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Standard Guide for Use of Protective Coating Standards in Nuclear Power Plants[1]

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INTRODUCTION

Protective coatings (paints) have been used extensively in the nuclear industry to protect the surfaces of facilities and equipment from corrosion and contamination by radioactive nuclides in accordance with ALARA. In the absence of a standard method of selecting, testing, and evaluating coatings, many sites evaluated paints by empirical tests to determine which were useful in their particular operation. Understandably, the methods of testing were not uniform throughout the industry. It has been very difficult, consequently, to compare the results obtained at one site with those obtained at another. Standard tests whereby industrial (nuclear) users of paints systematically prepare specimens and subject them to selected evaluations, thus permitting uniform comparisons, are advantageous, internationally as well as domestically.

The designer of light water-moderated nuclear reactor systems must consider the possibility of a Design Basis Accident (DBA) and the subsequent events which might lead to the release or expulsion of a fraction of the fission-product inventory of the core to the reactor containment facility. Engineered safety features, principally a reactor containment facility, are provided to prevent the release of fission products to the biological environment during and after this improbable event. The design, fabrication, quality assurance, and testing of these engineered safety features ensure reliable operation and safety under all anticipated conditions.

Large areas of the reactor-containment facility are painted with safety-related coatings. If severe delamination, peeling, or flaking causes significant portions of the coating to be discharged into the 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. Safety-related coatings may also exist outside of the reactor-containment.

This guide is the result of a comprehensive examination of the experience and data that have been developed on protective coatings in the nuclear industry over approximately 40 years. Standards pertaining to nuclear coatings have historically been covered by ANSI N5.12, N101.2, and N101.4. Responsibility for updating, rewriting, and issuing appropriate ANSI replacement standards has been transferred to ASTM, specifically ASTM Committee D-33, on Protective Coating and Lining Work for Power Generation Facilities.

The objective of this guide is to provide a common basis on which to define and specify the performance requirements for the coatings that will be used in nuclear facilities. Quality assurance in the nuclear industry is a mandatory requirement for all aspects of safety-related nuclear coatings work. Licensees of nuclear power plants are required to determine if coated surfaces are within the scope of 10CFR50.65,“ The Maintenance Rule”. Any coated surfaces found to be within the scope of 10CFR50.65 must satisfy the requirements of 10CFR50.65. ASME Section XI, Subsection IWE contains the requirements for periodic evaluation of the reactor-containment steel pressure boundary.

1. Scope

1.1 This guide provides a common basis on which protective coatings for the surfaces of nuclear power generating facilities may be qualified and selected by reproducible evaluation tests. This guide also provides guidance for application and maintenance of protective coatings. Under the environmental operating and accident conditions of nuclear power generation facilities, encompassing pressurized water reactors (PWR's) and boiling water reactors (BWR's), coating performance may be affected by exposure to any one, all, or a combination of the following conditions: ionizing radiation; contamination by radioactive nuclides and subsequent decontamination processes; chemical and water sprays; high-temperature high-pressure steam; and abrasion or wear.

1.2 The content of this guide includes:

	Section
Referenced Documents	2
Terminology	3
Significance and Use	4
Coating Material Testing	5
Surface Preparation, Coating Application, and Inspection for Shop and Field Work	6
Thermal Conductivity	7
Quality Assurance	8
Keywords	9

1.2.1 In addition, this guide addresses technical topics within ANSI N5.12 and ANSI N101.2 that are covered by separate ASTM standards, for example, surface preparation, (shop and field) and coating application, (shop and field).

1.2.2 Applicable sections of this guide and specific acceptance criteria may be incorporated into specifications and other documents where appropriate.[2]

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

2. Referenced Documents

2.1 *ASTM Standards:*

C 177 Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Guarded-Hot-Plate Apparatus[3]

D 3843 Practice for Quality Assurance for Protective Coatings Applied to Nuclear Facilities[4]

D 3911 Test Method for Evaluating Coatings Used in Light-Water Nuclear Power Plants at Simulated Design Basis Accident (DBA) Conditions[4]

D 3912 Test Method for Chemical Resistance of Coatings Used in Light-Water Nuclear Power Plants[4]

D 4060 Test Method for Abrasion Resistance of Organic Coatings by the Taber Abraser[5]

D 4082 Test Method for Effects of Radiation on Coatings Used in Light-Water Nuclear Power Plants[4]

D 4227 Practice for Qualification of Coating Applicators for Application of Coatings to Concrete Surfaces[4]

D 4228 Practice for Qualification of Coating Applicators for Application of Coatings to Steel Surfaces[4]

D 4537 Guide for Establishing Procedures to Qualify and Certify Inspection Personnel for Coating Work in Nuclear Facilities[4]

D 4538 Terminology Relating to Protective Coating and Lining Work for Power Generation Facilities[4]

D 4541 Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers[4]

D 5139 Specification for Sample Preparation for Qualification Testing of Coatings to Be Used in Nuclear Power Plants[4]

E 84 Test Method for Surface Burning Characteristics of Building Materials[6]

E 1461 Test Method for Thermal Diffusivity of Solids by the Flash Method[7]

E 1530 Test Method for Evaluating the Resistance to Thermal Transmission of Materials by the Guarded Heat Flow Meter Technique[7]

2.2 *Other Standards:*

ANSI N5.12 Protective Coatings (Paints) for the Nuclear Industry[8]

ANSI N 101.2 Protective Coatings (Paints) for Light Water Nuclear Reactor Containment Facilities[8]

ANSI N101.4 Quality Assurance for Protective Coatings Applied to Nuclear Facilities[8]

ASME Boiler and Pressure Vessel Code (BPVC), Section XI, "Rules for Inservice Inspection of Nuclear Power Plant Components,"Subsection IWE "Requirements for Class MC and Metallic Liners of Class CC Components of Light-Water Cooled Power Plants"[9]

EPRI TR-109937 (1998) Guideline on Nuclear Safety-Related Coatings[10]

10CFR50. Appendix B: Title 10, Chapter 1, Energy, Part 50, Domestic Licensing of Production and Utilization Facilities, Appendix B, Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants[11]

10CFR50.65 Requirements for Monitoring the Effectiveness of Maintenance at Nuclear Power Plants[11]

Guide 1.54 Regulatory/(1973) Quality Assurance Requirements for Protective Coatings Applied to Water-Cooled Nuclear Power Plants[11]

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[1] This guide is under the jurisdiction of ASTM Committee D-33 on Protective Coating and Lining Work for Power Generation Facilities and is the direct responsibility of Subcommittee D33.02 on Service and Material Parameters.

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[2] Certain ASTM standards are available in compilation form (which includes this guide), as *Compilation of ASTM Standards for Use of Protective Coating Standards in Nuclear Power Plants* for expedient reference and usage by personnel involved in nuclear coating work.

[3] *Annual Book of ASTM Standards*, Vol 04.06.

[4] *Annual Book of ASTM Standards*, Vol 06.02.

[5] *Annual Book of ASTM Standards*, Vol 06.01.

[6] *Annual Book of ASTM Standards*, Vol 04.07.

[7] *Annual Book of ASTM Standards*, Vol 14.02.

[8] Available from American National Standards Institute, 11 W. 42nd St., 13th Floor, New York, NY 10036.

[9] Available from American Society of Mechanical Engineers, Three Park Ave., New York, NY 10016-5990.

[10] Available from EPRI Distribution Center, 207 Coggins Drive, P.O. Box 23205, Pleasant Hills, CA 94523 (510) 934-4212.

[11] Available from the U.S. Government Printing Office, Washington, DC 20402.

USNRC Review Plan 6.1.2 Protective Coating Systems (Paints) Organic Materials[11]

10CFR20.1(C) Standards for Protection Against Radiation; Purpose[11]

USNRC Regulatory Guide 8.8 Information Relevant to Ensuring that Occupational Radiation Exposures At Nuclear Power Stations Will Be As Low As Is Reasonably Achievable[11]

3. Terminology

3.1 *Definitions*—Definitions for use with this guide are shown in Terminology D 4538 or other applicable standards.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *ALARA*—the concept of reducing radiation exposure to personnel to levels "as low as is reasonably achievable," as defined in the USNRC Regulation Guide 8.8, and 10CFR20.1(C).

3.2.2 *Coating Service Level I*—Terms used to describe areas inside the reactor-containment where coating failure could adversely affect the operation of post-accident fluid systems and, thereby, impair safe shutdown.

3.2.3 *Coating Service Level II*—Terms used to describe areas outside the reactor-containment where coating failure could impair, but not prevent, normal operating performance. The function of *Coating Service Level II* coatings is to provide corrosion protection and decontaminability in those areas outside the reactor-containment subject to radiation exposure and radionuclide contamination. *Service Level II* coatings are not safety-related.

3.2.4 *Coatings Service Level III*—Terms used to describe areas outside the reactor-containment where coating failure could adversely affect the safety function of a safety-related structure, system or component (SSC).

3.2.5 *Safety-Related Coating System*—A coating system used inside or outside of the reactor-containment, the detachment of which could adversely affect the safety function of a safety-related structure, system or component (SSC).

3.2.6 *DBA Qualified Coating System*—A coating system used inside reactor-containment that can be attested to having passed the required laboratory testing, including irradiation and simulated Design Basis Accident (DBA), and has adequate quality documentation to support its use as DBA qualified.

3.2.7 *DBA Unqualified Coating System*—A coating system used inside reactor-containment that *cannot* be attested to having passed the required laboratory testing, including irradiation and simulated Design Basis Accident (DBA), or has inadequate quality documentation, or both, to support its use as DBA qualified.

3.2.8 *Acceptable Coating or Lining System*—A safety-related coating or lining system for which a suitability for application review which meets the plant licensing requirements has been completed and there is reasonable assurance that, when properly applied and maintained, the coating or lining will not detach under normal or accident conditions.

3.2.9 *Indeterminate Coating or Lining System*—A safety-related coating or lining system for which there is insufficient evidence to demonstrate that it is suitable for its intended use and that it is acceptable.

3.2.9.1 *Discussion*—Note that ultimately a decision must be made as to whether or not an indeterminate coating system is acceptable.

4. Significance and Use

4.1 This guide addresses the concerns of Regulation Guide 1.54 and Standard Review Plan 6.1.2, and the replacement of ANSI Standards N5.12, N101.2, and N101.4. This guide covers coating work on previously coated surfaces as well as bare substrates. This guide applies to all coating work in Service Level I and III areas (that is, safety-related coating work). Applicable sections of this guide may also be used to evaluate and select protective coatings for Service Level II areas where deemed appropriate by the licensee.

4.2 The testing referenced in this guide is particularly appropriate for safety-related coatings inside the reactor-containment. Other test methods may be used for assessing the suitability for service of safety-related coatings outside the reactor-containment. Criteria for evaluation and selection of Service Level III coatings shall be addressed in job specifications. Guidance for selecting safety-related and other coatings located outside the reactor-containment is provided in Sections 4.4 and 4.5 of EPRI TR-109937(1998).

4.3 Users of this guide must ensure that coatings work complies not only with this guide, but also with the licensee's plant-specific quality assurance program and licensing commitments.

4.4 *Safety-Related Coatings*:

4.4.1 The qualification of coatings for Service Levels I and III are different even though they are both safety-related. This standard guide provides the minimum requirements for qualifying Service Level I coatings and also provides guidance for additional qualification tests that may be used to evaluate Service Level I coatings. This standard guide does *not* provide minimum requirements for qualifying Service Level III coatings but does provide guidance for qualification tests that may be applicable for use in evaluating Service Level III coatings.

4.4.2 *Service Level I Coatings*:

4.4.2.1 All Service Level I coatings must be resistant to the effects of radiation and must be DBA qualified. The test specimens shall be prepared, irradiated and DBA tested and evaluated in accordance with the requirements of:

(*a*) Test Method D 3911 or plant specific requirements as applicable,

(*b*) Test Method D 4082, and

(*c*) Specification D 5139.

4.4.2.2 In addition to the requirements of 4.4.2.1, Service Level I coatings may be evaluated for additional qualities or may require application controls when deemed applicable by the job specifications or licensing commitments. The following documents provide guidance for application, possible additional testing or for the further evaluation of Service Level I coatings when applicable:

(*a*) Test Method C 177,

(*b*) Practice D 3843,

(*c*) Test Method D 3912,

(*d*) Test Method D 4060,

(*e*) Practice D 4227,

(*f*) Practice D 4228,

(*g*) Guide D 4537,

(*h*) Test Method D 4541,
(*i*) Test Method E 84,
(*j*) Test Method E 1461, and
(*k*) Test method E 1530.

4.4.3 *Service Level III Coatings*:

4.4.3.1 Service Level III coatings must be evaluated for use in accordance with the requirements of plant licensing commitments and the job specifications. Service Level III coatings may include linings used in areas such as service water systems, essential cooling water heat exchanger heads and emergency diesel generator air intakes. There are *no* specific testing or qualification *requirements* included in this guide for Service Level III coatings or linings. Testing and evaluation of Service Level III coatings should be conducted as necessary to ensure the licensee that the coatings are suitable for the specific service environment to which the coatings will be exposed. The following documents provide guidance for testing and inspection, which the licensee may consider when preparing job specifications for Service Level III coatings or linings:
(*a*) Practice D 4541,
(*b*) EPRI TR-109937(1998), Sections 4.4 and 4.5,
(*c*) 10CFR 50.65, and
(*d*) 10CFR50. Appendix B.

4.5 *Service Level II Coatings*:

4.5.1 Service Level II coatings are not safety-related and are restricted to the radiation controlled area (RCA) outside of the reactor-containment in nuclear facilities. There are *no* specific testing or qualification *requirements* included in this guide for Service Level II coatings. The following documents provide guidance for testing and inspection, which the licensee may consider when evaluating or specifying Service Level II coatings:
(*a*) Test Method D 3912,
(*b*) Test Method D 4060,
(*c*) Test Method D 4082,
(*d*) Test Method D 4541,
(*e*) Specification D 5139,
(*f*) Test Method E 84, and
(*g*) USNRC Regulatory Guide 8.8.

5. Coating Material Testing

5.1 The coating material test specimen preparation and testing standards in 5.2-5.8 may be used to evaluate coatings applied in nuclear power plants as discussed in Section 4 of this guide.

5.2 *Preparation of Qualification Test Specimens*:

5.2.1 All test specimens used for qualification testing of coatings shall be prepared in accordance with Specification D 5139.

5.3 *Radiation Tolerance Tests*:

5.3.1 Coating film resistance to radiation exposure shall be evaluated in accordance with Test Method D 4082.

5.4 *Decontamination*:

5.4.1 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.

5.5 *Physical Properties*:

5.5.1 *Adhesion*—Panels shall be tested for adhesion in accordance with Test Method D 4541. A minimum of two panels shall be tested for each coating system. If the size of the test specimen is less than 3 by 5 in., an annular bearing ring should be used if necessary, to ensure full contact of the tester legs to the test specimen.

5.5.1.1 Minimum adhesion shall be 200 psi, consisting of three adhesion tests on each test panel.

5.5.2 *Abrasion Resistance*—Abrasion resistance characteristics of coating systems for floors and other surfaces where abrasion is a factor shall be determined in accordance with Test Method D 4060.

5.5.2.1 Weight loss shall not exceed 175 mg/1000 cycles when a CS-17 wheel is used with a 1000-g load.

5.6 *Chemical Resistance Tests*:

5.6.1 Test specimens shall be tested in accordance with Test Method D 3912.

5.6.2 The specific chemicals to be used should be selected to characterize the anticipated exposure; the chemicals indicated in Test Method D 3912 are shown only as examples and are not mandatory.

5.7 *Fire Evaluation Tests*:

5.7.1 *Flame Spread Tests*—Flame-spread tests, when required, shall be conducted and evaluated in accordance with Test Method E 84. The permissible flame-spread and smoke generation, when tested on a noncombustible substrate, shall not exceed the limits set by the nuclear power generating facility.

5.7.2 The coating systems should be tested to cover the specified film thickness range (or greater) since the flame-spread and smoke density can vary with film thickness. Smoke density is significant where a coating is utilized in enclosed spaces and smoke generation can reduce visibility and prevent effective fire fighting operations. Historic test data indicates that most coatings applied at less than 25-mils dry film thickness over noncombustible substrates and tested in accordance with Test Method E 84 demonstrate flame-spread values below 25.

5.8 *DBA Testing*:

5.8.1 The test specimen shall be tested and evaluated in accordance with plant specific requirements or Test Method D 3911 as applicable.

6. Surface Preparation, Coating Application, and Inspection for Shop and Field Work

6.1 It is recommended that the *Manual of Coating Work for Light-Water Nuclear Power Plant Primary Containment and Other Safety-Related Facilities Guide*,[12] prepared by ASTM Subcommittee D01.43, be reviewed in the course of nuclear coating work.

6.2 Surface preparation for steel, concrete, and previously coated surfaces shall be at least as good as that used in the qualification testing of the coating system intended for use.

[12] ASTM, 1979.

6.3 Coating application shall be in accordance with the job specifications and procedures and the coating manufacturer's latest published instructions to the extent referenced in the job specification and procedures. Coating Applicator qualification shall meet the requirements of the applicable quality assurance (QA) program. Practices D 4227 and D 4228 provide guidance for qualifying coating applicators. Coating dry film thickness shall be in the range used in the qualification testing of the coating system.

6.4 Coatings work shall be inspected by coatings inspectors qualified and certified in accordance with the licensee's applicable QA program. Guide D 4537 provides guidance for qualifying coating work inspectors. Inspections shall be documented to provide a record of the coatings work.

6.5 Maintenance painting work shall follow the requirements of 6.2, 6.3, and 6.4. The maintenance painting specifications shall take into consideration the plant environment in which the coating work must be accomplished. Maintenance painting work qualification testing should be based on proposed surface preparation, coating application methods, and film thickness ranges, all of which may be different than the original design qualification work.

7. Thermal Conductivity

7.1 If required, thermal conductivity for coating systems may be determined by Test Methods C 177, E 1461 or E 1530. See appendix for typical thermal conductivity values.

8. Quality Assurance

8.1 A quality assurance program for Service Level I and III coating work shall be established in accordance with the licensee's licensing commitments. Practice D 3843 provides guidance for achieving the objectives of the licensee's quality assurance program with respect to safety-related coatings work. Quality assurance requirements may also be established for Service Level II coating work based on criticality. Coating Service Levels I and III coating work is considered a Special Process as defined in 10CFR50 Appendix B, criterion 9.

9. Keywords

9.1 ANSI replacement standards; decontamination; Design Basis Accident (DBA); nuclear power plants; protective coating standards; qualification testing; quality assurance Service Level I, Service Level II, and Service Level III; radiation; safety related

APPENDIX

(Nonmandatory Information)

X1. THERMAL CONDUCTIVITY OF TYPICAL COATING SYSTEMS

X1.1 Table X1.1 illustrates thermal conductivity.

TABLE X1.1 Thermal Conductivity of Typical Coating Systems

NOTE 1—Thermal conductivities listed here are indicated for the coating system shown and should not be considered additive.
NOTE 2—To find the thermal conductivity of a coating system 2, 3, 4, etc., mils thick, divide the thermal conductivity for one mil (right-hand column) by 2, 3, 4, etc.

Coating System	Thermal Conductivity (Coefficient)	
	(B.t.u.) (in.)/(h) (ft^2) (°F)	(B.t.u.) (mil)/(h) (ft^2) (°F)
Inorganic zinc primer—no top coat	11 to 18	11 000 to 18 000
Inorganic zinc primer—inorganic top coat	7 to 12	7 000 to 12 000
Inorganic zinc primer—organic top coat	2.5 to 7	2 500 to 7 000
Organic zinc primer—no top coat	2.5 to 5	2 500 to 5 000
Organic zinc primer—organic top coat	1 to 3.5	1 000 to 3 500
Organic primer—organic top coat	1 to 3.5	1 000 to 3 500