Summary

This chapter has provided background information on coatings used in safety significant areas of a nuclear power plant. Individuals responsible for coating work should:

1. Understand the CSL I, II, and III classifications and the requirements associated with each.
2. Know the type of coating(s) used in the facility for all major items located within CSL I, II, and III areas.
3. Be able to locate documentation of the coating systems used during the construction phase.
4. Know the allowable limit of unqualified coating material inside reactor containment for the particular plant.
5. Know which items are coated with unqualified coating.

References

[1] ASTM D4256, *Standard Test Method for Determination of the Decontaminability of Coatings Used in Light-Water Nuclear Power Plants*, ASTM International, West Conshohocken, PA, **www.astm.org**

[2] ASTM D4082, *Standard Test Method for Effects of Gamma Radiation on Coatings for Use in Light-Water Nuclear Power Plants*, ASTM International, West Conshohocken, PA, 2010, **www.astm.org**

[3] ASTM E84, *Standard Test Method for Surface Burning Characteristics of Building Materials*, ASTM International, West Conshohocken, PA, 2015, **www.astm.org**

[4] ASTM D4541, *Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion-Testers*, ASTM International, West Conshohocken, PA, 2009, **www.astm.org**

[5] ASTM D7491, *Standard Guide for Management of Non-Conforming Coatings in Coating Service Level I Areas of Nuclear Power Plants*, ASTM International, West Conshohocken, PA, 2015, **www.astm.org**

Chapter 2 | Significance of Maintenance Coating

Richard L. Martin[1] and Daniel L. Cox[2]

In the nuclear utility industry, maintenance coating is performed to replace or repair coatings that have been damaged or degraded for one or more of the following purposes:

1. Corrosion mitigation and prevention (life extension)
2. Facilitation of decontamination
3. Regulatory compliance
4. Secondary containment
5. Tank lining (corrosion prevention and product contamination prevention)
6. Fire proofing
7. System color coding
8. Human factor considerations (aesthetics, lighting, identification, etc.)
9. Facilitation of housekeeping

Corrosion Mitigation and Prevention

The increasing costs associated with replacement of capital equipment have made corrosion mitigation or life extension much more important in nuclear power plant maintenance.

Modern protective coatings utilize three fundamental methods to mitigate corrosion: barrier protection, sacrificial, and inhibition.

1. *Barrier Protection:* This is a relatively impermeable barrier between the environment and the substrate. Among the coatings that function in this manner are coal tar epoxies, chlorinated rubbers, epoxies, modified phenolic epoxies, and urethanes. Epoxy coatings are the predominant choice for use in containment.
2. *Sacrificial:* Metallic zinc, for instance, is less noble than a carbon steel substrate on a galvanic scale. As such, zinc can act as a sacrificial anode when coupled with carbon steel and can protect the substrate. Zinc-filled coatings are available in both organic and inorganic binder versions.
3. *Inhibition:* Passivating primers incorporating anticorrosive pigments inhibit corrosion formation.

No coating will provide protection against all types of corrosive media. However, it is possible to protect against a wide variety of corrosive agents by using "defense in depth." Often this is accomplished by applying a coating system that uses multiple coats of the same (generic) composition. When multiple layers of different coatings are applied, the coatings must be compatible with each other and preferably from the same manufacturer. In all cases, the coating system must be compatible with the existing substrate. This does not imply that unlimited thickness of coating material can be applied to a given surface. The coating manufacturer designs a product to an optimal thickness and thus must be consulted for advice on the system thickness. Most importantly, design of coating systems for maintenance work respects a different set of selection parameters than those systems used in new construction. These selected parameters are explained in more detail elsewhere.

Decontamination

The word *contamination* as used in the nuclear utility industry means radioactive nuclides in an unplanned or undesirable location. Contamination also can be used to describe the unplanned presence of a chemical on a surface. *Decontamination,* conversely, is the removal of the contamination product.

The selection of protective coatings to control contamination is the same for *both* radioactive and chemical contamination; a coating should be selected that will not be damaged by a given type of contamination or its removal and that will not allow contamination to become affixed to the protected substrate. Concrete surfaces, for instance, are easily contaminated and are normally more difficult to decontaminate; therefore, a carefully selected coating should fill all voids and smooth the surface, which would aid in the decontamination effort.

Typical areas in utility plants that should receive careful attention regarding contamination control are nuclear containment structures, waste treatment buildings, fuel buildings, water treatment areas, chemical storage areas, chemical addition rooms, and any declared radiological controlled area (RCA).

Regulatory Compliance

The Nuclear Regulatory Commission (NRC) requires that a plant meet the requirements of its final safety analysis report (FSAR) for

[1] Altran Solutions Corp., 20 North Ave., Burlington, MA 01803
[2] Structural Integrity Associates, 2321 Calle Almirante, San Clemente, CA 92673
DOI: 10.1520/MNL820130029

required protective coatings and coating systems acceptable in the plant. Changes to the plant FSAR will require concurrence of the NRC prior to making that change.

Following years of operation and maintenance many coatings in Coating Service Level I (CSL I) applications have either become damaged or degraded. A significant effort has been spent maintaining these coating such that they continue to meet the respective licensee's regulatory or design basis.

System Color Coding

Many insurance carriers, as well as National Fire Protection Association (NFPA) and Occupational Safety and Health Act (OSHA) requirements, dictate the use of distinctive or contrasting colors for identification of safety components within utility facilities. The most commonly used colors are "safety yellow" for handrails, toe plates, and so forth; red for fire protection system components; and yellow and magenta for radioactive areas.

Color codes also are used in many facilities to assist in plant operations. Operator training is also made easier by color coding of process equipment (piping, valves, switchgears, etc.). Color coding is also used in two-unit plants to differentiate between units.

Human Factor Considerations (Aesthetics)

In some plants, protective coatings are selected for appearance as well as protection. In addition to serving a functional purpose, these coatings are aesthetically pleasing. As a result, plant operations and maintenance personnel are motivated to keep the facility clean and attractive, resulting in an overall upgrading of plant performance.

In addition, the careful selection of protective coatings can increase the efficiency of the plant lighting system. Lighter colored topcoats that perform well significantly brighten the plant environment without requiring an increase in the size of the lighting system. The increase in lighting system performance decreases lighting system costs (less lighting system power required) and provides increased personnel safety.

Housekeeping

Smooth, hard surfaces are much easier to decontaminate and keep clean than rough surfaces. Lighter surfaces can show dirt and surface defects more readily. Most protective coatings, properly selected, will assist in providing a more easily cleaned surface. However, zinc coatings and some primers have a rougher surface texture that is more conducive to retaining contaminants; thus, they are more difficult to clean and/or decontaminate. Uncoated surfaces can be more difficult to keep clean than coated surfaces.

Summary

Maintenance coating will provide the following benefits:

- Delay the deterioration of the surface and thus prolong the useful life of equipment
- May reduce the amount of graffiti
- Reduce the electrical energy used to illuminate given areas
- Identify mechanical or electrical system functions through the use of color coding
- Assist in meeting as low as reasonably achievable (ALARA) [**1**] requirements through selection and application of a coating system that is easily decontaminated
- Maintain and/or increase human factor considerations and improve housekeeping

An added benefit to maintenance coating is that it can help when the plant is decommissioned. Because coatings facilitate decontamination, decommissioning operations can be less cumbersome and can reduce radioactive waste volume and radiation exposure. (See USNRC Regulatory Guide 8.8.) [**1**]

References

[1] USNRC Regulatory Guide 8.8, "Information Relevant to Ensuring that Occupational Radiation Exposures at Nuclear Power Stations Will Be As Low As Reasonably Achievable," Revision 3, June, 1978.

Chapter 3 | In-Service Condition Monitoring and Assessment

Timothy Shugart[1] and Daniel L. Cox[2]

This chapter reviews the requirements associated with in-service coating condition assessment and covers guidelines for monitoring coating performance in an operating nuclear power plant. Condition monitoring is an ongoing process of evaluating the condition and performance of the in-service coating systems. Establishment of an in-service coatings condition assessment program permits planning and prioritization of coatings maintenance work to maintain coating integrity and performance in all coating systems. It also enables identification and detection of potential problems in coating systems known in advance to be suspect or deficient for some reason and provides a basis for recommendations regarding follow-up actions necessary to resolve any significant deficiency relative to coating work.

Coatings in a nuclear power plant, where their detachment could adversely affect the safety function of a safety-related structure system or component (SSC), are classified as safety related. These safety-related coatings are further defined as Coatings Service Level I (used inside primary reactor containment) and Coatings Service Level III (used in applications outside reactor containment). The performance of these coating systems are of particular importance due to the potential impact on safety-related SSCs. A coating condition assessment plan will usually be necessary to fulfill performance monitoring requirements contained in technical specifications, safety analysis report commitments, other regulatory commitments—such as those made in response to U.S. Nuclear Regulatory Commission (USNRC) Generic Letters 98-04 [**1**] and 2004-02 [**2**], for Coatings Service Level I (CSL I) and licensing renewal commitments made in response to NUREG 1801 [**3**] and Regulatory Guide 1.54, Rev 1 or 2 requirements for Coatings Service Level III (CSL III) [**4**] coating work.

The organization or department in a plant responsible for the coatings program establishes the requirements and procedures necessary for in-service coatings condition assessment. The plant may, however, delegate this responsibility to other qualified organizations. The recommended practice for CSL I coatings is to perform in-service coating condition assessment during each refueling outage or during other major maintenance activities.

During the assessment of CSL I coatings, particular attention must be given to the areas and equipment where coating debris can readily transport to the containment emergency core cooling system (ECCS) pump suction screens and strainers. Degraded coatings may generate debris under design basis accident conditions that could adversely affect the performance of the post-accident safety systems. The coating performance determined during the assessment is reported to responsible personnel in the plant. The coating integrity should be verified to determine that it will not affect the safety of the emergency core cooling system, the protection of the substrate, or the projected life of the coating system. The condition assessment plan shall meet, as a minimum, ASTM **D5163**, *Standard Guide for Establishing a Program for Condition Assessment of Coating Service Level I Coating Systems in Nuclear Power Plants* [**5**].

During the CSL III coatings/linings assessment, attention must be given to the specific application and to the potential impact of degraded coatings/linings. Degraded coatings/linings may generate debris under normal operation and testing or during upset conditions that could adversely affect the performance of the safety-related systems. In most cases, the consequence of the debris generation is flow blockage, essential heat transfer reduction, or both—ultimately leading to degradation of equipment or system performance. As with CSL I coatings, the performance of CSL III linings determined during the assessment is reported to responsible personnel in the plant. The lining integrity should be verified to determine that it will not affect the design function of the system or component in which it is installed. ASTM **D7167**, *Standard Guide for Establishing Procedures to Monitor the Performance of Safety-Related Coating Service Level III Lining Systems in an Operating Nuclear Power Plant* [**6**], provides guidance for the establishment of an effective program to monitor CSL III coating systems.

Coating performance will depend on the operating conditions experienced by the coating systems. Records of these conditions are normally maintained by the plant operating personnel. These may include, but not be limited to, ambient conditions; upset temperatures; humidity; chemical exposure such as immersion, splash, and spillage; abrasion; and physical abuse. All past history pertaining to the coating systems must be available for review during the condition assessment. This may include:

1. Copies of coating specifications and application procedures used for the existing coatings

[1] Alliant Energy, 200 1st St. SE, Cedar Rapids, IA 52401
[2] Structural Integrity Associates, 2321 Calle Almirante, San Clemente, CA 92673
DOI: 10.1520/MNL820130014

2. Quality control documentation for the existing coating application
3. Copies of previous inspection or condition monitoring reports
4. Documentation pertaining to any maintenance work performed on existing coating systems
5. Radiation-related data and decontamination procedures followed

Personnel performing condition assessment are subject to all station access procedures, including those pertaining to escorted or unescorted security clearance, health physics clearance, health physics classroom training, issuance of film badges and dosimeters, radiation work permits, anticontamination clothing suit-up requirements, radiation control, and disposal of contaminated clothing at authorized work areas. In addition to the aforementioned access procedures, personnel are also subject to any Occupational Safety and Health Administration (OSHA) or station-specific safety requirements/procedures (or both) including, but not limited to, confined spaces, lock out tag out (LOTO, also known as clearance tagging), fall protection, and so on.

Prior to conducting a condition assessment of the coating systems, the plant shall ensure that all support services and equipment are provided. These may include one or more of the following:

1. Sufficient temporary lighting to provide adequate illumination for all areas to be inspected, plus localized high-intensity lights for thorough visual observations or photography.
2. Mobile ladders, scaffolding, and other temporary rigging for access to areas beyond the reach of fixed ladders and platforms normally provided in primary containment. This may include temporary rigging on or from the polar crane for pressurized water reactor (PWR) containment.
3. Services of a qualified diver—who also satisfies the organization's qualification requirements for personnel performing coating condition assessment—inflatable rubber rafts or rigid boats, and underwater lights or TV cameras for the underwater inspection areas.
4. Services for cleaning deposits or buildup from some coated surfaces (selected by the assessor/assessment team).
5. Provisions for adequate ventilation during coating condition assessment.

The responsible department or organization involved in the coatings condition assessment must ensure that only those personnel within their organization who meet the minimum requirements for qualifications and training are permitted to perform the assessment activities. It is recommended that a qualified nuclear coatings specialist be responsible for supervising the assessment activities, data collection, and documentation, and ensuring that assigned personnel are adequately trained and instructed. The nuclear coatings specialist should (as a minimum) meet the requirements of ASTM D7108, *Standard Guide for Establishing Qualifications for a Nuclear Coatings Specialist* [7]. Assessment personnel should at least meet the requirements for qualification of Level I capability in accordance with ANSI N45.2.6, *Qualification of Inspection, Examination, and Testing Personnel for Nuclear Power Plants* [8] or ASTM D4537, *Standard Guide for Establishing Procedures to Qualify and Certify Personnel Performing Coating Work Inspection in Nuclear Facilities* [9]. When testing is performed, inspection personnel shall also be trained in the specific tests to be performed. Assessment teams may be formed with two or more qualified personnel in each team, and each team may be assigned a specific area inside containment for the assessment. A pre-assessment briefing shall be conducted to familiarize all personnel with objectives of the assessment, procedures to be followed, and precautions to be taken. A condition assessment plan would consist of a general visual inspection on all accessible coated surfaces during a general walk-through to determine the general condition of the coating, noting areas evidencing coating deterioration (for example, rusting, blistering, delamination, and cracking) or other coating deficiencies.

ASTM Standard Guides D5163 [5] for CSL I coatings and D7167 [6] for CSL III coatings both call for thorough visual inspections and close examination to be carried out on areas deemed to be suspect prior to, or during, the general walk-through. Areas of deterioration should be marked and mapped, and location, direction, and orientation charts should be kept for either future surveillance or immediate repair. Photographic documentation of coatings inspection areas should be made with special attention to defects and failures. Documentation standardized by the power plant to the past and present appearances of coating surfaces is recommended. Defects can be compared by a standardized reproducible method. One method for obtaining consistent, comparable, close-up photographs is provided in ASTM E312, *Standard Practice for Description and Selection of Conditions for Photographing Specimens Using Analog (Film) Cameras and Digital Still Cameras (DSC)* [10].

If additional data are required to make an analysis of the coating failure, the coatings specialist may decide to perform one or more of the specific physical tests, such as dry film thickness measurements, sampling, and measurement of size of defective pattern; adhesion/cohesion testing; hardness testing; and continuity testing. The relevant ASTM or Society for Protective Coatings (SSPC) standards shall be used for these tests.

The following instruments and equipment are recommended for each of the following tests:

1. For general and thorough visual inspections—flashlight, spotlight, measuring tape, mirror, × 5 or × 10 magnifier, and × 7 or × 8 35mm binoculars.
2. For sampling—polyethylene sample bags, 6 × 10 in. (15.24 to 25.4 cm), identification tags, and a scraper or pocket knife.
3. For general photography—camera with good flash equipment and appropriate sized lens. Record make and lens size so that a similarly equipped camera can be used on subsequent inspections.
4. For dry film thickness measurements—calibrated magnetic film thickness gauge, NBS calibration standards, and dial calipers with 0.001 in. (0.00254 cm) graduations.

Additional equipment may include laboratory spatulas, depth gauges, templates for marking areas for subsequent reinspection, permanent ink-type markers, and premade legends to identify plant, unit, and location for photographic records.

The following ASTM standards may be used for evaluation of visual defects, such as blistering, cracking, flaking or peeling, and rusting.

- *Blistering*—ASTM D714, *Standard Test Method for Evaluating Degree of Blistering of Paints* [11]
- *Flaking/Peeling*—ASTM D772, *Standard Test Method for Evaluating Degree of Flaking (Scaling) of Exterior Paints* [12]. ASTM D6677, *Standard Test Method for Evaluating Adhesion by Knife* [13] may be used for isolation of affected area(s)
- *Rusting*—ASTM D610, *Standard Test Method for Evaluating Degree of Rusting on Painted Steel Surfaces/SSPC-VIS-2* [14]

Condition assessment reports for submittal to responsible personnel should be prepared after the assessment and should include at least the following information:

1. A summary of findings and recommendations for future condition assessment or repair—this would include an analysis of the reasons or suspected reasons for failure. The repair work should be prioritized into major and minor defective areas. A recommended corrective plan of action must be provided for the major defective areas so that the plant can repair these areas during the same or next outage.
2. A list and location of all areas evidencing minor deterioration, the repair of which can be postponed to future outages and that will be kept under condition monitoring in the interim.
3. Condition assessment data sheets and photographic documentation.
4. An evaluation should be performed using data from coating/lining assessments to ensure acceptance of margin prior to mode ascension or SSC being placed back into service.

References

[1] USNRC Generic Letters 98-04, "Potential for Degradation of the Emergency Core Cooling System and the Containment Spray System after a Loss-of-Coolant Accident Because of Construction and Protective Coating Deficiencies and Foreign Material in Containment," U. S. Nuclear Regulatory Commission, Washington, DC.

[2] USNRC Generic Letter 2004-02, "Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized-Water Reactors," U. S. Nuclear Regulatory Commission, Washington, DC.

[3] USNRC Generic Aging Lessons Learned (GALL) Report—Final Report (NUREG-1801, Revision 2, U. S. Nuclear Regulatory Commission, Washington, DC.

[4] USNRC Regulatory Guide 1.54, "Service Level I, II, and III Protective Coatings Applied to Nuclear Power Plants," U. S. Nuclear Regulatory Commission, Washington, DC.

[5] ASTM D5163, *Standard Guide for Establishing a Program for Condition Assessment of Coating Service Level 1 Coating Systems in Nuclear Power Plants*, ASTM International, West Conshohocken, PA, 2008, **www.astm.org**

[6] ASTM D7167, *Standard Guide for Establishing Procedures to Monitor the Performance of Safety-Related Coating Service Level III Lining Systems in an Operating Nuclear Power Plant*, ASTM International, West Conshohocken, PA, 2012, **www.astm.org**

[7] ASTM D7108, *Standard Guide for Establishing Qualifications for a Nuclear Coatings Specialist*, ASTM International, West Conshohocken, PA, 2012, **www.astm.org**

[8] ANSI N45.2.6, *Qualification of Inspection, Examination, and Testing Personnel for Nuclear Power Plants*, American National Standards Institute, January, 1978.

[9] ASTM D4537, *Standard Guide for Establishing Procedures to Qualify and Certify Personnel Performing Coating Work Inspection in Nuclear Facilities*, ASTM International, West Conshohocken, PA, 2012, **www.astm.org**

[10] ASTM E312, *Standard Practice for Description and Selection of Conditions for Photographing Specimens Using Analog (Film) Cameras and Digital Still Cameras (DSC)*, ASTM International, West Conshohocken, PA, 2011, **www.astm.org**

[11] ASTM D714, *Standard Test Method for Evaluating Degree of Blistering of Paints*, ASTM International, West Conshohocken, PA, 2009, **www.astm.org**

[12] ASTM D772, *Standard Test Method for Evaluating Degree of Flaking (Scaling) of Exterior Paints,* ASTM International, West Conshohocken, PA, 2011, **www.astm.org**

[13] ASTM D6677, *Standard Test Method for Evaluating Adhesion by Knife,* ASTM International, West Conshohocken, PA, 2012, **www.astm.org**

[14] ASTM D610, *Standard Test Method for Evaluating Degree of Rusting on Painted Steel Surfaces*, ASTM International, West Conshohocken, PA, 2012, **www.astm.org**

Chapter 4 | Preparing for Maintenance Coating

Timothy Shugart[1], Timothy B. Ridlon[2], and Peter Blattner[3]

The first step in the development of a maintenance coating program for an operating nuclear plant is to determine the painting schedules, materials, and application procedures used during construction. A turnover of this information by the constructor to the utility has not occurred at all plants. The plant coating engineer may have to survey each plant area and then develop a program that best fits into the plant's coating maintenance program.

During plant construction, a number of different coating systems may have been used. However, the logistics of using many coating systems in an operating plant may be difficult. In many instances, the plant will be using their own personnel to do repair and touch-up of the coating. The fewer coating systems for which they must qualified to repair, the easier the logistics.

An operating plant is often faced with coating much smaller areas where only a few gallons may be used at any one time, and the painters doing the work may change from one assignment to the next.

The plant owner must select the coating system to be used. This may involve testing the application of new coatings over existing systems to determine the compatibility of the two materials. The new coating material is generally required to meet the exposure intent of the original applied system. The same considerations regarding decontamination and the coating's ability to withstand plant normal operating and emergency conditions have to be addressed.

For all safety related coating systems, it is essential to have a quality assurance/quality control documentation program for all materials used. Specifically, for Service Level I and III coatings, this program must include a certification of compliance from the manufacturer stating that the material being supplied is, in fact, the same formula, that it uses the same quality materials, and that it was made under the same quality controls as was the original coating that was approved for use in the plant. This may mean the operating plant will have to perform additional work or testing to ensure that this is, in fact, true.

To accomplish this, the plant could consider a receipt testing program commercial grade dedication process for coatings that are not supplied in accordance with 10CFR50/NQ1 as applicable. This could include such quality tests as (1) weight per gallon, (2) viscosity of material, and (3) infrared red (IR) or gas chromatograph (GC) printouts of the materials being received. Comparing this information to previously received values from the manufacturer would give the user a basis for acceptance of the materials.

An in-plant training and qualification program will be necessary to qualify painters and inspectors regardless of whether they consist of plant personnel or personnel from an outside agency. A plan must be ready for implementation before the need for maintenance coatings becomes acute. The guidance contained in ASTM D4227, *Standard Practice for Qualification of Coating Applicators for Application of Coatings to Concrete Surfaces* [1]; ASTM D4228, *Standard Practice for Qualification of Coating Applicators for Application of Coatings to Steel Surfaces* [2]; and ASTM D4537, *Standard Guide for Establishing Procedures to Qualify and Certify Personnel Performing Coating Work Inspection in Nuclear Facilities* [3], provide the basis for this qualification program.

After this is completed, a program should be developed to incorporate the plant's licensing commitments. It should also address generically the areas to be coated and should specify the coatings to be used for typical substrates. Another approach is to develop a specific definitive specification/procedure as the need arises for coating work. The rest of this chapter will be devoted to preplanning for a specific coating job.

Preplanning Coating Work

Preplanning of all protective coating work is important and has become more important as years pass and as the cost of maintenance labor and materials increases.

All aspects of the specific job have to be considered. To ensure all considerations are covered, a checklist of items to address is advisable. The checklist should include the scope of work being contemplated (i.e., what is to be coated, what are the anticipated desired results, what is the projected completion date, and what personnel will be utilized), as well as who will do the work (i.e., will the job be done with unskilled plant laborers from the plant, journeyman painters on the plant staff, or an outside contractor). Applicators shall be qualified by a formal qualification/certification procedure for safety-related coating application.

[1] Alliant Energy, 200 1st St., SE, Cedar Rapids, IA 52401-1409
[2] First Energy Corporation, 5501 N. State Route 2, Mailstop DB3105, Oak Harbor, OH 43449
[3] KTA-Tator, 115 Technology Dr., Pittsburgh, PA 15275
DOI: 10.1520/MNL820130033

Develop a list of plant restrictions:

a. What are the administrative plant procedures for initiating coating work, that is, technical requirements, purchasing procedures, quality assurance/quality control (QA/QC) requirement, and so forth?
b. What are the atmospheric conditions in the area where the coating must be applied?
c. Will the coating work be done in the summer (when there is a chance of hot, humid weather or hot, dry weather), or will it be done in the winter (when low temperatures might be a problem or other adverse weather conditions might exist)?
d. Is the work going to be done outside the plant or inside the plant where it can be protected from the elements?
e. What are the time restrictions imposed for the coating work?
f. Is the "time window" to complete the work and cure the coatings large enough after all preparations and material applications specified have been scheduled? (If not, modifications for doing the work will have to be made.)
g. Will the coating work interfere with other plant operations while setting up? (The scaffolding and painting equipment, protecting/covering of equipment adjacent to the work area, and the odor created with most types of paint materials may create problems for the coatings engineer.)
h. Will the coating be used for decorative purposes, for chemical resistance, for heat resistance, for contamination control, or for other purposes?
i. What precautionary measures must be implemented to protect areas of the plant that are serviced by engineered safety feature atmospheric clean-up system high efficiency particulate air (HEPA) filters and charcoal absorption heating, ventilating, air conditioning (HVAC) systems during surface preparation and coating operations? (See U.S. Regulatory Guide 1.52 and 1.140 for guidance.)
j. Will special ventilation equipment be needed?
k. Will the coating be done in a fire-protected area?
l. What types of equipment will be used for the coating work? (Equipment may have to be used under limiting conditions.)
m. Do coatings meet licensing commitments and design bases (such as Reg. Guide 1.54 compliance, ASTM E84 [4] requirements, thermal conductivity, etc.)?
n. Could the coating affect moving parts of an SSC?
o. Have worker training and qualification requirements been verified as current?

All of the preceding factors affect both the selection of a coating system and its ability to be applied under the conditions set down and established here and by the plant.

Coating System Selection

Make a list of the coating systems that might be applicable for the job intended, taking into consideration not only the items listed earlier but whether the coating(s) being recommended is compatible with any previous coating on the surface and whether that previous coating should need to be completely removed.

List the advantages and disadvantages for each of the coating systems being considered. Weigh these against the conditions under which work is to be performed, the exposure to which the coatings are to be subjected, and the required life of the coatings.

Has the coating system selected been tested under conditions for which it is to be applied and used, and is it suitable for the environment in which it will be exposed? Has this testing included DBA, if applicable? If not, time may be required to make these evaluations.

Surface Preparation Requirements

Coating considerations have to be made with the methods of surface preparation in mind. Will the method create dust or airborne or radioactive contamination? Are there engineered safety feature atmosphere clean-up systems, HEPA filters, and absorption units in the area that would be affected by the coating and its solvent systems? Is there a restriction on the amount of water that could be used in the cleaning of the surfaces, and could the water used be allowed to enter the plant drainage system?

Coating Byproduct and Equipment Disposal

Consider the disposables that are generated by the coating process. Is the cost of processing these disposables factored into the total job?

Many different types of hazardous wastes can be generated during maintenance coating work. These unwanted substances include but are not limited to:

- Coating chips and flakes
- Nonradiologically contaminated spent abrasives
- Heavy metals (lead, cadmium, chromium)
- Spent solvents
- Unused coating materials
- Asbestos
- Coating, ventilation, and surface preparation equipment
- Radioactive or mixed waste

These waste materials and equipment can be found alone or in conjunction with other hazardous substances in coating work debris and must be handled and disposed of in accordance with federal, state, and local regulations. Containment and disposal of coating hazardous wastes are significant logistical, scheduling, and cost factors to be considered during the planning of coating work projects.

Prior to commencing coating maintenance work, the responsible engineer/person should investigate the existing coating materials that will be removed as part of the work as well as the new coating materials to be applied. This investigation should identify all hazardous substances that will be contained in the coating work waste; the information obtained should then be factored into the coating work specifications, the job plan, and the project cost estimate.

In nuclear plant coating work, coating wastes that are hazardous as defined by 40 CFR 261, Identification and Listing of Hazardous Wastes, can become contaminated with radioactive materials, creating a waste material referred to as “mixed waste.”

A systematic approach for maintenance painting/coating in a nuclear plant is to have a checklist. This list can help ensure that all aspects of a coating job have been addressed. The checklist found in **Table 4.1** is an example and can be used as is or modified to fit a specific situation. Questions that can be answered with a yes, no, or a check mark also provide a quick and easy reference document for the record.

After all the aforementioned considerations have been made, select the coating system that best fits the condition and limitations of the area to be coated. Then verify that the material selected is compatible with the surface preparation and the previous coating and then write a specific specification/procedure.

TABLE 4.1 Maintenance Coating Considerations

Accessibility	**Yes/No**
1. Is the area accessible for the coating operation?	
2. Is the equipment required to perform the coating work accessible to the work area?	
3. Is the removal of interferences such as insulation, equipment, piping, and so on, required?	
4. Does the area have enough accessibility to permit the specified surface preparation or coating application technique, or both?	
5. Is scaffolding equipment required for the coating work? (Ensure proper safety for workers.)	
6. Is any special breathing equipment needed for personnel in order to support work? Refer to Occupational Safety and Health Administration (OSHA), radiation control, or government requirements.	
Design Requirements and Configuration of the Surface(s) to be Coated	**Yes/No**
1. Is the surface to be coated:	
a. Flat?	
b. Smooth?	
c. Vertical?	
d. Horizontal?	
e. Does it contain weld seams?	
f. Does it contain weld attachments?	
g. Is the weld surface smooth? (Check weld spatter.)	
2. What is the service level of equipment or components? (Refer to ASTM D3843, *Standard Practice for Quality Assurance for Protective Coatings Applied to Nuclear Facilities* [5].)	
3. What are the quality assurance requirements? (Refer to ASTM D3843 [5].)	
4. What are the quality control and testing requirements?	
5. Is the reason for coating:	
a. Corrosion protection?	
b. Decontaminability?	
c. Aesthetics?	
d. Cleanliness?	
e. A combination of these factors?	
Material (Substrate) to be Coated	**Yes/No**
1. Carbon steel	
2. Stainless steel	
3. Alloys	
4. Plastic	
5. Concrete	
6. Other nonferrous materials	
7. Other	
a. Is the coating material approved for the substrate?	
b. Is the coating material recommended by the coating manufacturer for the substrate and service?	

(Continued)

TABLE 4.1 (Continued)

Previously Coated Substrate	Yes/No
1. Investigate existing coating's historical performance.	
a. Is historical coating information available?	
2. Investigate possible failure mode and cause.	
3. Can existing coating materials still be certified as qualified coating?	
4. Could the present coating material continue to be used?	
5. Do present coatings contain hazardous waste material (i.e., lead, asbestos, coal tar, etc.)?	
6. Should a new coating material be selected to prevent future failures?	
7. If the coating process is inadequate, is this due to:	
a. Improper surface preparation?	
b. Improper coating application?	
c. Inadequate testing?	
d. Inadequate training of application personnel?	
e. Inadequate training of preparation personnel?	
f. Inadequate training of inspection personnel?	
g. Inadequate procedures?	
Present Substrate Corrosion Condition	**Yes/No**
1. Is the substrate presently corroded?	
2. What is the extent of the corrosion, as a percentage? (See ASTM D610 [6].)	
3. Is the type of corrosion:	
a. General?	
b. Pitting?	
c. Stress corrosion?	
d. Intergranular?	
e. Other?	
4. Are repairs to the substrate required prior to coating?	
5. Can the substrate be repaired?	
6. Are procedures required for the repair?	
7. Are repair procedures available?	
Plant Operational Conditions	**Yes/No**
1. Do any of the following operating conditions affect the coating work or ability to work?	
a. High radiation levels	
b. Area security requirements	
c. Area temperature restrictions	
d. Material and substrate temperatures	
e. Accessibility (including confined space entry)	
f. Ventilation requirements	
g. Fire control restrictions	
h. Protection required for plant's engineered safety-feature atmospheric cleanup system, HEPA filters, and absorption units	
Radiation Levels	**Yes/No**
1. Is the substrate radioactively contaminated?	
2. Is the substrate radioactive?	
3. Are the general area radiation levels within acceptable limits? (Verify with plant health physics department.)	
4. Is there airborne contamination? (Verify with plant health physics department.)	
5. Will surface preparation generate airborne contamination?	
6. What types of breathing apparatus and clothing are required? (Verify with plant health physics department and OSHA requirements.)	
7. Is decontamination practical?	

(Continued)

Radiation Levels	Yes/No
8. Should decontaminability be considered in the future?	
9. If decontamination is not practical, can the contamination be sealed to the substrate?	
10. Will special ventilation and filtration equipment be required?	
11. Are special procedures required for the ventilation equipment operation?	
12. Are special and additional arrangements required for contaminated material disposal?	
In-Service Inspection Requirements	**Yes/No**
1. Does the substrate require inspection as a part of an in-service inspection program?	
2. Can the substrate remain uncoated to facilitate inspection?	
Time Constraints	**Yes/No**
1. Can the coating work be completed at one time?	
2. Should the coating work be divided into phases?	
3. If the work is completed in phases, is the material/equipment to remain on-site?	
4. Has the remobilization of workers been negotiated?	
Weather/Climatic Conditions	**Yes/No**
1. Is the work area susceptible to adverse climatic conditions?	
2. Can the work area be protected from adverse conditions?	
3. Are there temperature and humidity requirements for the coating material?	
4. Have provisions been made for controlling temperature and humidity?	
5. Can work area cleanliness be maintained?	
6. Have equipment placement and protection been evaluated?	
7. Has equipment operation been evaluated?	
8. Have material storage requirements been considered (i.e., heating and ventilation requirements)?	
9. Are there personnel considerations?	
Material/Waste Disposal	**Yes/No**
1. Have disposal requirements for the coating material waste been checked?	
2. Have disposal requirements for the surface preparation material been checked?	
3. Has disposal of radioactively contaminated material and equipment been arranged?	
Ventilation Requirements	**Yes/No**
1. Is humidity control required? (Refer to coating data sheets.)	
2. Is temperature control required? (Refer to coating data sheets.)	
3. Is particulate filtration required? (Refer to OSHA requirements.)	
4. Are there confined entry precautions?	
5. Are there explosive concentrations to be monitored?	
6. Have air changes per hour been calculated and found to be adequate?	
Safety Requirements	**Yes/No**
1. Have personnel safety requirements been checked? Refer to health physics, OSHA, Mine Safety and Health Administration (MSHA), National Institute of Occupational Safety and Health (NIOSH), Environmental Protection Agency (EPA), Nuclear Regulatory Commission (NRC), company, and plant requirements.	

References

[1] ASTM D4227, *Standard Practice for Qualification of Coating Applicators for Application of Coatings to Concrete Surfaces*, ASTM International, West Conshohocken, PA, 2012, **www.astm.org**

[2] ASTM D4228, *Standard Practice for Qualification of Coating Applicators for Application of Coatings to Steel Surfaces*, ASTM International, West Conshohocken, PA, 2012, **www.astm.org**

[3] ASTM D4537, *Standard Guide for Establishing Procedures to Qualify and Certify Personnel Performing Coating Work Inspection in Nuclear Facilities*, ASTM International, West Conshohocken, PA, 2012, **www.astm.org**

[4] ASTM E84, *Standard Test Method for Surface Burning Characteristics of Building Materials*, ASTM International, West Conshohocken, PA, 2015, **www.astm.org**

[5] ASTM D3843, *Standard Practice for Quality Assurance for Protective Coatings Applied to Nuclear Facilities*, ASTM International, West Conshohocken, PA, 2008, **www.astm.org**

[6] ASTM D610, *Standard Practice for Evaluating Degree of Rusting on Painted Steel Surfaces*, ASTM International, West Conshohocken, PA, 2012, **www.astm.org**

Chapter 5 | Planning and Scheduling Maintenance Coating Work

Daniel L. Cox[1]

This chapter is closely related to Chapter 4. However, this chapter goes into more detail as to the specific area being coated.

Perform an Inspection Survey

One of the best ways to begin a protective coatings maintenance program is to *perform a thorough condition assessment* of the coated and uncoated surfaces in the plant. This will allow an accurate determination of the locations and extent of damage and/or deficiencies in the protective coating systems.

1. The emphasis of the coating condition assessment work should be on areas within the containment structure and other areas of the plant subject to contamination (i.e., Coating Service Levels I and II areas as identified in the controlling documents). During plant outages, accessible surfaces and areas that are classified as Coating Service Level III should also be assessed to monitor the condition.
2. The results of the survey should be reported in written form and retained as a permanent plant record by the maintenance organization and by the nuclear coatings specialist or coatings engineer. The file should be reviewed each operating cycle and updated as coating work is performed.
3. The survey should identify areas that are mechanically damaged, delaminated, cracked, excessively worn, lacking incorrect or proper coating, or that have other coating flaws, or combinations thereof. Additionally, the surface characteristics (e.g., surface profile and configuration) of the previously coated surface should be considered.
4. Photographs or a video of the areas needing remedial work are useful ways for describing and recording the affected areas. They may also be used as a means of mapping the locations.
5. Survey personnel shall meet the qualifications detailed in Chapter 3.

[1] Structural Integrity Associates, 2321 Calle Almirante, CA 92673

DOI: 10.1520/MNL820130015

Prepare Maintenance Plan

The next major step in a protective coating maintenance program is to *prepare a maintenance plan* for the restoration of the damaged or deficient coating systems identified by the survey.

1. The plan should address both a short-term and long-term program typically spanning as much as five years (two to three operating/refueling cycles).
2. Coating work should be prioritized with regard to its effect on structure, system, or component operability; serviceability; and availability of equipment (particularly required cure times for immersion coatings), room/area, and so forth to be coated. The level of radiation present in the area should be taken into consideration. An ALARA plan may have to be developed for the work.
3. The plan should include an accurate description of the surfaces to be restored, the time frame for the restoration, and the related labor and material cost estimates.
4. The schedules for future outages and other major projects that would affect or control the coating maintenance work (or both) should be closely reviewed with outage planning and maintenance department representatives.
5. The type of equipment necessary to perform the upcoming work should be determined and arrangements made to have the equipment and materials on site.
6. The potential impacts the coating work will have on the plant's operation (e.g., how will the engineered safety feature atmospheric cleanup systems' HEPA, and charcoal filters, and absorption units be protected or affected by the painting program) should be determined.

Seek early management approval of the coating maintenance program. See that the necessary funds are budgeted for the performance of the work planned for the upcoming projects. Ensure that the coating maintenance plan is communicated to all involved parties. Determine the best way to economically handle the project (i.e., lump-sum contract, cost plus contract, use of on-site personnel). If the work is safety related, consider the necessity and cost of QA/QC oversight.

For contracted work:

1. Prepare commercial, technical, and QA documents.
2. Competitively bid the work.
3. Analyze bids (i.e., review for approval, qualifications, application procedures, work plan, etc.).
4. Award contract or, for projects involving onsite personnel: prepare man hour estimates, train and qualify contract painters, and obtain approval to proceed with work.

Scheduling

Generally, protective coating maintenance work within the primary containment structure must be performed during an outage.

Outages are normally periods of high maintenance activity with many crafts competing for plant resources, time, and space to accomplish their maintenance projects. Typically, all activities during an outage are scheduled and planned well in advance to ensure a productive outage. For this reason, it is necessary to know the entire scope of work required for a specific coating activity before the activity is scheduled so that adequate time and support are available to perform the desired application.

Protective coatings maintenance work may have to be performed during the second or third shift or in limited specified locations. It is very important to incorporate cure times and recoat intervals into the schedule of activities. Night shifts may also be required when floors, handrails, or other traffic areas require recoating.

The following steps should be considered in developing a maintenance painting schedule:

1. Determine and clearly identify the scope of work for the particular project under consideration. It is often useful to divide the work into individual parts that are readily handled at one time (i.e., a floor at a specific location and elevation or an area of liner plate within given quadrants and elevations).
2. The protective coating specifications or procedures (or both) should be updated and appropriate for maintenance work. If specifications are not suitable for maintenance painting, refer to later chapters of these guidelines for direction. Verify that all workers are qualified per the project specification and plant work requirements for lockout/tagout, confined space, fall protection, and so on.
3. Depending upon how the provision of labor, supervision, and inspection personnel will be handled—whether by outside contractor or by other means—the arrangements for labor, supervision, and inspection personnel should be finalized at least three months prior to the start of the project. The requirements for personnel access (an in-depth background investigation, a psychological evaluation, and fitness for duty evaluation) may require two weeks or more. In addition, employees will have to undergo nuclear general employment training or site-specific training, or both. In some cases, prospective employees may have to have a medical examination.
4. Determine whether adequate coating materials (i.e., coatings, thinners, solvents for surface preparation and cleanup) are on hand. If not, the materials must be ordered sufficiently in advance of the intended usage and be received with the required documentation. However, care must be taken to ensure that the material will not exceed its "shelf life" as specified by the manufacturer when ordering material in advance.
5. Obtain necessary permits such as radiation work permits. It may be necessary to discuss potential problems relating to generation of airborne contamination or to the prospects of working in highly contaminated areas with radiation protection or health physics personnel. The site person responsible for the coating project should be aware of clearance requirements for systems and equipment and the need for any special permits required at the particular site.
6. Establish a priority list for the work to be undertaken during the subject project. The priorities should be reviewed with the plant management, the maintenance department, and other involved parties. A pre-project meeting should take place with engineers, operations, and maintenance foremen as well as with craft, radiation protection, health physics, station, safety, QA/QC, and other personnel as necessary who may interface directly or indirectly with the project.
7. A detailed schedule is a useful tool for maintaining priorities and for monitoring the progress of the work. The schedule should include time for:
   a. Personnel in-processing and days off to accommodate work hour limitations
   b. Setup of scaffolding or other rigging, or both
   c. Gathering of materials
   d. Entrance and exit time
   e. Mobilization/demobilization for intermittent outages
   f. Surface preparation
   g. Cleanup following surface preparation
   h. Primer application (touch-up or complete coat)
   i. Cure/recoat time interval
   j. Finish application (sometimes multicoat)
   k. Final cure time
   l. Removal of scaffolding and equipment

Major equipment (blast equipment, ventilation, filtration, etc.) may require structural analysis to ensure that staging locations are able to support the weight and that during an accident event (earthquake) the equipment will not fall on or in any way impair the plant's structural integrity or the safe shutdown of the plant. This may mean that additional support or anchoring (or both) may be required. This analysis may be required whether the plant is in an operating or shutdown condition.

Proper attention given to the considerations stated here should provide a reasonable basis for a well-planned and scheduled maintenance painting project.

Chapter 6 | Qualification of Nuclear-Grade Maintenance Coatings

John O. Kloepper[1] and Steve L. Liebhart[1]

Purpose

To qualify maintenance coating systems for use in Coatings Service Level I (CSL I) areas of a nuclear power plant, it is necessary to prepare coated samples that represent the original coating system and any proposed repair coatings. Any such coating system may be tested and qualified as shown in this chapter. Because individual nuclear plant sites have differing CSL I requirements, it is the responsibility of the licensee to ensure that all required testing was performed as stipulated by their operating license and that the reported results of such testing were acceptable.

Typically, testing is performed on coated carbon steel test panels or concrete test blocks representing existing plant conditions (or both) where either maintenance coatings will be applied to damaged areas or new maintenance coatings will be applied over bare substrate in CSL I areas. For situations involving application of maintenance coatings over existing coatings, when and wherever possible, coated substrate should be removed from containment, and application of the proposed repair coatings should be made over these samples in lieu of artificially aging and testing newly prepared test blocks or panels. ASTM **D5139** provides detail on preparation of carbon steel test panels and concrete test blocks [1].

Substrate Preparation

CARBON STEEL TEST PANELS

Substrate shall consist of carbon steel meeting the requirements of ASTM A36 [2], as specified by ASTM **D5139** [1], or as required by the project. Sample size shall be a minimum of 2 in × 4 in × 0.125 in or as required for testing, and surface preparation shall be a minimum of SSPC-SP 10 or as required by the project.

CONCRETE TEST BLOCKS

Composition of the concrete shall be as shown in ASTM **D5139** or as required by the project [1]. Sample size shall be a minimum of 2 in × 2 in × 4 in, and surface preparation shall be as specified in ASTM **D5139** or as required by the project [1]. Forms may be constructed of wood, pine sides and plywood base, or other suitable materials such as polyethylene. Wooden forms should be coated with a clear epoxy to prevent absorption of water into the wood and for easy release of the concrete test blocks upon curing. Steel hooks are embedded into the top of one end of each block for use as a hanger and to hold the block while testing.

Application of Coatings to Substrate

The proposed repair system will be applied to either:

- Artificially aged coatings representing the coating system in containment, prepared as follows:
  1. Prepare substrate as required. Note that the depth of any bug holes present in concrete substrates should be measured and visually recorded as shown in **Figs. 6.1–6.4**.
  2. Apply existing coating system to the substrate in accordance with the manufacturer's application instructions or as modified by the licensee.
  3. After the existing coating system has been applied and allowed to cure at lab ambient for 14 days, place in a control oven set at 150°F. Allow the test panels to cure seven days at 150°F.
  4. The panels are now ready to be damaged prior to application of the repair coating system.
- Coated substrate removed from containment.

Existing Coating System Damaging and Topcoating with the Proposed Repair System

In an effort to simulate the damaged condition of the existing coating system, one or more of the following can be employed.

- Holes and broken areas of coatings on concrete substrate:
  1. In the middle portion of one side of one panel drill a 1/2 in. (1.27 cm) hole through the coating to bare concrete.

[1] Carboline Company, 350 Hanley Industrial Ct., St. Louis, MO 63144

DOI: 10.1520/MNL820130035

FIG. 6.1 Broom finished surface of a concrete test block before surface preparation.

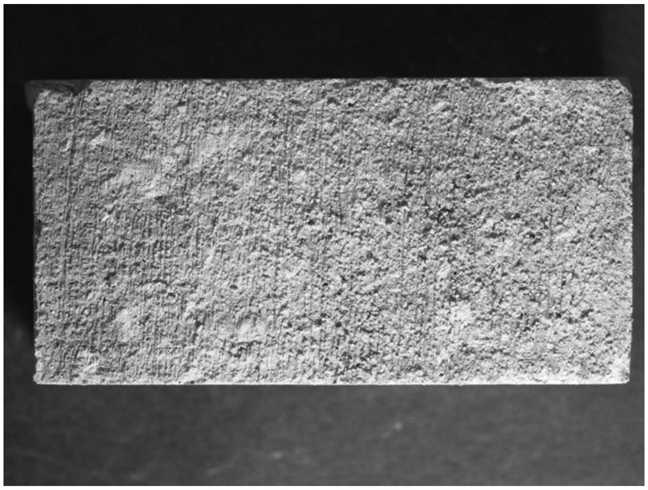
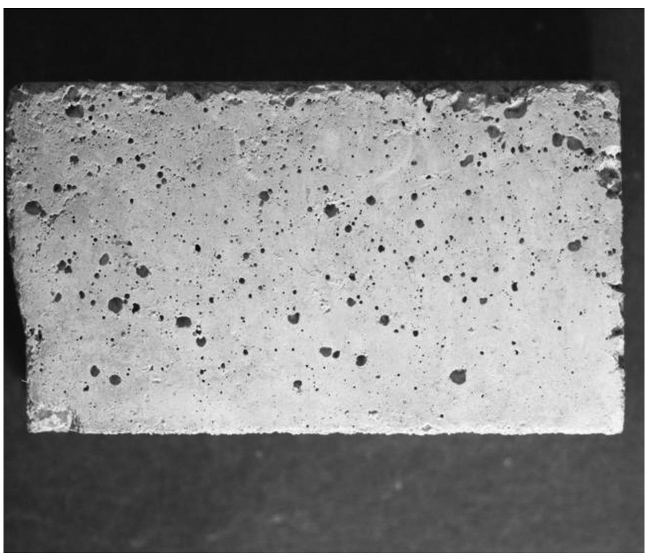


FIG. 6.2 Form side of a concrete test block before surface preparation.



2. Abrade all test surfaces of the panel in accordance with the manufacturer's instructions. This may include sanding, needle-gun, abrasive blasting, or any other agreed upon method.
3. Apply the proposed coating system in accordance with the manufacturer's instructions or as required by the project or any other agreed upon method.

- Damaged coatings on carbon steel substrate:

1. In the middle portion of one side of one panel, drill a 1/2 in. (1.27 cm) hole through the coating to bare steel.
2. Place the damaged panels in a water fog chamber for 14 days to allow rust to form.

FIG. 6.3 Concrete test block sweep blasted with Black Beauty to remove laitance and open up bug holes.

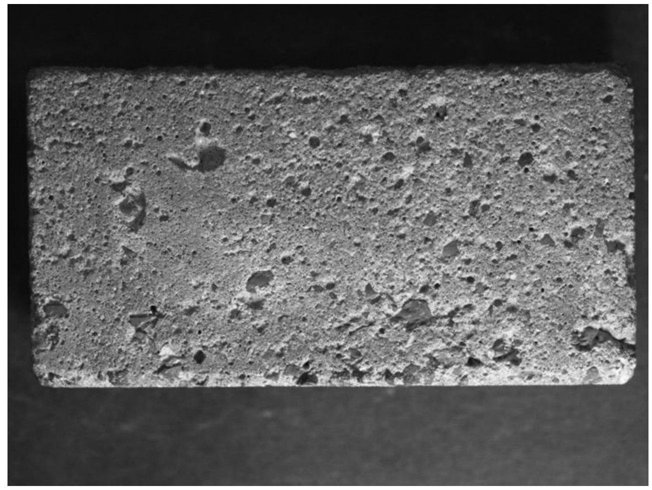
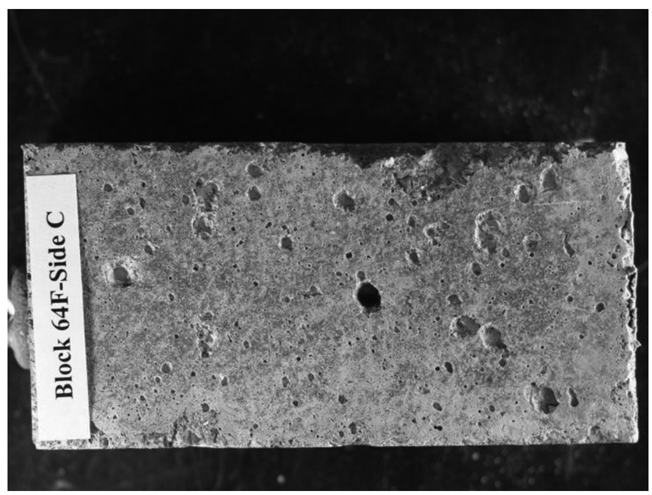


FIG. 6.4 Concrete test block power-tool cleaned with a needle-gun (SSPC-SP3 followed by vacuuming to remove loose debris) to remove laitance and open up bug holes.



3. Remove rust from the damaged area and abrade all test surfaces of the panel in accordance with the manufacturer's instructions. This may include sanding with an abrasive, needle-gun, or, but not limited to, abrasive blasting (or both). Refer to standards such as SSPC-SP 11, Power Tool Cleaning to Bare Metal.
4. Apply the proposed coating system in accordance with the manufacturer's instructions or as required by the project (or both).

Testing

The test samples shall be subjected to design basis accident testing in accordance with ASTM D4082 [3] and ASTM D3911 [4] or as required by the project. Total accumulated radiation dose shall be 1×10^9 rd unless specified otherwise.

Other testing may also be required on one or more of the coatings or the coating system (or both) as required by the project. Such testing may include:

- ASTM D2794, *Standard Test Method for Resistance of Organic Coatings to the Effects of Rapid Deformation (Impact)* [5]
- ASTM D3912, *Standard Test Method for Chemical Resistance of Coatings Used in Light-Water Nuclear Power Plants* [6]
- ASTM D4060, *Standard Test Method for Abrasion Resistance of Organic Coatings by the Taber Abraser* [7]
- ASTM D4541, *Standard Test Method for Pull-Off Strength of Coatings using Portable Adhesion Testers* [8]
- ASTM E84, *Standard Test Method for Surface Burning Characteristics of Building Materials* [9]
- ASTM E1530, *Standard Test Method for Evaluating the Resistance to Thermal Transmission of Materials by the Guarded Heat Flow Meter Technique* [10]

Documentation

All testing shall be performed under a 10CFR50 Appendix B QA/QC program, and all documentation pertaining to the testing program shall be comprehensive. Examples of such documentation are as follows:

- For new substrate, the type, size, surface preparation, and when applicable, cure.
- For samples removed from containment, relevant information should include the date removed and how, location from within containment that the sample was taken, and any other pertinent facts.
- Batch numbers of all coatings utilized along with application parameters (thinning information, cure, etc.).
- The tests performed including the issue date or version along with all documentation specified by the test methods and a description of deviations, if any.
- Photo documentation:
  - Samples removed from containment should be photographed both before and after surface preparation and after the application of the repair coating system.
  - For new concrete substrate the samples should be photographed both before and after surface preparation as shown in Figs. 6.1–6.4 and after applying the coating system as shown in Figs. 6.5–6.6.
  - For new steel substrate the samples should be photographed after applying the coating system as shown in Fig. 6.9.
  - All samples should be photographed both before and after irradiation testing as shown in Figs. 6.5–6.7 and Figs. 6.9–6.10.
  - All samples should be photographed both before and after DBA testing as shown in Figs. 6.5–6.11.
- All documentation specified by the test methods utilized should be included.

FIG. 6.5 Concrete test block after coating and with approximately 1/2 inch intentional drill damage.

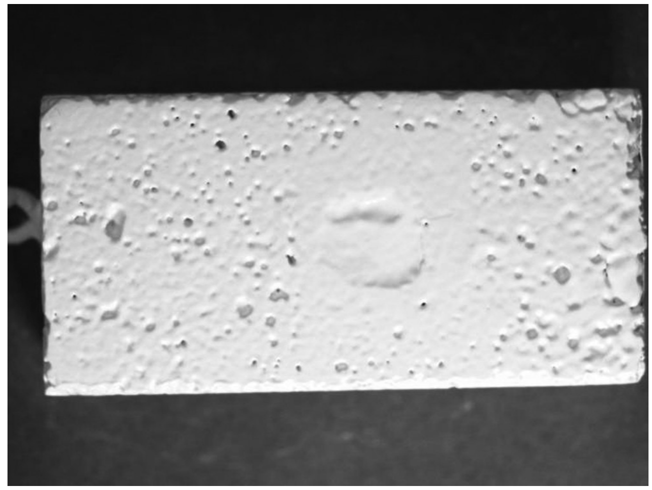


FIG. 6.6 Concrete test block before testing.

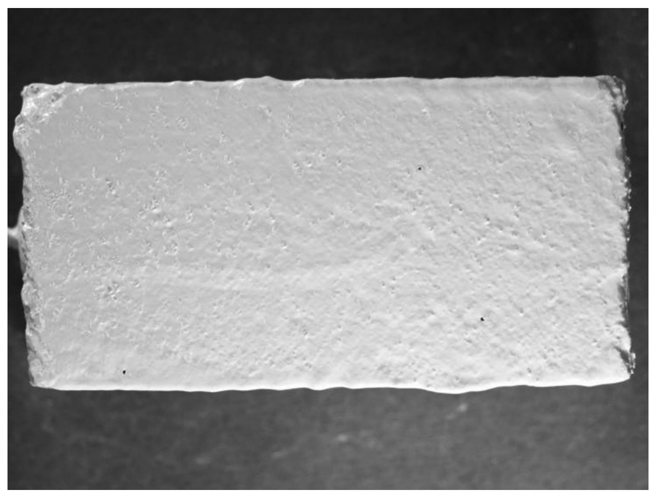


FIG. 6.7 Coated concrete test block after irradiating.

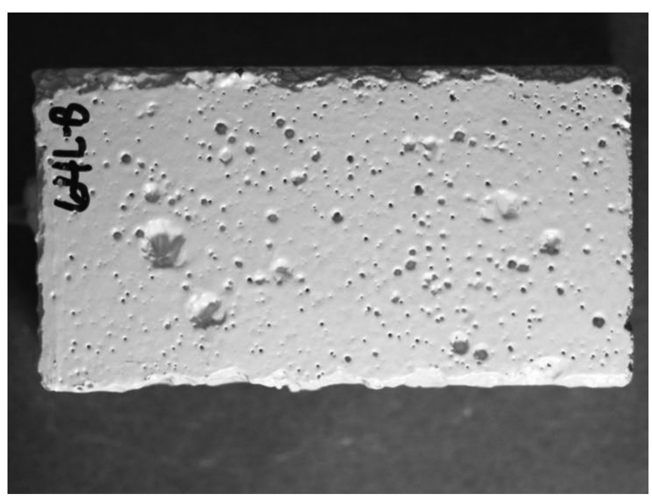


FIG. 6.8 Coated concrete test block after irradiating and design basis accident (DBA) testing.

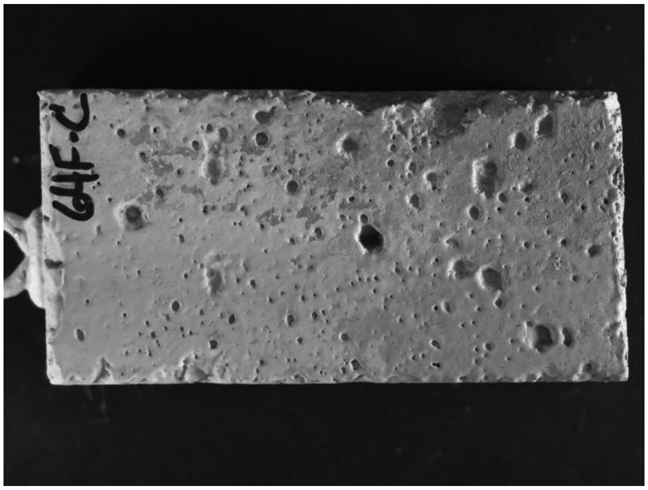


FIG. 6.9 Coated carbon steel test panel before testing.

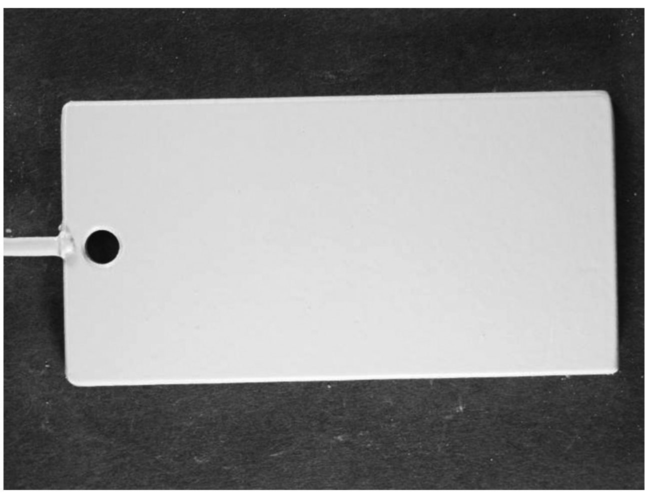


FIG. 6.10 Coated carbon steel test panel after irradiating.

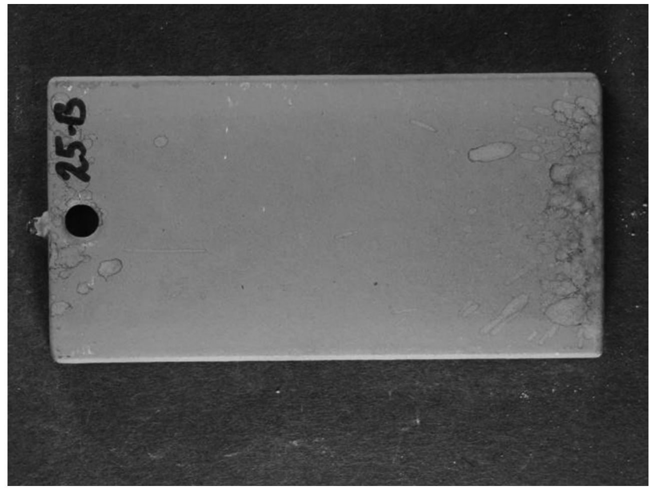
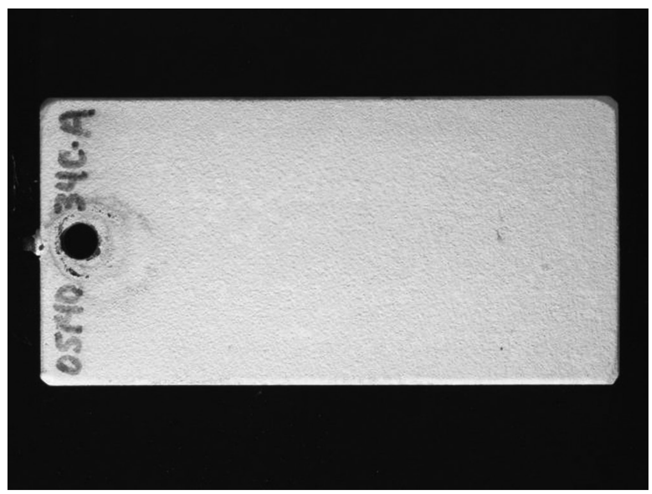


FIG. 6.11 Coated carbon steel test panel after topcoating, irradiating, and DBA testing.



References

[1] ASTM **D5139**, *Standard Specification for Sample Preparation for Qualification Testing of Coatings to be Used in Nuclear Power Plants*, ASTM International, West Conshohocken, PA, 2012, **www.astm.org**

[2] ASTM **A36**, *Standard Specification for Carbon Structural Steel*, ASTM International, West Conshohocken, PA, 2014, **www.astm.org**

[3] ASTM **D4082**, *Standard Test Method for Effects of Gamma Radiation on Coatings for Use in Light-Water Nuclear Power Plants*, ASTM International, West Conshohocken, PA, 2010, **www.astm.org**

[4] ASTM **D3911**, *Standard Test Method for Evaluating Coatings Used in Light-Water Nuclear Power Plants at Simulated Design Basis Accident (DBA) Conditions*, ASTM International, West Conshohocken, PA, 2008, **www.astm.org**

[5] ASTM **D2794**, *Standard Test Method for Resistance of Organic Coatings to the Effects of Rapid Deformation (Impact)*, ASTM International, West Conshohocken, PA, 2010, **www.astm.org**

[6] ASTM **D3912**, *Standard Test Method for Chemical Resistance of Coatings and Linings for Use Nuclear Power Plants*, ASTM International, West Conshohocken, PA, 2010, **www.astm.org**

[7] ASTM **D4060**, *Standard Test Method for Abrasion Resistance of Organic Coatings by the Taber Abraser*, ASTM International, West Conshohocken, PA, 2014, **www.astm.org**

[8] ASTM **D4541**, *Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion-Testers*, ASTM International, West Conshohocken, PA, 2009, **www.astm.org**

[9] ASTM **E84**, *Standard Test Method for Surface Burning Characteristics of Building Materials*, ASTM International, West Conshohocken, PA, 2015, **www.astm.org**

[10] ASTM **E1530**, *Standard Test Method for Evaluating the Resistance to Thermal Transmission of Materials by the Guarded Heat Flow Meter Technique,* ASTM International, West Conshohocken, PA, 2004, **www.astm.org**

Chapter 7 | Coating Materials

John F. De Barba[1] and Christopher Palen[1]

The selection of coatings for use in nuclear power plants is based upon requirements for normal operations as well as established accident requirements. Coating manufacturers evaluate materials in accordance with current standards or outdated standards that a nuclear power plant may be bound to in the plant final safety analysis report (FSAR) to determine radiation resistance, decontamination properties where required, and service ability under design basis accident conditions [1]. Other criteria for the testing, selection, and application of coatings in nuclear power plants are defined in American National Standards Institute (ANSI) and American Society for Testing and Materials (ASTM) documents or plant specific documents such as AP1000.

The subject of protective coating maintenance work for power-generating facilities is specific to maintenance coatings applied over existing substrates. Areas of concern that are not necessarily considered in a new construction phase include:

1. *Downtime*—A determination has to be made as to the amount of time allowable to accomplish coating work due to constraints such as plant shutdown period or coating repair work that must be accomplished during plant operation.
2. *Environmental conditions*—It may not be possible to control temperature, relative humidity, air movement and ventilation, and other application factors.
3. *Existing substrates*—Coatings may have to be applied over existing substrates (i.e., previously applied coatings or previously prepared substrates). Special surface preparation techniques such as scarifying and methods described in various power tool cleaning to bare metal standards, or in SSPC-SPl 1, would have to be considered because it may not always be possible or desirable to remove coatings and prepare substrates in accordance with original new construction specifications.
4. *Personnel safety*—Rapid coating application may be necessary where minimal personnel exposure can be tolerated due to existing levels of radiation in the workplace. Innovative application techniques may have to be developed.
5. *Inaccessibility*—Unusual methods of application may be necessary due to physical constraints such as inaccessible areas for normal coating application methods, blockage caused by equipment, instruments, piping, walkways, and so on. Coating materials would have to be compatible with such application techniques as brushing, rolling, troweling, squeegeeing, and innovative spray methods.

Once these parameters are defined, then and only then can coating materials be selected so that they are compatible with given conditions of application, environment, and substrate preparation procedures.

Protective coatings are used extensively in nuclear power plants for protection of assets, corrosion protection, maintaining appearance, and to aid in the removal of radionuclide soils (contamination). Normally, the corrosive atmosphere near any power plant is considered mild because most facilities are located in rural or suburban areas. However, when facilities are located adjacent to oceans, bays, or a general saltwater corrosive atmosphere, atmospheric corrosion is a significant factor in the selection of coating systems. Coatings are used significantly in nuclear plants for the protection of steel, concrete surfaces, and nonferrous surfaces from: (a) contamination by radioactive nuclides and subsequent decontamination processes; (b) ionizing radiation, chemical, and water sprays; (c) high temperature and high pressure steam; and (d) abrasion [1]. Some typical conditions of nuclear, chemical, and physical exposure are described by Watson and West [2] as follows:

> Radiation—For severe or moderate exposures to radiation, a coating is usually selected on the basis of its radiation-resistant properties. Obviously, film integrity must be maintained, otherwise the coating cannot function properly as an anticontamination and anticorrosion medium. To evaluate these and other properties, accelerated radiation exposure tests are necessary and are defined in applicable ANSI and ASTM standards.

Organic materials, including coatings, dissipate the energy of gamma radiation and energetic particles through ionization and electronic excitation. Both modes of energy dissipation lead to

[1] PPG Protective & Marine Coatings, 79 Ronzo Road, Bristol, CT 06010

DOI: 10.1520/MNL820140016

broken valence bonds in the form of an electrically charged site or unpaired electron. Both species are quite reactive and chemical reaction products can be expected in a variety of types and yields. Under radiation exposure, a coating may crack, blister, soften, chalk, discolor, become brittle, or exhibit a combination of these phenomena. Additives such as pigments, plasticizers, and other coating ingredients, as well as types of surfaces on which the coatings are applied, influence the radiation stability of the coatings.

The color of a pigment cannot be related by present-day empirical tests to its resistance to radiation. All colors studied are darkened or discolored by exposure to radiation. Initially, the surface discolors and, as the exposure increases, the depth of discoloration in the film also increases. White pigmented epoxies and modified epoxies turn yellow after exposure of about 5×10^8 rd and progressively darken to brown after exposure of about 2×10^9 rd.

Studies indicate that, for many coating materials, the effect of radiation is essentially a curing process characterized by an increase in hardness, a decrease in solubility, and sometimes, initially, by an increase in strength. The eventual stability of a polymer depends on its chemical structure. Epoxies and modified epoxies show a great deal of stability in a radiation field. Epoxy resins, when cured, are generally hard, extremely tough, and chemically inert. These resins are above average in radiation resistance—very likely because of their rigidity and aromatic content. The resistance of organic coatings to radiation can be predicted to some degree from data available from polymers and plastics. However, because of the complicating factors introduced by pigments, plasticizers, and other coating ingredients, coatings' resistance to radiation should be obtained only by empirical testing.

Epoxy coatings are exceeded in radiation resistance by inorganic zinc coatings. The ranking of zinc coatings in resistance to radiation is sometimes negated in practice because of marginal resistance to chemical and poorer decontamination properties. However, inorganic zinc primers are often used in conjunction with epoxy or modified epoxy topcoats in high radiation areas.

Decontamination

Contamination by radioactive substances is believed to occur through chemisorption, by ion exchange with free surface ions, by physical adhesion, or by migration of the radioactive nuclides into cracks and crevices. Generally, decontamination can be defined as a highly effective cleaning process. It is the practice or art of removing radioactive materials from surfaces. The purpose of decontamination is to render the affected areas harmless to unprotected workers and the biological environment, and to salvage costly equipment in work areas.

In nuclear installations, ferrous and nonferrous surfaces in various areas should be protected from radiation deposits. Suitable coatings applied over ferrous, nonferrous, and concrete surfaces allow for decontamination and provide resistance to radiation as well as abrasion resistance. It is, therefore, imperative that all areas where radioactive contamination is possible be protected with suitable coatings. As a case in point, if a bare concrete surface is contaminated, there is no practical way to decontaminate the surface except to remove the contaminated concrete.

In the past, decontamination testing provided methods for the quantitative evaluation of the ease and degree of decontamination of protective coatings. Essentially, decontamination testing measures the ratio of original beta-gamma activity versus the activity after decontamination. Historical data can be found in documents such as ANSI N 5.12 Section 4 and ASTM D4256-94 [3] (withdrawn). These test procedures determined a decontamination factor that compared the relative ease of decontamination of coatings using a laboratory procedure. The test methods were not intended to be directly related to decontamination methods used in practice. Unfortunately, these test methods created a mixed radioactive hazardous waste and go against the nuclear industry's as low as reasonably achievable (ALARA) procedures. Certain coatings may contaminate more readily than others, and the responses to decontamination treatments also vary. For this reason, there is no reliable test to compare the decontaminability of different coatings. In some cases, the desired level of decontamination may be achieved merely by cleaning the coating surface; in other cases, decontamination may be achieved only by partial or complete removal of the coating.

In the past, a variety of coatings were used in nuclear facilities because of their acceptable decontamination properties. Currently, epoxies or modified epoxy coatings have replaced other generic types because they provide satisfactory decontamination properties as well as superior abrasion resistance, elevated temperature service, and solvent and radiation resistance. Inorganic zinc coatings are not readily decontaminable; however, they are used in areas that require immersion or heat transfer capabilities. Chloride-bearing coating materials are prohibited from coming in contact with stainless steel components and—consequently—vinyl, and chlorinated rubber coating applications are restricted in critical areas of nuclear power plants.

DESIGN BASIS ACCIDENT

In the design and operation of light-water-moderated nuclear power plants, consideration must be given to various types of design basis accidents (DBAs) because the subsequent events might lead to a fractional release or expulsion of the fission product inventory of the core into the primary containment facility. Engineered safety features, principally a primary containment facility, are provided to prevent a release of fission products into the biological environment during and after this improbable event. Large areas of the primary containment facility are coated with a protective coating for the purpose of corrosion protection as well as ease of decontamination. If severe peeling, flaking, or chalking causes significant portions of the coating to be discharged into a common water reservoir, the performance of the safety systems could be seriously compromised by the plugging of strainers, flow lines, pumps, spray nozzles, and core coolant channels. If coating failure occurred during a DBA, the performance of the safety systems could be seriously compromised. Therefore, it is important that coatings withstand the harsh DBA conditions as well as meet the other stated criteria that are unique to nuclear plant operations [4].

The coatings are tested using the applicable time-temperature-pressure (TTP) curves that have been used to simulate primary

FIG. 7.1 Design basis accident (DBA) test facilities (courtesy of Oak Ridge National Laboratory).

containment atmospheres during a DBA as shown in Figures 1 and 2 of ASTM D3911 [5] and ANSI N101.2. The parameters of the curves may be simulated during testing as continuous functions or as an enveloping stepwise function. Steam is generated from deionized water and is used initially to achieve the desired thermal shock and to raise the test chamber and its environment to the prescribed test conditions. The temperature of the test chamber is maintained by means of internal or external heating elements, or both, or other suitable means. The inlet steam should not impinge directly on the test specimen. The duration of steam injection should be minimized, as much as feasible, and the duration recorded.

Test results have shown that two-component epoxy or two-component modified epoxy systems and inorganic zinc coatings are the best of the air-dried systems tested. Blistering and peeling caused by heat, pressure, and chemical attack are the principal causes of failure of coatings. Suitable DBA test programs are essential to develop valid empirical data to reinforce the choice of coating systems used. The results of DBA testing (Fig. 7.1) have demonstrated that technology currently exists to produce acceptable coatings to meet DBA conditions specified in various plant safety analysis reports (SARs). Coatings applied under maintenance conditions to existing substrates should meet the SAR criteria, taking into consideration the chemical effects to charcoal filters and, in some cases, the volatile organic compounds (VOC) regulation(s) of the state in which the plant is located, where required.

Considerations for Coating Selection

The major requirements for coating in nuclear power plants have been described. Although there are many specific requirements for coatings, the more general requirements can be listed as follows:

a. Radiation resistance.
b. Decontamination. Keep in as historical or eliminate?
c. Design basis accident.
d. Resistance to continuous immersion in deionized water (as required).
e. Physical properties.
f. Chemical resistance.
g. Thermal conductivity.
h. Fire evaluation.

There are many generic types of coatings being used in nuclear power plants today, the most common of which are:

a. Inorganic zinc-rich primers
b. Organic zinc-rich primers
c. Epoxy and modified epoxy coatings
d. Conventional alkyds, latex, engineered siloxane, urethane, and specialty coatings for noncritical areas

A brief description of these generic types follows.

Inorganic Zinc-Rich Primers

A zinc-rich coating is characterized by a very high degree of pigmentation, normally above 75 % of metallic zinc in the dried paint film. One essential property is that the paint film is electrically conductive and that it is in electrical contact with the steel substrate. These properties are obtained when a high portion of metallic zinc particles are in electrical contact with each other in the paint film and with the steel. An inorganic zinc-rich primer has properties similar to that of a galvanized coating. When it is applied on an electrically conductive media, the zinc-rich coating will provide electrochemical protection.

The inorganic binder is essentially a solution of silicates. The inorganic zinc-rich primer is unaffected by most organic solvents, is nonflammable, provides good sacrificial release of zinc to provide cathodic protection, has relatively high heat resistance (in excess of 400°F [204.4°C]), and is resistant to thermal shock cycles. The inorganic zinc coatings are normally applied by spray techniques. (Spray applications might not be permitted inside containment without elaborate over-spray controls.) They adhere well to properly prepared steel and give excellent protection against corrosion throughout the normal life of a nuclear plant.

In a nuclear facility, inorganic zinc-rich coatings are usually topcoated in areas requiring high decontaminability.

Organic Zinc-Rich Primers

Organic zinc-rich primers are similar to inorganic zinc-rich primers in pigmentation loading, upwards of 85 %. The primary difference is organic zinc-rich primers utilize an organic binder to hold together a high-ratio zinc pigment. The binder resin can be an epoxy (chemical cure) or a moisture-cured urethane.

Like the inorganic counterpart, the organic primer provides galvanic (sacrificial) protection to steel substrates. However, galvanic protection is less than that of inorganic zinc due to encapsulation of zinc pigment by binder resin. Unlike the inorganic zinc, the organic version's heat resistance is a function of the binder resin and is usually limited to a dry heat resistance of approximately 300°F.

Because the organic zinc-rich primer has a longer pot life than inorganic zinc, and is generally less difficult to apply than inorganic zinc, it is often used to repair inorganic zinc.

Adhesion is a function of the binder, and is generally very good on power-tool-prepared surfaces.

Organic topcoats are usually applied because they are more easily decontaminated. Care must be taken when topcoating inorganic zinc-rich coatings. All evidence of dry spray must be removed by screening or sanding. Often a mist coat is required to eliminate outgassing or bubbling.

Epoxy and Modified Epoxy Coatings

The catalyzed epoxy coatings are composed of an epoxy resin and a suitable catalyst (activator, hardener, or curing agent). Epoxy resins most commonly used in room-temperature-cured coatings are the reaction products of various proportions of bisphenol A, bisphenol F, and epichlorohydrin. Many resins are formed by this chemical reaction, and they vary in degree of polymerization, solubility in various solvents, and physical form.

The modified epoxy (epoxy-phenolic) is another variety of an epoxy coating in which phenolic groups are introduced into the backbone of the resulting polymer. The amine adduct epoxy and the modified epoxy (epoxy-phenolic) perform similarly when tested under nuclear environments. Each is capable of being formulated to meet specific requirements. Generally, the unmodified epoxy coatings have application advantages over the modified (epoxy-phenolic) coatings in that they are more tolerant to adverse field painting conditions of high humidity, varying temperatures, and prolonged drying periods between coats.

The cured epoxy or modified epoxy resin is a hard thermoset material in which the epoxy resin molecules are joined in a three-dimensional network of linkages and cross linkages. It is no wonder that these materials are primarily used in nuclear plants for their excellent resistance to radiation, decontamination properties, immersion service, and abrasion resistance. It is important to note that epoxy or modified epoxy coatings can vary significantly due to formulation differences. Therefore, certain epoxy coating formulations must be tested to determine whether they meet the criteria for the particular service intended.

ALKYD OR MODIFIED ALKYD PRIMERS AND TOPCOATS

Alkyd resins are polymeric esters prepared by the reaction of polyhydric alcohols and polybasic acids or their anhydrides. In the trade, they are often referred to as short-oil or long-oil alkyds. Long-oil alkyds contain a relatively high percentage of oil, while short-oil alkyds contain a relatively small percentage of oil. The long-oil alkyds are softer, more flexible, and slower drying, while the short-oil alkyds are harder, fast drying, and more brittle. Coating manufacturers often use a blend of different types of alkyds to achieve desired properties.

The alkyds as a group offer a durable film with good weather resistance. A high-quality alkyd will offer moderate resistance to radiation in the air and will seal a substrate from radioactive particles at ambient conditions. Alkyds do not have good resistance to strong chemicals and solvents and consequently are not normally used where frequent decontamination procedures are anticipated.

Alkyd coatings can be used for most noncritical areas within a nuclear facility due to their ease of application, overall good durability, and aesthetic properties. Alkyds are capable of being modified with silicone resins that provide added durability, and they are often used on turbines and other showplace areas. These coatings can easily be cleaned.

Engineered Siloxanes

Engineered siloxanes are a functional group in organosilicon chemistry with the Si-O-Si linkage. The parent siloxanes include the oligomeric and polymeric hydrides. Polysiloxanes are generally recognized as the newest generic class of high-performance protective coatings and include coating types based on inorganic siloxane and organic–inorganic siloxane hybrids.

Polysiloxane coatings based on a pure inorganic siloxane binder are curable at ambient temperature and have high solids and low volatile organic compounds (VOC), excellent temperature resistance, and good resistance to certain acids and solvents. They are well suited for high heat and selected chemical lining applications.

Polysiloxanes based on organic–inorganic siloxane hybrid binders have high solids and low VOC and provide an improved level of performance compared to traditional organic coating systems. Acrylic siloxane hybrids have superior weatherability and offer a cost-effective, isocyanate-free alternative to aliphatic polyurethane topcoats. Epoxy siloxanes have very high solids and low VOC. They have outstanding resistance to corrosion and better weatherability than aliphatic urethane. They also are readily decontaminable and are very resistant to radiation.

Polyurethane

Polyurethane coatings are another group that, like the epoxies, can have a number of coating combinations that create different properties. As with the epoxies, this is due to the reactivity of the isocyanate with many basic materials of various properties.

Polyurethane coatings contain resins made by the reaction of isocyanates with hydroxyl-containing compounds. Actually, whenever there is an active hydroxyl group, the isocyanate will react with it. Unfortunately, urethane coatings have isocyanate reaction products. These are toxic materials and add a special hazard to the use of urethane coatings.

Latex Paints

In general, when latex emulsion paints are compared with solvent-based resinous paints of the same type, they have many advantages: faster drying, easier application, improved cleanup of application tools with tap water, no fire hazard, improved resistance to mild alkali, resistance to fats and oils, and less color change. Latex paints do have disadvantages in that they are subject to freezing and may be damaged by the freeze-thaw process. They should not be applied below 10°C. At these temperatures, poor film formation can be expected due to poor coalescing action.

Many variations of latex coatings can be formulated. They are generally of three chemical compositions: (1) styrene-butadiene, (2) polyvinyl acetate, and (3) acrylic. Many variations of these basic types can be formulated, and they can be plasticized with different plasticizers to give a variety of properties, such as flexibility, stability, and so on.

Normally, latex coatings will be used in noncritical areas. Latex concrete block fillers are used commonly on much of the concrete surfaces to fill small voids prior to topcoating with latex or alkyd finish coats.

References

[1] Meyers, R. R. and Long, J. S., *Treatise on Coatings,* Vol. 4, Marcel Dekker, New York, 1984.

[2] Watson, D. C. and West, G. A., “Protective Coatings (Paints),” *Decontamination of Nuclear Reactors and Equipment,* J. A. Ayres, ed., Ronald Press, New York, 1970.

[3] ASTM D4256, *Standard Test Method for the Determination of Decontaminability of Coatings Used in Light-Water Nuclear Power Plants*, ASTM International, West Conshohocken, PA, **www.astm.org**

[4] Watson, C. D., Griess, J. C., Row, T. H., and West, G. A., “Protective Coatings for PWR & BWR Reactor Containment Facilities,” presented at the ANS National Meeting, Los Angeles, CA, June 28–July 2, 1970.

[5] ASTM D3911, *Standard Test Method for Evaluating Coatings Used in Light-Water Nuclear Power Plants at Simulated Design Basis Accident (DBA) Conditions*, ASTM International, West Conshohocken, PA, 2008, **www.astm.org**

Other Applicable References

ASTM’s *Manual of Coating Work for Light-Water Nuclear Power Plant Primary Containment and Other Safety-Related Facilities,* 1979, Chapter 3, “Coating System Selection,” and Chapter 12, “Topcoating of Cured Coatings,” provide a guide to pertinent information necessary for the selection of suitable coating systems for the primary containment and for other safety-related facilities of nuclear power plants. The chapters describe recommended procedures for topcoating intact cured coating systems, or primed coats, for nuclear plant facilities that have been exposed for extended periods of time after fabrication or during plant construction and prior to plant operation. These chapters should serve as ready references prior to selection of coating systems for maintenance purposes.

In addition, the NACE International technical committee report “Combating Adhesion Problems When Applying New onto Existing Finish Coats of Paint” should serve as another ready reference prior to commencing any refurbishing and maintenance work.

Chapter 8 | Practical Methods of Surface Preparation for Maintenance Painting

Jon R. Cavallo[1]

Introduction

Surface preparation is the most important part of any painting project. Historical analysis of failures of industrial painting systems indicates that up to 75 % of all coating system failures are the result of inadequate surface preparation.

Surface preparation for maintenance painting is far more difficult than in new construction work for a number of reasons, including:

1. The proximity of painting work to plant equipment
2. The radioactive and chemical contamination of paint films and substrates
3. Restricted work area access

In this chapter, the surface preparation methods that have been used successfully in maintenance painting work are discussed. These methods can be used singly or in conjunction with others, depending upon the maintenance paint system to be applied. **Table 8.1** (general production rates for blast cleaning) contains information to assist in surface preparation scheduling.

The selected surface preparation methods are:

A. Solvent cleaning
B. Hand tool cleaning
C. Power tool cleaning
D. Power tool cleaning to bare metal
E. Abrasive blasting
F. Water washing/water jetting

General Guidance

When planning a maintenance painting project at a commercial nuclear power plant, a number of factors that directly impact surface preparation must be considered. These factors include:

- Limitations on abrasive blasting, including protective measures to avoid grit intrusion, and dust control (negatively ventilated enclosures, dust minimizing blast media, and vacuum blasting)
- Preliminary cleaning/degreasing; limitations on solvent and cleanser use with respect to plant heating, ventilating, and air conditioning (HVAC); charcoal filters; personnel habitability (control room manning); and expendables that are plant-approved (controlled chemical list)
- Determination of lead (29CFR1926.62), cadmium (29CFR1926.1127), chromium (29CFR1926.1126), and other hazardous constituents
- Systems to ensure clean, dry compressed air (for example, coalescing/deliquescent filters downstream of air or water-cooled moisture separators)
- Source of compressed air, compressor location, weatherproofing and spill containment, fuel delivery, and provisions for a standby compressor
- Suitability of tools and media
- Cleanliness and profile requirements and how they are measured
- Radiological concerns:
  - Mixed waste (radiological and hazardous waste) handling/prevention
  - Personnel protection
  - Minimization of airborne contamination
  - Decontamination of substrates
  - Potential loss of contractor-supplied equipment
  - Containing, collecting, and disposal of waste

Surface Preparation Methods

SOLVENT CLEANING

Solvent cleaning is one method for removing grease, oil, soot, and other hydrocarbon contaminants from existing paint films and substrates. Contaminants may be visible or invisible to the naked eye, but they will cause premature failure of applied maintenance paint films if not completely removed. Thorough removal of contaminants must be performed prior to subsequent surface preparation efforts.

Nonflammable detergents and emulsifiers have proven efficient when used by hand or with water washing equipment.

[1] Jon R. Cavallo, PE LLC, 14 Patterson Ln. Newington, NH 03801
DOI: 10.1520/MNL820140003

The industry standard for solvent cleaning is the Society for Protective Coatings (SSPC) document SP-1, Surface Preparation Specification 1—Solvent Cleaning.

Production rates for solvent cleaning will vary significantly with the degree of contamination present. Normally, manual solvent cleaning rates are found to be approximately 500 ft^2 (46.45 m^2) per working hour per person. Solvent cleaning with volatile materials is not permitted in Coating Service Level I areas unless proper ventilation is provided to avoid contamination of charcoal filters.

HAND TOOL CLEANING

Hand tool cleaning is widely used for surface preparation of small areas or for areas not readily accessible. The tools used are scrapers, chippers, slag hammers, chisels, sandpaper, and abrasive pads. This surface preparation method will not effectively remove tight mill scale or rust and is not appropriate for high-performance protective coating systems that require a high degree of surface cleanliness and profile. A widely used standard for hand tool cleaning is SSPC SP-2, Surface Preparation Specification 2—Hand Tool Cleaning.

Production rates for this surface preparation method are usually 50 to 100 ft^2 (4.64 to 9.29 m^2) per person hour worked.

POWER TOOL CLEANING

Many technical improvements have been made in power tools and attachments in recent years, resulting in higher quality and production rates in surface preparation. If used properly, power tool cleaning can produce surface preparation quality appropriate for subsequent application of high-performance coating materials.

There are three major categories of power tools:

1. *Impact cleaning tools*—These tools include needle-guns, chipping hammers, and power chisels. They are useful for preparing small areas or areas not readily accessible (or both), such as nuts and bolts, rivets, hatch covers, and so on. However, they often do not uniformly clean the entire surface, except that needle-guns using sharpened 2 mm diameter needles can produce a uniformly clean surface with a profile *similar* to shot-blasted steel.
2. *Rotary cleaning tools*—For surface preparation work, semiflexible captive abrasive wheel and disc products, constructed of nonwoven synthetic fiber web material of continuous filament impregnated with an abrasive grit (such as 3M Clean and Strip discs), are recommended. In addition, coated abrasive discs (sanding pads, coated abrasive flap wheels, etc.) are also acceptable in many instances. These new types of rotary tools produce both uniform and high degrees of surface cleanliness and, unlike wire wheels, do not burnish surfaces to be coated while leaving a surface profile. These tools may not be allowed in some areas of the plant due to foreign material exclusion (FME) concerns. Double-action (DA) sanders are recommended for feather-edging sound coating materials adjacent to repair areas.

   Operator training is mandatory for personnel who will be operating these high-performance power tools to prevent injury of personnel and damage to equipment or sound coatings.
3. *Rotary impact cleaning tools*—This category of power tools is new to the painting industry. Properly used, this type of equipment will remove heavy layers of existing coatings, mill scale, and tightly adherent rust, producing a controlled surface profile.

For preparation of metallic and concrete surfaces, a number of high-performance power tool surface preparation techniques are available. These power tool configurations are air or electric tool driven needle-guns/scalers, hub-mounted rotary nylon flaps tipped with tungsten carbide buttons (typically 3M Roto-Peen Type C), non-woven impregnated nylon discs (typically 3M Clean and Strip), and hub-mounted wire bristles (typically Bristle Blasters). For guidance on preparation of metallic substrates, see SSPC-SP 11, Power Tool Cleaning to Bare Metal, and SSPC-SP 15, Commercial Grade Power Tool Cleaning. This equipment is also available with vacuum attachment.

Power tool surface preparation rates will vary from 20 to 100 ft^2 (1.86 to 9.29 m^2) per work hour per person, depending upon job conditions. The following specifications provide comprehensive guidance concerning power tool cleaning:

- SSPC-SP 2, Hand Tool Cleaning—Removes loose rust, loose mill scale, and loose coating only. Produces no substrate profile.
- SSPC-SP 3, Power Tool Cleaning—Removes loose rust, loose mill scale, and loose coating only. Produces no substrate profile.
- SSPC-SP 11, Power Tool Cleaning to Bare Mental—Removes all rust, mill scale, and old coatings and produces a 1 mil minimum substrate profile.

ABRASIVE BLASTING

Abrasive blasting is often used to prepare flat surfaces in maintenance painting work. High production rates are obtainable, but containment of spent coatings and abrasives is a definite problem.

In open blasting, approximately 100 lb (45.36 kg) of abrasive is required to prepare between 10 and 17 ft^2 (0.92 to 7.71 m^2) of surface, depending upon the degree of cleanliness required. Disposal of large quantities of waste is a definite concern. Isolation of the blast area from all other areas in the facility must also be accomplished to protect personnel and equipment. In an operating facility, this may prove very costly or impossible.

A technique called vacuum blasting partially mitigates the problems associated with open blasting. The blast nozzle is surrounded by a vacuum head, which removes spent abrasive and coatings at the worksite. Usually, contaminants are removed away from the work area, and the reclaimed abrasive is reused unless it is contaminated. Vacuum blasting is of limited use on complex shapes, because the vacuum head cannot contour itself to fully capture the propelled abrasive from the nozzle. Small cup blasters may also be used for small jobs or tight spaces where abrasive blasting is required.

Several SSPC and comparable NACE International specifications cover abrasive blasting. The criteria for cleanliness of these degrees of blast cleanliness are:

- SSPC-SP-7/NACE 4, Brush-Off Blast Cleaning—Removes loose rust, loose mill scale, loose coating; no profile requirement.
- SSPC-SP-6/NACE 3, Commercial Blast Cleaning—Removes all rust, all mill scale, all old coating. Staining may be present on no more that 33 % of each unit area (9 sq in). Profile depth must be specified separately.
- SSPC-SP-10/NACE 2, Near-White Metal Blast Cleaning—Removes all rust, all mill scale, all old coating. Staining may be present on no more that 10 % of each unit area (9 sq in). Profile depth must be specified separately.
- SSPC-SP-5/NACE 1, White Metal Blast Cleaning—Removes all rust, all mill scale, all old coating. No staining may be present. Profile depth must be specified separately.

The approximate production rates for these SSPC/NACE blast cleaning standards are listed in Table 8.1.

POWER WATER WASHING/WATER BLASTING

With modern power water washing/blasting equipment, nozzle pressures vary from several hundred psi to more than 40,000 psi (275,790 kpa). With some units, solid abrasives can be injected into the fluid stream.

If detergents and surfactants are utilized in the fluid stream, manual solvent cleaning of surfaces to be painted may be unnecessary. Preparation of carbonsteel surfaces by power water washing or blasting will probably require the addition of inhibitors to prevent rusting. Use of detergents, surfactants, or inhibitors may affect adhesion of the coating unless special precautions are used. Manufacturer's recommendations must be followed. Joint SSPC/NACE standards have been developed covering water cleaning and water jetting. Post-water-jetting visual surface cleanliness is defined in four levels in the standard:

- SSPC WJ-1 / NACE WJ-1 Clean to Bare Substrate: A WJ-1 surface shall be cleaned to a finish that, when viewed without magnification, is free of all visible rust, dirt, previous coatings, mill scale, and foreign matter. Discoloration of the surface may be present.
- SSPC WJ-2 / NACE WJ-2 Very Thorough or Substantial Cleaning: A WJ-2 surface shall be cleaned to a matte (dull, mottled) finish that, when viewed without magnification, is free of all visible oil, grease, dirt, and rust except for randomly dispersed stains of rust, tightly adherent thin coatings, and other tightly adherent foreign matter. The staining or tightly adherent matter is limited to a maximum of 5 % of the surface.
- SSPC WJ-4 / NACE WJ-3 Thorough Cleaning: A WJ-3 surface shall be cleaned to a matte (dull, mottled) finish that, when viewed without magnification, is free of all visible oil, grease, dirt, and rust except for randomly dispersed stains of rust, tightly adherent thin coatings, and other tightly adherent foreign matter. The staining or tightly adherent matter is limited to a maximum of 33 % of the surface.
- SSPC WJ-1 / NACE WJ-4 Light Cleaning: A WJ-4 surface shall be cleaned to a finish that, when viewed without magnification, is free of all visible oil, grease, dirt, dust, loose mill scale, loose rust, and loose coating. Any residual material shall be tightly adherent.

Typical power water washing and water jetting production rates are approximately 3500 ft^2 (325.15 m^2) per day per person. When using water blasting near electrical or electronic equipment, appropriate safety precautions must be utilized.

An alternative surface preparation approach that might be used if the existing coating to be removed is contaminated with radionuclides or hazardous ingredients such as asbestos or heavy metals is to strip the lining and waterjet clean the substrate to SSPC WJ-1/NACE WJ-1 or SSPC WJ-2/ NACE WJ-2 followed by abrasive blast cleaning to SSPCSP 10/NACE 2. If waterjet cleaning methods are used, contaminated wastewater must be properly contained, collected, and disposed of. All production rates vary greatly depending on overall size of surface, accessibility, intricacies of detail, contamination factors, environmental factors, and so on.

TABLE 8.1 General production rates for blast cleaning of steel.

NACE Spec Title	No	SSPC Spec	No	Approximate Production Rates/Man'
Brush-off blast	1	SP	7	2400 ft^2/day
Commercial blast	2	SP	6	800 ft^2/day
Near-white blast	3	SP	10	400 ft^2/day
White metal blast	4	SP	5	400 ft^2/day

Note: 1 ft^2 = 0.093 m^2.

Chapter 9 | Practical Methods of Coating Application

Bryan M. Monteon[1]

This chapter outlines the methods and tools in common use for application of maintenance coatings at power generating facilities.

Introduction

An individual who has worked in the painting trade sufficiently long enough to master the use of all applicable tools and materials being applied is known as a *coating applicator*. Proper assessment of the following shall be considered in determining the appropriate coating application methods and tools:

1. *Skill of applicator*—The more sophisticated spray equipment requires greater skill in application. It is recommended that ASTM **D4227** [**1**] or ASTM **D4228** [**2**] be specified as the standards used for qualify the coating applicator in any method of application.
2. *Size of item and schedule*—The selection of application methods may be affected by size and configuration of the work areas or by short schedules.
3. *Accessibility*—The degree of difficulty in getting personnel and equipment to the work location and the amount of area available in which to work will have an impact on the selection of application techniques.
4. *Adjacent surfaces*—Among items to be considered in selecting an application method are the susceptibility of adjacent items to overspray, dust, solvent vapors, and so on.
5. *Other*—Power plant operations on each particular project must be considered.

Pre-Application Preparation

Preparation of the surface, work area, and paint materials are important for a successful coating application. The surface preparation should be checked prior to application of the coating to ensure that no deterioration or contamination of the cleaned surface has occurred.

Preparation of the work area involves verifying that all surfaces are accessible and making provisions for access to elevated areas (i.e., scaffolding). When access time to the work area is limited due to plant operation, a preliminary inspection (with photo documentation, if necessary) and accurate planning are critical. In addition to providing access to all areas, preparation of the work area may include such activities as masking and protecting sensitive equipment or surfaces not to be painted. Temporary enclosures may be needed if the work area is a small part of a large building or if masking is not practical. Carbon filters may have to be removed from the ventilation system and an alternate or auxiliary ventilation system installed. Proper ventilation of the work area is necessary for personnel and fire safety, as well as for the proper and timely cure of the coating components. Material preparation is the step that takes the coating from its storage configuration to a condition ready for application. This requires stirring and thoroughly mixing a single-component prepackaged container to ensure that all pigments and solids are resuspended to ensure uniform consistency. Multicomponent materials (including most high-performance industrial maintenance coatings) require mixing two or more components with a power mixer in strict accordance with manufacturer's instructions and straining the material (unless the coating intentionally contains large particles) into a container and, in some cases, waiting a prescribed induction period. Paint mixing and thinning should be done outside of containment, if possible.

Application

Most applications of coatings will fall into three broad classes: trowel or squeegee, brushes and rollers, or spray (material projection). Many materials are most efficiently applied by a combination of methods. An example would be spray application to get the material on the surface and then finishing by trowel or roller to provide a smooth or aesthetically pleasing finish (examples would include glass-flake-filled materials that are rolled).

TROWEL OR SQUEEGEE

This method is most commonly used for 100 % solids high viscosity materials applied at relatively high film thickness (more than 40 mils) to flat concrete surfaces. Some low viscosity floor sealers are applied by roller or by pouring the coating onto the surface and spreading it to the desired thickness with a rubber-bladed squeegee.

[1] Sherwin-Williams Co., 101 Prospect Ave., NW, Cleveland, OH 44115

DOI: 10.1520/MNL820140014

Trowels, in various sizes and configurations, are used for application of filled materials. These materials contain silica, carbon, glass flakes, fibers, or other resistant inerts. They are applied to floors and walls that are subject to acid corrosion, heavy traffic, or other rigorous conditions. Many linings are applied by trowel as are many fireproofing systems. Advantages include low equipment costs, the ability to get material into small or complex areas, and an attractive finish. Disadvantages include high labor cost (advanced applicator skill is required), slow application rates, and difficult control of thickness with some materials.

BRUSHES AND ROLLERS

The most common tool (method) is the paint brush. Brushes come in a myriad of sizes and shapes, with specific designs for specific purposes. When a brush is to be used, it must be compatible with the paint components. Certain solvents (such as ketones) affect synthetic bristles; therefore, camel's hair bristles or other special brushes may be required. Similarly, bristle brushes absorb water and should not be used with water-based coatings. The brush should be designed to hold a reasonable amount of coating commensurate with the thickness of the coating and the area to be coated. Typically, brushes are not the tool of choice for large flat areas. To be successfully brushed, a material must have a low enough viscosity to flow out after it has been applied and not show excessive brush streaks. Generally, thicknesses of more than 3 to 5 mils (0.762 to 1.27 mm) are not practical to apply in a single coat with a brush. Additional brush coats may be required to achieved required thickness.

Rollers hold more coating material than brushes and thus provide a more rapid method for coating large flat areas. They do not have the flexibility of a brush for working on complex structures or with coatings that have poor wetting characteristics. Rolling may also entrap air in the film, which can cause bubbling and pinholing in some coatings. Spiked rollers are used to mitigate air entrapment in the film. Brushes and rollers are most commonly used with solvent-reduced, single-component, thin film coatings and for minor touch-up of larger items. Both brushes and rollers must be resistant to the typical solvents found in most coatings.

Gloves and mitts are efficient alternates to brushing or rolling for irregular or small items such as handrails and small diameter piping. For inaccessible areas, irregular brushes and rollers are recommended for stripe coating structural edges such as pipe flanges, weld seams, or bolted connections.

SPRAY (MATERIAL PROJECTION)

The most common type of equipment for this kind of coating application is the spray unit, consisting of a paint container, a hose, and a spray gun. The three classes of spray equipment most broadly used today are (1) airless, where the high pressure of the fluid being forced through a small opening atomizes the coatings; (2) air spray, or conventional, where compressed air is used to atomize the liquid coating; and (3) plural component spray application. For materials with very short pot (pressurized paint container) lives, plural component spray transfers the individual components through separate fluid hoses while carefully metering the distribution at the pump. Rather than premixing in the pressure pot, the individual components are combined either just before the spray gun through a static mixing tube and a single fluid line (often called a "whip line") or at the spray tip during atomization. Airless spray is appropriate for a wide range of coatings with a wide range of viscosities and constituents.

The airless pumps are constructed of corrosion-resistant materials and can handle most types of solvents and resins. Airless equipment can be coupled with in-line heaters that raise the temperature of the coating to lower the viscosity and that allow materials to be sprayed at lower pressures and with faster cure times. Sand-filled or other similar materials generally cannot be pumped.

Air spray application is called conventional spray because it is the original method of spray application and has been in use for many years. (Most applicators are familiar with the equipment.) The speed advantages of spraying over brushing or rolling are dramatic. A typical air spray system includes a compressor, a pressurized paint container (pot), two hoses from the pot, and a spray gun. Because the paint is being atomized by a stream of air, much higher losses due to overspray occur than with airless spraying. Additional protection of applicators and adjacent surfaces are generally required. Most of the benefits and limitations of airless spray apply to air spray. Air spray has the additional limits of relatively short hoses (the paint supply must be within about 50 ft [15.24 m] of the spray gun) and a narrower range of viscosities. The air supply must be kept free of any oil or water from the compressor.

An advantage of airless spray is the ability to atomize higher viscosity material, which decreases the amount of thinning necessary, thus reducing the amount of solvent released to the atmosphere. One disadvantage of air spray is the high amount of overspray created in application; therefore, serious consideration should be given to either airless spray or brush/roller application inside containment. An advantage of air spray over airless is the ability to better disperse large solid particles. One final advantage of the air spray gun is the ability to make changes in the size and shape of the pattern without changing tips or stopping the spraying operation.

Plural component spray is commonly used for 100 % solids coating materials and lining materials with limited potlife (such as epoxies, vinyl esters, and flexible elastomeric urethanes or polyureas). A plural component spray setup consists of six basic components: proportioning pump, mix manifold, mixer, spray gun, material supply containers, and solvent purge (flush) container. A plural component spray setup uses more complicated equipment than that used in conventional or airless sprayers. Skill of the coating applicator should be assessed by both the manufacturer of the coating and by the equipment manufacturer.

References

[1] ASTM **D4227**, *Standard Practice for Qualification of Coating Applicators for Application of Coatings to Concrete Surfaces*, ASTM International, West Conshohocken, PA, 2012, **www.astm.org**

[2] ASTM **D4228**, *Standard Practice for Qualification of Coating Applicators for Application of Coatings to Steel Surfaces*, ASTM International, West Conshohocken, PA, 2012, **www.astm.org**

Chapter 10 | Inspection

Keith A. Miller[1] and Judy Cheng[2]

The Need for a Coating Inspection

Coatings formulated for various functions are used in a variety of locations throughout a nuclear power plant. When the safety-related coating fails (Coatings Service Level I and III), the debris can impact the safe operation of the plant. Coatings used in other areas of the plant (Coatings Service Level II and balance of plant), although not impacting safe operation of the plant when failure occurs, can impact general plant activities, material condition, and appearance. Over the life of the plant, maintenance of coatings is an important element of the overall plant maintenance program. Assuring the coating is applied in accordance with its specifications, that it remains in sound condition, and that it is repaired when damage or failure occurs, requires an effective inspection program. The inspection program should work with the various plant maintenance activities and maintenance programs to ensure the coatings provide the specified functions during normal operation as well as during design basis accidents without the risk of generating debris that can adversely affect the safety-related system, structure, or components (SSCs) needed to mitigate the accident.

The Purpose of Inspection

An effective inspection program provides the necessary technical expertise to verify that the requirements of both the original construction specification and the current maintenance coating specification are implemented. In good faith, both the coating manufacturer and the specifying engineer included details within the technical portion of the specification for the location and environment in which the coating system will be used. It is the responsibility of the station coating program and the coating inspectors to independently ensure that the requirements of the specifications are followed. The ultimate purpose of the inspection program is to achieve the maximum level of protection and length of life afforded by the specified coating system. This includes inspection of new coating applications as well as periodic monitoring and assessment of coating conditions during a plant's life as addressed in Chapter 3.

[1] Sargent & Lundy LLC, 55 E. Monroe St., Chicago, IL 60603
[2] Pacific Gas and Electric, 3400 Crow Canyon Rd., San Ramon, CA 94583

DOI: 10.1520/MNL820140027

Selecting the Inspector or Inspection Agency

Selecting inspection personnel or an inspection agency is not an easy assignment. Coating inspection is a specialized task and requires specialists, not generalists. A few considerations are:

1. The inspectors, either plant personnel or inspection agency personnel, must be independent from the plant or contract coating application personnel. They should be specifically trained and committed to the inspection of the project's coating work. Avoid utilizing inspectors from areas such as visual welding inspection, cathodic protection, nondestructive examination (radiographic testing, magnetic testing, penetrant testing, ultrasonic testing, etc.), electrical, or other such areas where personnel are qualified to perform an inspection, test, or examination other than coating work. Just because a person is an "inspector" does not mean they will be a suitable coatings inspector. Also, having inspectors jump from one type of inspection to another is not conducive to accurate and consistent inspection results.
2. The inspector must have knowledge not only in evaluating in-process application activities and final coating system acceptability but also must be familiar with the various instruments that are used for coating inspection purposes (film thickness gages, psychrometers, spark testers, etc.), and when they should be used.
3. The inspector must be qualified in accordance with the applicable procedure and stations' quality assurance program. ASTM **D4537** [1] is commonly used as a basis for qualifying inspection personnel.
4. The capability and experience of the inspection agency and the qualification and experience of the inspector(s) assigned to the project should be evaluated.
5. Physical capability can be a requirement of the inspection project. The inspector must have the physical ability to access the specific work areas where the painters are performing the coating work.
6. The attitude of the inspector is of extreme importance. More is achieved by cooperation than by intimidation. The inspector is there to confirm that the job is performed

in accordance with specifications. They are not there to interfere or to intimidate the applicators but are there to work toward the mutual goal of meeting the specification requirements.

The Knowledge and Attitude of the Inspector

The inspector must have adequate training and knowledge to:

- Understand the specification requirements for the applicable coating system and its proper application.
- Understand the limitations of the coating system, such as minimum and maximum dry film thickness, to ensure the system is applied within its specification.
- Know the aspects of preparation activities that will have a high risk of coating failure unless properly performed (e.g., residual chlorides, surface cleaning, abrasive blasting, required surface profile, proper mixing and thinning, etc.).
- Know the aspects of coating application that will have a high risk of coating failure unless properly performed (e.g., areas where it is difficult to obtain a full coating thickness—corners, welds, sharp edges, and so on, proper wet film thickness, recoat times, etc.).
- Know the environmental conditions that can interfere with proper coating application and curing (e.g., proper humidity, application temperatures, concrete moisture content, etc.).
- Know the indications of improper coating application (e.g., runs, sags, orange peel, pinholes, etc.).
- Know the indications of damaged or degraded coatings (e.g., checking, blisters, chalking, delaminations, rust staining, etc.).
- Communicate clearly the inspection results verbally and in written reports.

In summary, the inspector must be knowledgeable in all coating activities being performed. The inspector must be able identify deviations from specifications and to clearly communicate the issues and concerns. The inspector must ensure resolution of the issues to expedite the proper completion of the work through good communication and coordination among all parties.

The Pre-Job Meeting

Plant procedures typically require that a "pre-job" meeting be conducted to review the scope of work and any unique project requirements or areas of caution or concern. This is typically performed before the overall project begins as well as daily for each shift of work. It will be required that the inspection personnel, including supervisors, be present during the pre-job meeting.

When using an inspection agency, a pre-award meeting is useful in order to review those areas of the specification and project that would be of particular interest or concern to the agency and to ensure a complete and accurate bid. When the job includes assessment of coating conditions to determine the degree of maintenance coating work, photographs of areas of concern are a great asset. It is important to make sure the inspection agency is aware "up front" of the specification requirements, scope of work, and of unique project aspects to avoid surprises during the course of the job.

The Methods and Instruments Used During Inspection

The inspection methods and instruments used are dependent upon the item or surface being coated and its condition. For example, if the job is to refurbish the Service Level III coatings on the interior of a diesel fuel oil storage tank, it would be important to determine—after cleaning—if all oils have been removed prior to abrasive blasting. The inspector may wish to use a black light to determine these areas prior to the abrasive blasting operation. If the job is to refurbish the coatings on structural steel with the intention of leaving the existing coating system intact, it is necessary to determine the film thickness of the existing coating prior to the start of reapplication. For Service Level I coatings, it is necessary to ensure that the surface preparation and the coating system application are in strict compliance with the requirements as set by the coating system design basis accident qualification.

There are many instruments available for inspection purposes. Some of the more common ones are as follows:

1. Sling psychrometer and U.S. Weather Bureau psychrometric tables or electronic dew point measurement instruments
2. Surface thermometer
3. Continuous recording thermometer
4. Hypodermic needle pressure gauge
5. Blast nozzle aperture gauge
6. Replica tape with micrometer
7. Surface profile comparator
8. Society for Protective Coatings (SSPC) VIS 1 and VIS 3 visual standards
9. Wet film thickness gauge
10. NIST dry film thickness calibration standards
11. Magnetic coating thickness gauge
12. Low-voltage holiday detector
13. High-voltage holiday detector
14. Cross-hatch adhesion test kit
15. "Pull-off" adhesion tester
16. Destructive thickness and inspection (Tooke) gauge
17. Inspection mirrors
18. Inspection flashlight
19. Camera
20. Ruler

Marking Noncompliant Areas

When areas are found to be noncompliant with specification requirements it is useful to mark the applicable areas to aid in repair or rework. The markings should be clear and obvious and must not interfere with subsequent coating applications. The most common marking material, which is considered unaffected by subsequent coats, is the non-waxy ink marker. More recently, however, fluorescent ribbons or tapes have been used. These can be seen at a greater distance, and some are nondestructive to the surface being recoated if they meet the plant chemical control program and foreign material exclusion (FME) requirements.

Reporting Deviations or Deficient Areas

It is important to maintain a record of coating inspection activities and results and to provide documentation of these activities. These reports must meet the applicable inspection and record procedure requirements. Pre-established inspection report forms are extremely useful and should be established specifically for the type of coatings work requirements or for the inspection areas. Typically, containment area maps or heat exchanger tubesheet maps aid greatly in identifying locations. Usually, all deviations are reported through a plant's corrective action program. An important aspect of such a report is the ability to follow-through with any deviations or deficient areas and to ensure that those areas found are repaired or reworked in accordance with the applicable specification. Any repaired or reworked areas should be reinspected. A final report should be issued to indicate that all areas have been repaired or reworked in accordance with the specifications.

References

[1] ASTM **D4537**, *Standard Guide for Establishing Procedures to Qualify and Certify Personnel Performing Coating Work Inspection in Nuclear Facilities*, ASTM International, West Conshohocken, PA, 2012, **www.astm.org**

Chapter 11 | Safety

Daniel L. Cox[1]

Safety in an operating nuclear plant is generally site specific, though it follows federal (Occupational Safety and Health Administration), state, and local regulations. The information provided in this chapter should be considered when scoping, planning, and scheduling coating work and is meant only as a guide.

Plant Safety Program

Each plant will have a safety program to comply with the applicable laws and regulations. Courses in safety, the contents of the program, and times given (daily, weekly) are site specific. The length of time to process prospective employees, including taking courses, should be considered so as not to impact coating work scheduling. Successful completion of courses may be a prerequisite for working at the stations. Furthermore, the number of courses taken may/will govern the level of entry for the new employee. Entry into containment, fuel handling, building, and so forth may require successful completion of multiple courses in safety, whereas work in the station yard may require the successful completion of only one course. Courses may cover the areas outlined in the sections that follow.

Badging

The badging process for obtaining unescorted access is nuclear plant (site) specific. Upon successful completion of the required courses, the trainee is photographed. The photograph is placed on a color coded card, a number is assigned, and the card is laminated. Most plants have gone to hand geometry to gain access into the owner controlled or protected area (PA). Usually, general employee training and radiation worker training are the minimum required training to obtain a site badge for unescorted access.

General Employee Training

This course typically has two parts. Part one is general industry information for nuclear plant workers, which is based on and administered by the Institute of Nuclear Power Operations (INPO) via its NANTeL system. Part two is site-specific general information about emergency response to the station alarm systems for fire, radiation alert, evacuation, and so on. It may also include fire protection and hazardous material general information, such as types of fire suppression systems (water, Cardox, etc.). Additionally, it will contain general information about control points, radiation control areas, security system, function of health physics, personal hygiene, FME programs, and so forth.

Radiation Workers' Training

In-depth training is provided, again in two parts. Part one is general industry radiation protection limits and guidelines. This is also an INPO/NANTeL course. Part two will cover the site-specific radiation hazards, limits of exposure to radiation, use of protective clothing (PC) in radiation areas, training in dressing and removing PC, working permits in hazardous radiation areas, and so on.

Foreign Material Exclusion

Foreign material exclusion (FME) program training requirements have been developed as a result of industry operating experience, and FME issues have been among the most important factors involved in coatings or painting work in the recent past. Many items such as needle-gun parts, wire wheel frays, rust, and paint chips have been found in such locations as the fuel pool and the drywell. These are critical areas that could impact the safe shutdown of the plant, and issues with foreign materials must be prevented.

Station Safety Procedures and Manuals

In addition to training course materials, all plants will have detailed safety procedures or manuals that must be adhered to. The safety guidelines will cover almost every aspect of the coatings work to be encountered. The following are general guidelines that would be expected. If any question or concern arises, station safety personnel should be contacted.

[1] Structural Integrity Associates, 2321 Calle Almirante, San Clemente, CA 92673
DOI: 10.1520/MNL820130016

Respirator Protection Training

If the worker will be required to wear a respirator due to radiological conditions, respirator training/qualification will be required. In this course, the trainee is informed of the types of respirators, filtering mediums, and so forth that are available; how to put on, use, and remove a respirator; when and where a respirator should be used; and fitting of the trainee with a respirator mask. The correct combination of filters for the respirator will be required when used in a radiological airborne area. In most cases, this will not be an issue because of proper decontamination and cleaning prior to the commencement of painting activities. Certain physical and medical requirements may also be necessary, such as a pulmonary function test.

Material Storage Safety

Paints, coatings, and solvents should be stored in a separate building or van away from all plant buildings in accordance with National Fire Protection Association codes and plant-specific requirements. In addition, most paints and coatings may have specific temperature and humidity requirements while being stored. All manufacturers' requirements must be followed. Materials may be required to be labeled or color coded (or both) related to the plant systems in which they are compatible.

Coating Activity Safety Considerations

Though the plants will have approved safety programs, procedures, and manuals, these may not cover all activities associated with painting and coatings work. This is especially true for contracted work outside the normal maintenance coating activities, such as torus coating repairs or recoating. The plant and coating contractor must consider all activities planned to ensure there are adequate safety precautions and that training is augmented to support those activities. The following are the common painting and coatings activities that may not be specifically addressed in plant safety programs; this listing may not be all inclusive.

HANDLING AND MIXING OF MATERIALS

Generally, all handling and mixing of materials is done in accordance with the manufacturers' recommendations. However, nonsparking tools, safety cans for solvents and waste rags, protective clothing, gloves, goggles, hard hats, respirators, and so forth, should be considered for use. When inside the radiological controlled area (RCA), care should be taken to eliminate as much waste as possible to minimize disposal costs for radiologically contaminated materials. All manufacturers' requirements must be followed.

MECHANICAL CLEANING

When power tool cleaning, two forms of eye protection (i.e., goggles with a face shield), respirators, hard hats, gloves, forced air ventilation, and nonsparking tools should be considered. Tools should be operated at their recommended operating speed (ROS), not maximum operating speed (MOS), to guard against breakage/disintegration of sanding discs, rotary wire brushes, flapper wheels, and other abrasive media. Dust collection devices should be used on all power tools to reduce/eliminate any unwanted debris. The station's safety programs and procedures must be consulted and followed.

ABRASIVE BLAST CLEANING

Before abrasive blast cleaning is begun, check for worn, frayed, or broken air hoses; worn nozzle tips; worn hose connectors; a clean air supply; and so on. The use of forced air ventilation, force feed air safety helmets, gloves, protective clothing, and so forth should be considered. The station's safety programs and procedures must be consulted and followed.

SOLVENT CLEANING

Solvent mixes, alkaline cleaners, detergents, wetting agents, and so forth may be used in solvent cleaning. Care should be exercised in mixing solvents. The flash point may be altered, which could present an explosion hazard. The use of protective clothing, gloves, goggles, face shields, forced air ventilation, forced feed air safety helmets, and so forth should be considered. Avoid solvent spills and prevent solvents from entering the drains or waste system of the plant. Provide for lawful and proper disposal of spent solvents.

STEAM CLEANING

Hazards may arise from pressures, temperatures of solutions, cleaning agents, and so on. The use of protective clothing, gloves, goggles, boots, forced air ventilation, and forced feed air safety helmets (if required) should be considered. Hoses and connections, thermostats, and related electrical equipment should be checked.

HIGH AND ULTRA-HIGH PRESSURE WATER BLASTING AND WATER JETTING

Cleaning by using water pressure has its unique set of safety considerations. Water pressures vary substantially: low pressure water cleaning (LPWC), cleaning at less than 5000 psi; high pressure water cleaning (HPWC), cleaning at 5000–10,000 psi; high pressure water jetting (HPWJ), cleaning at 10,000–25,000 psi; and ultra-high pressure water jetting (UHPWJ), cleaning above 25,000 psi. At these pressures, special safety precautions are critical to protect personnel and equipment. Personnel properly trained for the operation of this equipment shall have the appropriate safety training. The station's safety programs and procedures must be consulted and followed.

ACID CLEANING

Hot and cold solutions are corrosive to the skin. Their fumes attack the mucous membranes. Forced air ventilation, forced feed air safety helmets, rubber gloves, boots, goggles, protective plastic, rubber clothing, and so forth should be considered for use.

Miscellaneous Safety Considerations

- *Toxic fumes from fires*—Know where the nearest exit is. If available, use a portable air supply.
- *Explosion hazard*—Use forced air ventilation to dilute solvent fumes. Do not allow welding or other open flames in the painting area. All electrical equipment must be explosion proof.
- *Waste solvent and waste rag hazard*—Place in safety cans and remove to a designated disposal area at the end of each shift.
- *Explosion proof lights*—Use during and after completion of coating work.
- *Ladder*—Inspect rungs and sides for broken parts. Does ladder have safety shoes? Wobble? Check for worn pulleys and frayed and worn rope. Ladders should be constructed of a material that is decontaminatable, if possible, and to the requirements of the individual plant.
- *Staging*—Inspect to ensure that all staging has been properly assembled and has been tagged "OK" by a member of the plant safety team or by a responsible person.
- *Scaffolds, hooks, block and falls, ropes*—Inspect to ensure that a scaffold is sound, hooks are not worn, block and falls have good connections and the wheels are free, and that ropes are not frayed and worn. Replace as required.
- *Boatswain's chair, lifelines, lifenets, lifebelts*—Inspect for frayed and worn ropes, belts, and so on. Replace as required.

High Efficiency Particulate Absorber Filters and Absorber Safety

Charcoal high efficiency particulate absorber (HEPA) filter and absorber efficiency to absorb radioactive iodine and other impurities may be reduced if volatile organic compounds (VOCs) from paint overspray and solvents are absorbed. In addition, the absorption of ketone solvents on charcoal presents a potential fire hazard.

Some suggested methods for preventing charcoal poisoning are to block off vents in the area being coated, to use fans to clear the fumes away from the charcoal filters, or to isolate the entire charcoal filter system (if required) and use an auxiliary charcoal filter system equipped with HEPA filters, as required. Refer to station procedures or Regulatory Guide 1.52 [**1**] and Regulatory Guide 1.140 [**2**] for regulatory requirements.

Air Ventilation

The ASTM *Manual of Coating Work for Light-Water Nuclear Power Plant Primary Containment and Other Safety-Related Facilities* [**3**] contains information on safe "respirable air" requirements for life support and ventilation equipment in Chapter 7, "Safety and Environmental Control."

General Safety Requirements

Hazards from volatilized toxic compounds, chromates, cadmium, hexavalent chromium, lead, zinc, and so on may be encountered. Protective clothing, gloves, forced feed air safety helmets, forced air ventilation, and so forth should be considered for use.

Volume 1 of the SSCP publication, *Good Painting Practice*, and the ASTM *Manual of Coating Work for Light-Water Nuclear Power Plant Primary Containment and Other Safety-Related Facilities* [**4**] contain many reference sources for safety. Follow station safety programs and federal, state, and local laws applicable to the specific hazard.

References

[1] USNRC Regulatory Guide 1.52, "Design, Inspection, and Testing Criteria for Air Filtration and Adsorption Units of Post-Accident Engineered-Safety-Feature Atmosphere Cleanup Systems in Light-Water-Cooled Nuclear Power Plants," U. S. Nuclear Regulatory Commission, Washington, DC.

[2] USNRC Regulatory Guide 1.140, "Design, Inspection, and Testing Criteria for Air Filtration and Adsorption Units of Normal Atmosphere Cleanup Systems in Light-Water-Cooled Nuclear Power Plants," U. S. Nuclear Regulatory Commission, Washington, DC.

[3] *Manual of Coating Work for Light-Water Nuclear Power Plant Primary Containment and Other Safety-Related Facilities,* ASTM International, West Conshohocken, PA, 1979.

[4] Society for Protective Coatings (SSPC), *Good Painting Practice,* Vol. 1, Fourth ed., SSPC, Pittsburgh.

Chapter 12 | Personnel Training and Qualification

Daniel L. Cox[1]

This chapter provides a discussion of the need and importance of training and qualifications of persons involved in each aspect of the nuclear coatings program.

Background

Personnel training and qualifications are essential for a solid coatings program. Each person directly involved in the program—coating specialist, applicator, inspector, and oversight—has unique training and qualification requirements that must be defined and integrated into the program.

There are numerous sources available to help define the training and qualification requirements. These sources include American Society for Testing and Materials (ASTM), American Society of Mechanical Engineers (ASME), National Association of Corrosion Engineers (NACE), and Society for Protective Coatings (SSPC) standards. In addition, the established training and qualification requirements at operating nuclear plants are based upon their respective licenses, many of which invoke the requirements of the American National Standards Institute (ANSI) standards.

The ANSI standards apply to Coating Service Level I and provide general guidance for quality assurance (QA) at nuclear facilities and for the training and qualification of all inspection personnel at nuclear facilities. This latter requirement is interpreted by some as suggesting that safety-related coating inspectors should have verifiable experience performing inspection of coating work.

The ANSI standards were retired in the late 1970s and have been replaced by numerous ASTM standards. For limited operating plants and the new generation of plants, these ASTM standards are used to define the training and qualification requirements. The more recent ASTM standards that are shown in the following sections should be considered for establishing appropriate training and qualifications of program personnel.

If the ASTM standards are used, it must be noted that the following ANSI standard requirements may still apply:

- Section 2.3.5 of ANSI N101.4 defines organizational criteria for inspection agencies [1]. Section 6.2.4 invokes ANSI N5.9, which was superseded by N5.12. Section 10.3.2 of N5.12 [2] includes the following requirement: "As an additional qualification, before starting work each assigned inspector may be required to undergo a training course with the materials to be used for the coating work."
- Section 6.3 of ANSI N101.4, Qualification of Coating Inspection Personnel, states: "These qualifications shall include his (the inspector's) prior training and inspection experience for work of comparable scope with generic coating systems similar to those used for the work in question."

Most operating plants have Coating Service Level III (CSL III; safety related outside the reactor containment) coatings. Through license renewal and other commitments to the USNRC, the licensing basis for establishing and controlling these CSL III coatings programs can vary substantially among plants. Many apply some or all of the QA requirements they would for CSL I coatings. Personnel training and qualification requirements also vary to meet the specific licensee's commitments.

Updated QA guidance for personnel training and qualifications is provided by ASME NQA-1 [3], which has been prepared to replace ANSI N45.2 and its daughter documents. Applicability of NQA-1 versus ANSI N45.2 [4] will be dictated and detailed by each licensee's regulatory commitments.

Application Personnel

As a proficiency demonstration, the following standards provide guidance and a good basis for establishing the training and qualification requirements for application personnel: ASTM **D4227**, *Standard Practice for Qualification of Journeyman Painters for Application of Coatings to Concrete Surfaces of Safety-Related Areas in Nuclear Facilities* [5] and ASTM **D4228**, *Standard Practice for Qualification of Journeyman Painters for Application of Coatings to Steel Surfaces of Safety-Related Areas in Nuclear Facilities* [6]. The standards require that the candidate applicator be experienced in coating application, that the applicator demonstrates proficiency in the application of coatings to a surface similar to one that will be coated in the plant, and that the test application is evaluated in accordance with the requirements of the governing documents (procedures, specifications, and manufacturer's product data sheets).

[1] Structural Integrity Associates, 2321 Calle Almirante, San Clemente, CA 92673

DOI: 10.1520/MNL820140018

In addition, ANSI Standard N45.2 requires that the necessary qualifications of personnel involved in these "special processes" be defined.

Personnel Performing Inspections of Coating Work

The following standards provide guidance and a good basis for establishing the training and qualification requirements for personnel performing inspection of coating work:

- ANSI N45.2.6, *Qualification of Inspection, Examination and Testing Personnel for Nuclear Power Plants* [7], referenced in the foreword of ANSI N5.2
- ASTM D4537, *Standard Guide for Establishing Procedures to Qualify and Certify Personnel Performing Coating and Lining Work Inspection in Nuclear Facilities* [8]
- ASTM D5498, *Standard Guide for Developing a Training Program for Personnel Performing Coating and Lining Work Inspections for Nuclear Facilities* [9]

Personnel Performing Coatings Condition Assessment

The preceding provided guidance for establishing the requirements for training and qualification of personnel performing in-process inspections of coating work (i.e., surface preparation, ambient controls, coating application, etc.). Performing condition assessment of in-service coatings requires different experience and knowledge. The following provides guidance for establishing the training and qualification requirements for personnel performing condition assessments of in-service coatings.

COATINGS SURVEILLANCE PERSONNEL

Individuals performing the condition assessment visual inspections should meet the applicable plant licensing commitments and be approved by the utility's nuclear coating specialist. These assessment personnel should have demonstrated knowledge of coatings, obtained through training or plant experience, and should be knowledgeable in applicable plant procedures. The qualifications of assessment personnel should be verified to be current and properly documented in accordance with plant-specific requirements regarding personnel qualification.

NUCLEAR COATING SPECIALIST

ASTM D7108, *Standard Guide for Establishing Qualifications for a Nuclear Coating Specialist* [10], provides guidance and a good basis for establishing the training and qualification requirements for nuclear coating specialist personnel. The nuclear-safety-related coatings program should be under the technical direction of an engineer or technical specialist knowledgeable in the areas of coating/lining selection, application, and inspection. In addition, the individual should have sufficient experience in the nuclear industry to assist in the performance of various evaluations and assessments on the impact of coating work on any plant systems that may be affected by that work. Assessing the impact on other systems should typically involve systems engineers or other personnel knowledgeable in the design and operation of the affected systems and components.

References

[1] ANSI N101.4-1972, "Quality Assurance for Protective Coatings Applied to Nuclear Facilities," American Society of Mechanical Engineers, New York, NY.

[2] ANSI N5.12 (N5.9)-1974, "Protective Coatings (Paints) for the Nuclear Industry," American Society of Mechanical Engineers, New York, NY.

[3] ASME NQA-1, "Quality Assurance Requirements for Nuclear Facility Applications," American Society of Mechanical Engineers, New York, NY.

[4] ANSI N45.2, "Quality Assurance Requirements for Nuclear Facility Applications," American Society of Mechanical Engineers, New York, NY.

[5] ASTM D4227, *Standard Practice for Qualification of Coating Applicators for Application of Coatings to Concrete Surfaces*, ASTM International, West Conshohocken, PA, 2012, **www.astm.org**

[6] ASTM D4228, *Standard Practice for Qualification of Coating Applicators for Application of Coatings to Steel Surfaces*, ASTM International, West Conshohocken, PA, 2012, **www.astm.org**

[7] ANSI N45.2.6, *Qualification of Inspection, Examination and Testing Personnel for Nuclear Power Plants*, American Society of Mechanical Engineers, New York, NY.

[8] ASTM D4537, *Standard Guide for Establishing Procedures to Qualify and Certify Personnel Performing Coating and Lining Work Inspection*, ASTM International, West Conshohocken, PA, 2012, **www.astm.org**

[9] ASTM D5498, *Standard Guide for Developing a Training Program for Personnel Performing Coating and Lining Work Inspection for Nuclear Facilities*, ASTM International, West Conshohocken, PA, 2012, **www.astm.org**

[10] ASTM D7108, *Standard Guide for Establishing Qualifications for a Nuclear Coatings Specialist*, ASTM International, West Conshohocken, PA, 2012, **www.astm.org**

Chapter 13 | Underwater Maintenance of Nuclear-Safety-Related Immersion Service Coatings

Charles Vallance[1]

Protective coatings relate to critical operational and licensing issues. A coatings failure in a Service Level I area, such as the suppression chamber, during a design basis loss of coolant accident (LOCA) has the potential to produce foreign material capable of blocking emergency core cooling system (ECCS) strainers. In addition, coating failures expose the substrate to corrosion attack. Pitting corrosion can quickly compromise the minimum allowable wall thickness of a pressure boundary or liner.

Immersion areas are particularly hostile environments for coatings and the substrates they protect. Periodic inspection and maintenance is required to ensure protective coatings systems perform as designed, but access to immersion areas can be difficult and expensive. Mark I and Mark II suppression chambers, condensate storage tanks, safety storage water basins, and fire-water storage tanks are examples of such areas.

Advantages of Underwater Maintenance

Before the advent of underwater maintenance procedures, it was necessary to drain the vessel in order to perform coating and corrosion inspections. This often resulted in extended outage schedules, increased radiation exposure, and damage to otherwise sound coatings. Techniques have now been developed that permit detailed inspection without the need to drain the vessel.

There are a number of advantages to the underwater maintenance process.

- Reduces radiation exposure—Divers take advantage of water shielding during all operations. Because the pool is not drained, dry workers are not exposed to concentrated contaminated materials as they would be during a conventional drain and decon operation.
- Reduces load on rad waste processing—No water has to be moved, stored, or processed by plant radwaste systems.
- Systems remain operable—Eliminating drain-down allows critical systems to remain operable and permits system tests that would otherwise be impossible.
- Improves water quality—Settled solids and suspended particulate are removed during desludging prior to inspection. This addresses foreign material exclusion (FME) requirements as well as various water quality issues such as conductivity.
- Prevents additional coating damage—Mechanical damage caused by cleaning, rigging, and scaffolding is eliminated. No scaffolding or rigging is required for divers to reach upper elevations. Stresses placed on coatings by pressure changes and drying during the draining process are eliminated.
- Simplifies repair process—If coating repairs are necessary, surface prep and application are localized to the defect area. No blasting is required so the introduction of foreign material such as blast media and coating debris is eliminated.
- Reduces Cost—An underwater coatings maintenance program can potentially save several million dollars over a 10- to 15-year maintenance cycle when compared to the costs associated with draining for coating maintenance.

Desludging and Cleaning for Coatings Maintenance

Regardless of the care with which FME procedures are practiced, sludge and debris collects in suppression chamber and tanks. The BWR Owners Group estimates that approximately 150 lb of ferric oxide accumulates yearly. Even debris from the dry well finds its way into the pool via the vent lines and downcomers.

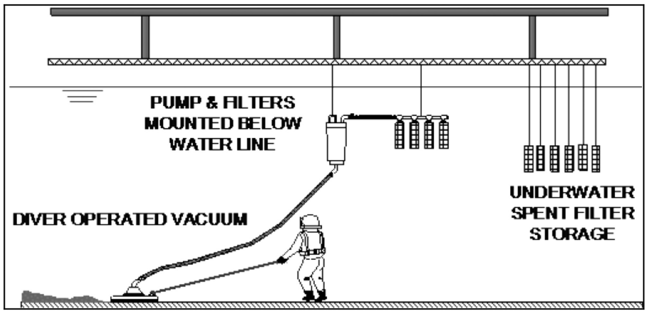
Underwater coatings maintenance requires desludging before effective inspection or repairs can be performed (**Fig. 13.1**). For example, in a suppression pool, the vessel shell and internals, including strainers, are cleaned using an underwater vacuum system operated by divers. As the shell is cleaned, divers can inspect and document 100 % of the underwater surfaces.

To perform an effective underwater inspection, water clarity should be sufficient to allow visualization and documentation of relevant indications. This is typically demonstrated by having the inspector read the standard Jaeger Visual Acuity Card under the conditions where the inspection will be conducted. Surfaces to be inspected must also be reasonably free of sludge and debris. Vessels such as the torus and condensate storage tank usually require some cleaning before inspection. Cleaning has the added advantage of

[1] Underwater Engineering Services, Inc., 3306 Enterprise Rd., Fort Pierce, FL 34982

DOI: 10.1520/MNL820130019

FIG. 13.1 Underwater desludging using submersible vacuum and filtration system (courtesy of Underwater Engineering Services, Inc.).



removing any loose debris that might clog strainers, piping, pumps, or spray nozzles. This also reduces the possibility that by-products from deteriorated coatings or the corrosion of exposed metal surfaces will find their way into the primary cooling system and plate-out on the interior of the residual heat removal system (RHR) or on the fuel itself.

Divers typically use an underwater vacuum system to clean submerged surfaces. The vacuum head is designed to prevent coating damage. Water is discharged through an underwater filtration system to remove solids. Larger debris is removed by hand during the vacuuming. Divers are able to move carefully to avoid placing particulate in suspension, which prevents increased turbidity and helps to maintain water quality.

Underwater filtration systems are capable of removing small particles down to one micron in size and below, if required. The process also filters suspended particulate, which reduces turbidity and conductivity, and improves water clarity. If the sludge is contaminated, spent filters are stored underwater until desludging is complete. This reduces handling and takes advantage of water shielding. Filters are then drained and removed from the vessel for disposal.

Coating and Corrosion Inspection

The underwater inspection often combines coating and corrosion inspection because the two processes are closely related. Other inspections, such as weld inspection, are sometimes included in the work scope. The coating is evaluated to determine its potential to disbond from, and its ability to provide corrosion protection to, the substrate.

Qualified divers inspect the condition of immersion coatings and steel substrate using essentially the same methods and equipment used in the dry. Defects are categorized and film thickness readings are taken. If corrosion is present, it is assessed by measuring pit depths to determine metal loss and by taking ultrasonic thickness readings to determine actual plate thickness.

Inspections are documented on field data sheets, by electronic means such as digital thickness readings and by still color photography and video. Divers are equipped with helmet-mounted cameras and voice communication so that topside personnel can monitor the inspection.

Detailed documentation permits long-term monitoring of coating and corrosion conditions. Such inspections are often part of the licensee's response to the Nuclear Regulatory Commission (NRC) Maintenance Rule, and are performed under a quality assurance program that meets the requirements of 10 Code of Federal Regulations (CFR) Appendix B for special process controls as well as American National Standards Institute (ANSI) N101.4 [1] or ASTM International (ASTM) D3843 [2], depending on plant design basis. Coating inspectors are certified in accordance with ANSI N45.2.6 [3] as well as ASME Section XI, CP 189 requirements.

Coating Inspection

Defects commonly found in coatings in immersion service include mechanical damage, blistering, cracking, flaking, adhesion loss, delamination, pinpoint rusting, and uniform corrosion. The latter two are reevaluated during the corrosion inspection.

MECHANICAL DAMAGE

Evaluation of mechanical damage is normally limited to a visual assessment of the frequency and distribution of indications. This can be summarized on an inspection map. A photographic or video record of representative samples is also made. Mechanical damage that exposes the substrate leads to corrosion. Pitting or general corrosion may require a more detailed corrosion evaluation.

BLISTERING

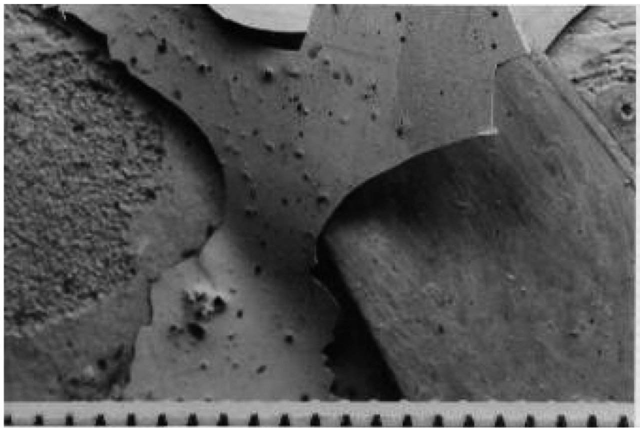
Blistering occurs when the coating disbonds in small isolated areas. Small 1/16 to 3/4-in blisters or bubbles appear in the coating at the interface of multiple layers of coating (intercoat blistering) or between the substrate and the full coating thickness. The coating film forming the blister initially remains intact but may fracture latter. Fractured blisters that expose substrate can lead to corrosion problems.

Sample areas may be selected and mapped to quantify blister count, size, and distribution. The diver/inspector can use low-power magnification to identify individual fractured blisters within the test area. Information gathered in this type of investigation can be used to estimate the quantity of coating that might be dislodged during an LOCA and to project trends if new blister formation is suspected. Vacuum box testing has also been used underwater to aid in determining whether blisters are likely to fracture or flake-off under conditions of reduced ambient pressure such as those postulated for a typical LOCA.

LOSS OF ADHESION

Blistering is one example of a condition that can be caused, at least in part, by low coating adhesion. Flaking, peeling, and general delamination are also manifestations of low adhesion. A strictly visual assessment can be performed using ASTM Standard D772, *Standard Test Method for Evaluating Degree of Flaking (Scaling) of Exterior Paints* [4]. The knife peel test (Fig. 13.2) is a destructive test used to assess adhesion qualitatively.

FIG. 13.2 Loosely bonded coating removed in knife peel test (courtesy of Underwater Engineering Services, Inc.).



Quantitative values can be obtained using mechanical pull testers underwater. The test is performed exactly as it is above water except that a 100 % solids underwater curing epoxy is used to glue test dollies to the coating. Testing is performed in accordance with ASTM D4541 *Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers* [5].

COATING INTEGRITY

Sometimes the substrate may be unprotected simply due to insufficient film thickness. Low film thickness can be an application defect or can be caused by normal wearing and aging of the coating. Varieties of instruments are available to measure coating thickness. Mechanical magnetic pull-off gauges can be used underwater and are inexpensive. However, they can be difficult for the diver to read, and each reading must be manually logged as it is taken.

Digital gauges offer greater accuracy and the ability to log data electronically. Using this type of gauge, a diver can quickly take hundreds of readings over a relatively large area. The readings are logged at the surface and can then be downloaded for statistical analysis.

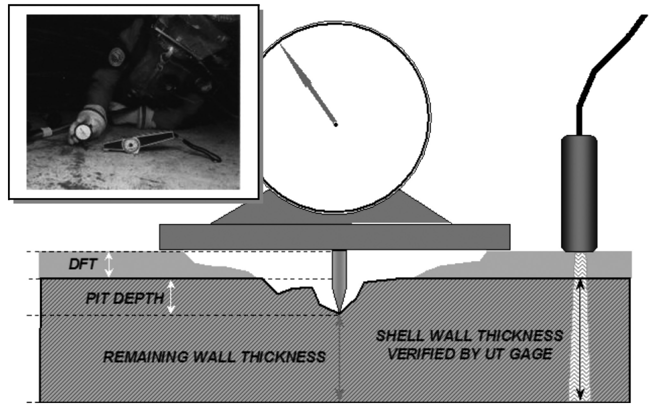
Corrosion Inspection

In most instances, the corrosion inspection focuses on determining the effect of pitting on the vessel wall corrosion allowance. After a general visual examination, selected worst-case pitting is measured to determine the range of gross pit depths.

Pit evaluation sites are selected based on the general visual examination. These are usually one foot square and located in areas of worst-case pitting. Representative pits within the site are then selected for quantitative evaluation. Care must be taken to ensure that pits selected for evaluation do, in fact, represent samples of the deepest pitting.

After careful cleaning to remove all corrosion deposits, the diver/inspector probes the pit with a dial depth micrometer

FIG. 13.3 Quantitative pit depth measurement process. (courtesy of Underwater Engineering Services, Inc.).



to determine the maximum pit depth. Dry film thickness readings are then taken over the coating adjacent to the pit. Finally, the vessel wall thickness proximate to the pit is verified using an ultrasonic thickness gauge. This data is used to correct pit depth readings for coating thickness. Corrected pit depth measurements can be compared to local ultrasonic thickness readings to determine actual remaining wall thickness at the base of the pit.

Detailed documentation of pit depth and vessel wall thickness can be used in a structural analysis, to project corrosion rates and to assess affects on corrosion allowance. Pit depth evaluation sites are permanently marked for future assessment. Periodic evaluation will produce data that allows analysis of trends in corrosion activity. From this, it is possible to predict corrosion rates and plan ahead for remedial action. Fig. 13.3 illustrates the process.

REPAIR SCOPE

Before the initial as-found inspection, any previous coating inspection reports are reviewed and used to develop a preliminary coating repair scope. The as-found condition report then provides specific data used to classify current conditions. The final repair recommendation identifies and prioritizes all repairs.

Deficient areas should be documented so that the scope of coating repair can be clearly identified. Defects can be classified and prioritized based on criteria such as in Table 13.1.

Coating repair typically addresses small, localized defects ranging in size from 1/16 in to 12 in in diameter. The repair of many small defects can be accomplished in a short time. It is possible to repair larger areas using special techniques. Areas up to several hundred square feet have been successfully repaired.

Table 13.2 is an example of how various repair options might be structured. The option selected will depend upon site-specific criteria for meeting regulatory commitments. Total number of repairs will ultimately depend upon overall coating condition.

TABLE 13.1 Coating Defect Classifications

TYPE 1 DEFECT	Coating defects to substrate that may lead to pitting corrosion with a probability of exceeding the minimum allowable wall thickness of the pipe wall or causing section loss exceeding 10 % in a structural member
TYPE 2 DEFECT	Coating defects that may lead to generalized coating failure or that are allowing generalized corrosion and pitting of the substrate
TYPE 3 DEFECT	Coating defects likely to cause disbonding of coating over areas greater than one square foot or in quantities sufficient to violate FME requirements (or both)
TYPE 4 DEFECT	Minor coating defects such as pinpoint rusting, isolated intact blisters (size less than No. 4) and general corrosion less than Rust Grade 4

TABLE 13.2 Coating Repair Options

REPAIR OPTION 1	Repair only Type 1 defects to prevent through-wall pitting of piping or structural damage due to corrosion.
REPAIR OPTION 2	Repair Type 1, 2, and 3 defects to prevent corrosion damage and to extend coating service life 18 to 36 months.
REPAIR OPTION 3	Repair Type 1, 2, 3, and 4 defects to prevent corrosion damage and to extend coating service life 36 to 72 months.

Repair of Deficiencies in the Principle Coating

COATING REPAIR OBJECTIVES

As stated previously, underwater coating repair allows the licensee to address maintenance issues while maintaining operability of critical systems. Beyond this, underwater spot repair is designed to reestablish the coating system as an effective barrier to corrosion and to prevent further coating deterioration due to undercutting. This can result in years of additional service from a coating system that might otherwise require replacement.

UNDERWATER COATING REPAIR MATERIALS

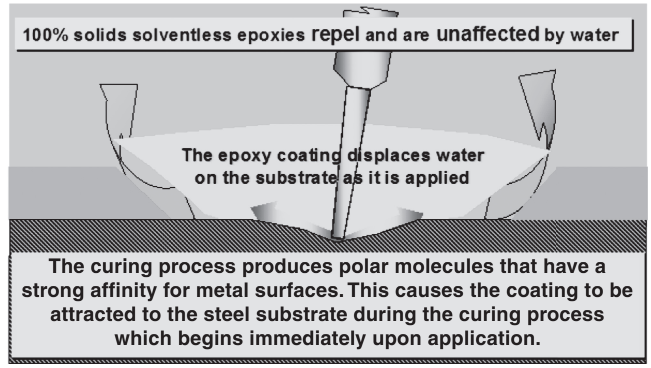
Testing

Underwater repair coatings are tested to ANSI and/or ASTM standards. Testing methods are intended to demonstrate that coatings will remain intact under design basis accident (DBA) conditions and will not produce debris that could compromise engineered safety systems. The test parameters are based on expected conditions inside the drywell during a loss of coolant accident (LOCA). Coatings in-service in suppression chamber immersion areas are unlikely to see drywell type conditions. Water will mitigate the effects of both temperature and radiation.

Coating Suitability

The service environment found in nuclear power plants places unique stresses on coatings. Solventless or 100 % solids epoxies are the coatings of choice for critical underwater coating repair applications. Fig. 13.4 illustrates typical characteristics.

FIG. 13.4 Underwater epoxy characteristics (courtesy of Underwater Engineering Services, Inc.).



Epoxy coatings are copolymeric, meaning they cure by the chemical reaction of two substances. Generically, 100 % solids epoxies undergo a reaction caused by a curing agent (such as a polyamide or polyamine) resulting in a cross-linked polymeric structure. This produces a very strong corrosion and abrasion resistant barrier. Solventless epoxies are able to cure underwater because none of the coating components are water miscible, and no air or solvents are required in the curing process.

An effective barrier coating must be highly adherent. The polymerization process that epoxy coatings undergo produces chemical radicals (polar molecules) that have a strong affinity for metal surfaces. This results in a stronger attraction to the steel substrate than the surrounding water. Epoxy coatings adhere to the substrate by a strong mechanical bond.

Vendors and utilities have researched and tested a variety of epoxy repair coatings over the principle coatings typically found in suppression chambers. On the strength of available test data, several coatings have been selected as suitable for this application. Some coatings have even been qualified under vapor phase drywell conditions to 1.1×10^9 RADs and the more aggressive 340^0 F BWR temperature/pressure curve.

Performance of In-Service Repair Coatings

Underwater coating repair in commercial nuclear plants has been proven as a sound maintenance approach. Some of the early applications have now been in service for more than 20 years. One of the first completely documented underwater coating projects took place in 1986. Hundreds of repairs were performed in a BWR Mark I suppression chamber. Additional repairs were also performed in the condensate storage tank. The condition of these repairs has been periodically monitored, and they continue to perform well while the principal coating continues to degrade.

It is difficult to predict the absolute service life of repair coatings because their performance is closely linked to that of the existing principal coating. However, anecdotal evidence and the characteristic robustness of epoxies suggest that they will outlast the principal coating.

REPAIR PROCEDURES

Work Planning

Coating repair is tracked and documented by repair sites or areas. A repair map, as shown in Fig. 13.5, is used to identify areas for coating repair, and individual repairs are coded according to priority. Repair locations and quantity of material applied are carefully logged. In this way, repair performance can be tracked over time.

Surface Preparation

Deficient areas to be repaired are cleaned to white metal in accordance with the Society for Protective Coatings (SSPC) No. 11, using a 3M Clean and Strip™ Wheel or an equivalent. A rotary file may be used for pit cavities and other depressions in the base metal that are inaccessible to the Clean and Strip.

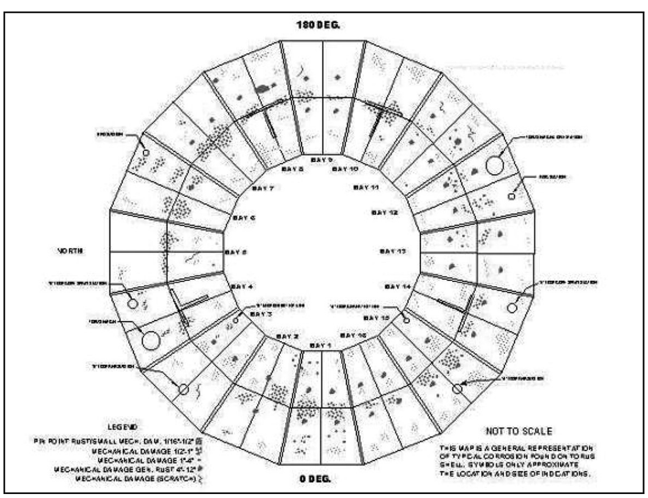
Roughen and feather the adjacent coating with medium grade wet abrasive paper or a Clean and Strip Wheel to create a suitable anchor profile. Loose corrosion deposits, metal shavings, and other debris should be removed from the repair area. Verify that the surface preparation is in accordance with the requirements of SSPC SP No. 11 by observing the power-tool-cleaned area with adequate lighting.

Application of Coating Material

Coating material is applied immediately following surface preparation and prior to the appearance of surface rusting. This time frame is approximately 3 to 5 min. Application of the material may be by hand, hypodermic syringe, brush, roller, plural component mixing gun, or other suitable application tool.

Repair of areas that exhibit localized metal loss due to pitting corrosion or other means requires that the material be forced into the bottom of the cavity in a manner that displaces the water. This is best achieved by placing the tip of the application device into the cavity and filling it from the bottom. Once the cavity is filled, apply additional material and work it into the surface to ensure intimate contact of the coating material with the substrate. Work the material until a uniform thickness that is free of discontinuities is achieved. The coating material should completely cover the substrate and overlap the adjacent sound coating a minimum of 1/4 in to 1/2 in as necessary to ensure there are no holidays in the overlap area.

FIG. 13.5 Repair map (courtesy of Underwater Engineering Services, Inc.).



Material Curing

Due to the nature of the underwater cured epoxy, there is no requirement to verify final cure. During the post-repair inspection activities, the inspector randomly checks the repaired areas after 24 hr to ensure that there are no signs of insufficient cure.

Inspection and Acceptance Criteria

Repaired areas are inspected after 24 h. The acceptance criteria are as follows:

1) The coating material should not feel soft or tacky.
2) The dry film thickness should be as specified in the material technical data sheet.
3) The coating should be continuous.
4) No runs or sags are permitted.
5) Minor embedded material is acceptable on the surface of the cured film as long as it does not penetrate the film to substrate.

Coating thickness is measured using a properly calibrated dry film thickness gage. The inspector marks any deficient areas in a manner that is clearly visible to the applicator. The following outlines procedures for repair of certain deficiencies.

1) Repaired areas that exhibit low film thickness are roughened with medium grade wet abrasive paper and additional material is applied to bring the thickness to within the specified range.
2) Repaired areas that exhibit rusting due to discontinuities or insufficient overlapping of the adjacent coating are power tool cleaned and additional material applied.
3) Repaired areas that exhibit excessive embedded particles that appear to extend deep into the repair coating are power tool cleaned to remove the excessive particles and are recoated.
4) Areas of high film buildup are ground down to an acceptable thickness with a Clean and Strip™ Wheel and additional material applied to adequately seal the power tooled surface.

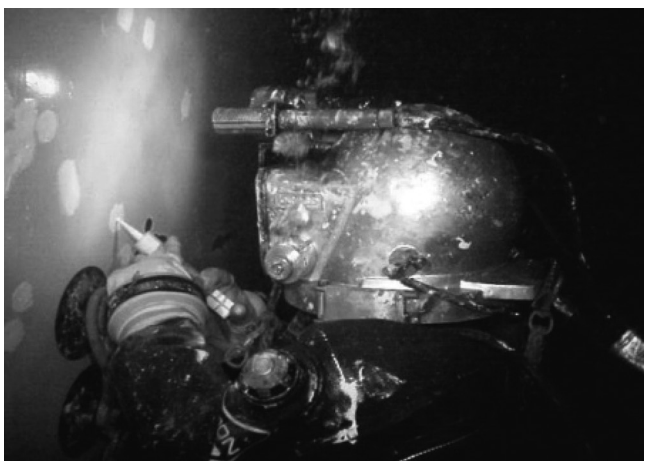
Results of the post-repair inspection are documented in the inspection section of the coating repair record.

Comprehensive Coating Program Management

Underwater coating maintenance should be part of a comprehensive coatings program that should be developed to manage all critical coatings. The mission of such a program is to preserve facility assets; support safe, efficient, and reliable operations; and to maximize return on investment. A properly implemented program will help to standardize practices and procedures, increase

FIG. 13.6 Underwater surface preparation (courtesy of Underwater Engineering Services, Inc.).

FIG. 13.7 Diver performing spot repair (courtesy of Underwater Engineering Services, Inc.).



efficiency and economies of scale, obtain and optimize funding, reduce life-cycle cost, promote safe operation, minimize operational impacts, ensure regulatory compliance, and improve information management.

References

[1] ANSI Standard N101.4, *Quality Assurance for Protective Coatings Applied to Nuclear Facilities*, American National Standards Institute, Washington, DC, 1972.

[2] ASTM D3843, *Standard Practice for Quality Assurance for Protective Coatings Applied to Nuclear Facilities*, ASTM International, West Conshohocken, PA, 2008, **www.astm.org**

[3] ANSI Standard N45.2.6, *Qualifications of Inspection, Examination, & Testing*, American National Standards Institute, Washington, DC, 1978.

[4] ASTM D772, *Standard Test Method for Evaluating Degree of Flaking (Scaling) of Exterior Paints*, ASTM International, West Conshohocken, PA, 2011, **www.astm.org**

[5] ASTM D4541, *Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers*, ASTM International, West Conshohocken, PA, 2009, **www.astm.org**

Appendix

The intent of this appendix is to provide the user with a reasonably comprehensive list of ASTM standards applicable to the use of protective coatings and linings in nuclear power plants. Several "withdrawn" standards are included for historical reference and in acknowledgment that these standards may continue to be specified in plant procedures. Other ASTM standards not included in this listing also may be applicable.

ASTM STANDARDS

ASTM **D610**	Standard Practice for Evaluating Degree of Rusting on Painted Steel Surfaces
ASTM **D714**	Standard Test Method for Evaluating Degree of Blister of Paints
ASTM **D772**	Standard Test Method for Evaluating Degree of Flaking (Scaling) of Exterior Paints
ASTM **D1186**	Withdrawn—Standard Test Methods for Nondestructive Measurement of Dry Film Thickness of Nonmagnetic Coatings Applied to a Ferrous Base
ASTM **D1400**	Withdrawn—Standard Test Methods for Nondestructive Measurement of Dry Film Thickness of Nonconductive Coatings Applied to a Nonferrous Metal Base
ASTM **D2794**	Standard Test Method for Resistance of Organic Coatings to the Effects of Rapid Deformation (Impact)
ASTM **D3276**	Standard Guide for Paint Inspectors (Metal Substrates)
ASTM **D3359**	Standard Test Method for Measuring Adhesion by Tape Test
ASTM **D3843**	Standard Practice for Quality Assurance for Protective Coatings Applied to Nuclear Facilities
ASTM **D3911**	Standard Test Method for Evaluating Coatings Used in Light-Water Nuclear Power Plants at Simulated Loss of Coolant Accident (LOCA) Conditions
ASTM **D3912**	Standard Test Method for Chemical Resistance of Coatings Used in Light-Water Nuclear Power Plants
ASTM **D4060**	Standard Test Method for Abrasion Resistance of Organic Coatings by the Taber Abraser
ASTM **D4082**	Standard Test Method for Effects of Gamma Radiation on Coatings for Use in Nuclear Power Plants
ASTM **D4138**	Standard Practices for Measurement of Dry Film Thickness of Protective Coating Systems by Destructive, Cross-Sectioning Means
ASTM **D4227**	Standard Practice for Qualifying Coating Applicators for Application of Coatings to Concrete Surfaces
ASTM **D4228**	Standard Practice for Qualifying Coating Applicators for Application of Coatings to Steel Surfaces
ASTM **D4256**	Withdrawn—Test Method for Determination of the Decontaminability of Coatings Used in Light-Water Nuclear Power Plants
ASTM **D4258**	Standard Practice for Surface Cleaning Concrete for Coating
ASTM **D4259**	Standard Practice for Abrading Concrete
ASTM **D4260**	Standard Practice for Liquid and Gelled Acid Etching of Concrete
ASTM **D4261**	Standard Practice for Surface Cleaning Concrete Masonry Units for Coating
ASTM **D4262**	Standard Test Method for pH of Chemically Cleaned or Etched Concrete Surfaces
ASTM **D4263**	Standard Test Method for Indicating Moisture in Concrete by the Plastic Sheet Method
ASTM **D4285**	Standard Test for Indicating Oil or Water in Compressed Air
ASTM **D4286**	Standard Practice for Determining Coating Contractor Qualifications for Nuclear Powered Electric Generation Facilities
ASTM **D4414**	Standard Practice for Measurement of Wet Film Thickness by Notched Gages
ASTM **D4417**	Standard Test Methods for Field Measurement of Surface Profile of Blast Cleaned Steel

(Continued)

DOI: 10.1520/MNL820130017

ASTM STANDARDS (Continued)

ASTM **D4537**	Standard Guide for Establishing Procedures to Qualify and Certify Personnel Performing Coating and Lining Work Inspection in Nuclear Facilities
ASTM **D4538**	Standard Terminology Relating to Protective Coatings and Lining Work for Power-Generation Facilities
ASTM **D4541**	Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers
ASTM **D5139**	Standard Specification for Sample Preparation for Qualification Testing of Coatings to be Used in Nuclear Power Plants
ASTM **D5144**	Standard Guide for Use of Protective Coating Standards in Nuclear Power Plants
ASTM **D5163**	Standard Guide for Establishing a Program for Condition Assessment of Coatings Service Level I Coating Systems in Nuclear Power Plants
ASTM **D5367**	Standard Practice for Evaluating Coatings Applied Over Surfaces Treated with Inhibitors Used to Prevent Flash Rusting of Steel when Water or Water/Abrasive Blasted
ASTM **D5498**	Standard Guide for Developing a Training Program for Personnel Performing Coating and Lining Work Inspection for Nuclear Facilities
ASTM **D6677**	Standard Test Method for Evaluating Adhesion by Knife
ASTM **D7091**	Standard Practice for Nondestructive Measurement of Dry Film Thickness of Nonmagnetic Coatings Applied to Ferrous Metals and Nonmagnetic, Nonconductive Coatings Applied to Nonferrous Metals
ASTM **D7108**	Standard Guide for Establishing Qualifications for a Nuclear Coating Specialist
ASTM **D7167**	Standard Guide for Establishing Procedures to Monitor the Performance of Safety-Related Coating Service Level III Lining Systems in an Operating Nuclear Power Plant
ASTM **D7230**	Standard Guide for Evaluating Polymeric Lining Systems for Water Immersion in Coating Service Level III Safety-Related Applications on Metal Substrates
ASTM **D7491**	Standard Guide for Management of Non-Conforming Coatings in Coating Service Level I Areas of Nuclear Power Plants
ASTM **D7602**	Standard Practice for Installation of Vulcanized Rubber Linings
ASTM **E84**	Standard Test Method for Surface-Burning Characteristics of Building Materials
ASTM **E312**	Standard Practice for Description and Selection of Conditions for Photographing Specimens Using Analog (Film) Cameras and Digital Still Cameras (DSC)
ASTM **E1530**	Standard Test Method for Evaluating the Resistance to Thermal Transmission of Materials by the Guarded Heat Flow Meter Technique

ASTM INTERNATIONAL
Helping our world work better

ISBN: 978-0-8031-7070-4
Stock #: MNL8-2ND

www.astm.org