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Standard Guide for Evaluating Polymeric Lining Systems for Water Immersion in Coating Service Level III Safety-Related Applications on Metal Substrates¹

This standard is issued under the fixed designation D7230; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This guide establishes procedures for evaluating lining system test specimens under simulated operating conditions.

1.2 Lining systems to be tested in accordance with this guide are intended for use in both new construction and for refurbishing existing systems or components.

1.3 The lining systems evaluated in accordance with this guide are expected to be applied to metal substrates comprising water-wetted (that is, continuous or intermittent immersion) surfaces in systems that may include:

1.3.1 Service water piping upstream of safety-related components,

1.3.2 Service water pump internals (draft tube, volutes, and diffusers),

1.3.3 Service water heat exchanger channels, pass partitions, tubesheets, end bells, and covers,

1.3.4 Service water strainers, and

1.3.5 Refueling water storage tanks and refuel cavity water storage tanks.

1.4 This guide anticipates that the lining systems to be tested include liquid-grade and paste-grade polymeric materials. Sheet type lining materials, such as rubber, are excluded from the scope of this guide.

1.5 Because of the specialized nature of these tests and the desire in many cases to simulate to some degree the expected service environment, the creation of a standard practice is not practical. This standard gives guidance in setting up tests and specifies test procedures and reporting requirements that can be followed even with differing materials, specimen preparation methods, and test facilities.

1.6 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical

conversions to SI units that are provided for information only and are not considered standard.

1.7 *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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.8 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 ASTM Standards:²

A36/A36M Specification for Carbon Structural Steel
C868 Test Method for Chemical Resistance of Protective Linings (Withdrawn 2015)³

D115 Test Methods for Testing Solvent Containing Varnishes Used for Electrical Insulation

D714 Test Method for Evaluating Degree of Blistering of Paints

D2240 Test Method for Rubber Property—Durometer Hardness

D2583 Test Method for Indentation Hardness of Rigid Plastics by Means of a Barcol Impressor

D2794 Test Method for Resistance of Organic Coatings to the Effects of Rapid Deformation (Impact)

D4060 Test Method for Abrasion Resistance of Organic Coatings by the Taber Abraser

D4082 Test Method for Effects of Gamma Radiation on Coatings for Use in Nuclear Power Plants

D4538 Terminology Relating to Protective Coating and

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² For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

³ The last approved version of this historical standard is referenced on www.astm.org.

- Lining Work for Power Generation Facilities
- D4541** Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers
- D5139** Specification for Sample Preparation for Qualification Testing of Coatings to be Used in Nuclear Power Plants
- D5144** Guide for Use of Protective Coating Standards in Nuclear Power Plants
- D6677** Test Method for Evaluating Adhesion by Knife
- D7167** Guide for Establishing Procedures to Monitor the Performance of Safety-Related Coating Service Level III Lining Systems in an Operating Nuclear Power Plant
- E96/E96M** Test Methods for Water Vapor Transmission of Materials
- G14** Test Method for Impact Resistance of Pipeline Coatings (Falling Weight Test)
- G42** Test Method for Cathodic Disbonding of Pipeline Coatings Subjected to Elevated Temperatures
- 2.2 *Federal Standards*⁴
- EPA Method 415.1** Total Organic Carbon in Water
- 2.3 *NACE International*⁵
- RP0394** Application, Performance and Quality Control of Plant-Applied, Fusion Bonded External Pipe Coating
- TM0174** Laboratory Methods for the Evaluation of Coating Materials and Lining Material on Metallic Substrates in Immersion Service
- TM0404** Offshore Platform Atmospheric and Splash Zone New Construction Coating System Evaluation

3. Terminology

3.1 Definitions of Terms Specific to This Standard:

3.1.1 In addition to the following terms, general terms applicable to this standard are found in Terminology **D4538**.

3.1.2 *cladding, n*—a thick coating system comprised of a liquid-grade prime coat, a paste-grade intermediate build coat, and a liquid-grade finish coat.

3.1.2.1 *Discussion*—This system is typically applied as a lining to heat exchanger tubesheets and as a repair material in localized areas of metal loss (for example, pump impeller cavitation, pipe wall corrosion) to restore surface contour. A modified (that is, thinner) cladding may be used on the warmer side of heat exchanger pass partitions to prevent “cold wall” blistering.

3.1.3 *Coating Service Level III (CSL III), n*—areas outside the reactor containment where lining (or coating) failure could adversely affect the safety function of a safety-related structure, system, or component (SSC).

3.1.3.1 *Discussion*—This definition is consistent with that found in Guide **D5144**.

3.1.4 *cold wall effect, n*—propensity for a fluid or vapor to permeate into/through a lining applied to the warmer side of a substrate that serves as a boundary between warmer and cooler fluids.

⁴ Available from U.S. Government Printing Office Superintendent of Documents, 732 N. Capitol St., NW, Mail Stop: SDE, Washington, DC 20401, <http://www.access.gpo.gov>.

⁵ Available from NACE International (NACE), 1440 South Creek Dr., Houston, TX 77084-4906, <http://www.nace.org>.

3.1.5 *lining, n*—particular type of coating intended for protection of substrates from corrosion as a result of continuous or intermittent fluid immersion.

3.1.5.1 *Discussion*—The normal operating service environments to which linings are subject are aggressive. As such, material and application process parameters are specialized and require exacting quality control measures.

3.1.6 *liquid-grade, adj*—lining material that is liquid when mixed and applied.

3.1.6.1 *Discussion*—Liquid-grade polymeric lining materials are typically used as prime and finish coats in a lining system.

3.1.7 *paste-grade, adj*—lining material that, when mixed, results in a paste-like material that is often applied by trowel or squeegee.

3.1.7.1 *Discussion*—Paste-grade polymeric lining materials are often used as the build coat in a lining system and are always incorporated in a cladding system. In addition to imparting thickness and impact resistance, the paste-grade build coat material has the ability to restore an extensively corroded surface to a relative smooth condition by filling corrosion-induced surface porosity, pits, and depressions.

3.1.8 *service water, n*—that water used to cool power plant components or extract heat from systems or components, or both.

3.1.8.1 *Discussion*—Cooling/heat extraction is generally accomplished via heat exchangers, fan coolers, or chillers. Service water may be raw water or water chemically treated to retard corrosion. Service water systems are distinct and separate from the circulating water system used to extract waste heat from the main steam surface condenser.

4. Summary of Guide

4.1 The objectives of the testing set forth in this guide are to evaluate a CSL III lining system’s ability to:

4.1.1 Prevent corrosion and erosion of the metallic materials of construction and

4.1.2 Remain intact during design basis conditions.

4.2 The Tests Outlined Comprise Two Distinct Phases:

4.2.1 *Phase 1*—Phase 1 includes two primary assessments and certain additional related physical testing. The Phase 1 tests are considered essential to the objective of developing a test database that can be used to rank and otherwise compare candidate-lining systems.

4.2.1.1 *Permeability Testing*—Defined thicknesses of liquid and paste-grade polymeric lining materials are tested to assess their relative imperviousness.

4.2.1.2 *Test (Atlas) Cell “Conditioning” Followed by Destructive Testing*—Test specimens representing thinner and thicker film candidate lining systems are “conditioned” by exposure to test conditions replicating water immersion environments that produce a temperature gradient across the specimen (that is, “cold wall” conditions). Following conditioning, the test specimens are tested for impact resistance, flexibility, adhesion, and hardness.

4.2.2 *Phase 2*—Phase 2 includes additional destructive tests. Phase 2 testing is intended to provide additional performance

data that can be used to refine the lining selection process. For instance, Phase 1 tests may be used to evaluate a relatively broad array of candidate materials. Once the field of candidate systems is narrowed via Phase 1 testing, Phase 2 tests can be used to fine-tune the system selection process.

5. Significance and Use

5.1 Safety-related service water system (SWS) components are designed to provide adequate cooling to equipment essential to the safe operation and shutdown of the plant. Linings in these systems are installed to maintain the integrity of the system components by preventing corrosion and erosion of the metal materials of construction. Linings on SWS surfaces upstream of components, including heat exchangers, orifice plates, strainers, and valves, the detachment of which may affect safe-plant operation or shutdown, may be considered safety-related, depending on plant-specific licensing commitments and design bases.

5.2 The testing presented in this guide is used to provide reasonable assurance that the linings, when properly applied, will be suitable for the intended service by preventing corrosion and erosion for some extended period of time. Additionally, the test data derived allows development of schedules, methods, and techniques for assessing the condition of the lining materials (see Guide [D7167](#)). The ultimate objective of the testing is to avoid lining failures that could result in blockage of equipment, such as piping or heat transfer components, preventing the system or component from performing its intended safety function.

5.3 It is expected that this guide will be used by:

5.3.1 Lining manufacturers for comparing specific products and systems and to establish a qualification basis for recommended linings and

5.3.2 End users seeking a consistent design basis for candidate coating systems.

5.4 In the event of conflict, users of this guide must recognize that the licensee's plant-specific quality assurance program and licensing commitments shall prevail with respect to the selection process for and qualification of CSL III lining materials.

5.5 Operating experience has shown that the most severe operating conditions with respect to heat exchanger linings occur on pass partitions. A phenomenon known as the "cold wall effect" accelerates moisture permeation through a coating applied to the warmer side of a partition that separates fluids at two different temperatures. The thickness and permeability of the lining are key variables affecting the ability of a lining to withstand cold wall blistering.

5.5.1 This effect is particularly pronounced when the separated fluids are water, though the effect will occur when only air is on the other side, for example, an outdoor tank filled with warm liquid. A heat exchanger pass partition represents geometry uniquely vulnerable to the water-to-water maximized temperature differentials (ΔT s) that drive the cold wall effect.

5.5.2 Pass partitions separate relatively cold incoming cooling water from the discharge water warmed by the heat exchanger's thermal duty. Improperly designed coatings will

exhibit moisture permeation to the substrate accelerated by the cold-wall effect. Many instances of premature pass partition warm-side blistering have been noted in the nuclear industry. Such degradation has also been seen on lined cover plate and channel barrel segments that reflect water-to-air configurations.

5.6 Large water-to-water ΔT s are known to be the most severe design condition. The test device used to replicate ΔT configurations is known as an "Atlas cell." Atlas cell testing is governed by industry standard test methodologies (Test Method [C868](#) and NACE TM0174). A lining proven suitable for the most severe hypothesized ΔT would also be suitable for service on other waterside surfaces.

5.7 Plant cooling water varies in composition and temperature seasonally. For purposes of standardization, demineralized water is used in Atlas cell exposures rather than raw plant water. It is generally accepted in polymeric coatings technology that low-conductivity water (deionized or demineralized) is more aggressive with respect to its ability to permeate linings than raw water. Thus, stipulating use of low-conductivity water as the test medium is considered conservative.

6. Reagents

6.1 Unless otherwise indicated in the project-specific test instructions or under a particular test method described hereinafter:

6.1.1 Reagent water used in conjunction with permeability tests and Atlas cell exposures should have a maximum conductivity of $1.0\mu\text{ S/cm}$.

7. Procedure

7.1 The user of this guide is expected to invoke only those tests that are applicable. Refer to [Table 1](#). A test specification should be developed to indicate the particular tests to be used. The test specification should include details on the lining systems to be evaluated.

7.2 For plant-specific applications, design and operating parameters will need to be reviewed. On the basis of that review, the site-specific design objectives for testing can be defined. Test parameters based on water temperatures and ΔT s more severe than the plant-specific normal and upset conditions might also be allowed. The test specimen should replicate the anticipated plant-specific substrate condition to the extent practicable (for example, new, corroded, etc.).

7.3 *Steel Test Specimens*—Duplicate test specimens should be provided fabricated from hot-rolled mild carbon steel conforming to Specification [A36/A36M](#). Thickness and other dimensions are stipulated for each specific test referenced herein.

7.4 *Product Information and Characterization*—Each batch of each component of the lining materials to be used for testing described herein should be identified and "fingerprinted" by means of the data and testing described in Section 3.2 of NACE TM0404, which includes Fourier transform infrared (FTIR) analysis. FTIR testing should be per method #4A of NACE TM0404, that is, the attenuated total reflection method for pigmented samples. Testing should be performed by a laboratory approved by the organization for which the testing is

TABLE 1 Matrix of Testing Requirements

Description	Phase 1 Tests										Phase 2 Tests					
	FTIR ^A	Permeability E96/ E96M, Procedure BW ^B	Atlas Cell Air-to- Water C868 ^B	Atlas Cell Water-to- Water C868 ^B	AC Imped- ance Air-to- Water	AC Impedance Water-to- Water	TOC EPA 415.1	Re- verse Impact D2794 ^B	Flex NACE RP 0394 ^B	Adhesion D4541 ^B or D6677	Hardness D2583 or D2240 ^C	Cathodic Disbond- ment G42 ^D	Dielectric Strength D115 ^D	Radiation Resis- tance D4082 ^D	Direct Impact G14 ^D	Abrasion Resistance D4060 ^D
Liquid- Grade		X 20 mils									X	X			X	
Paste- Grade		X 20 mils									X	X			X	
Thinner Film Sys- tem ≤25 mils	X		X	X	X		X	X					X	X		
Thicker Film Sys- tem >25 mils	X		X	X	X		X	X					X	X		
Each Test Cell Solu- tion																X

^A FTIR – Fourier Transform Infrared (spectroscopy).

^B As modified in accordance with Section 8.

^C Perform on all water-exposed faces.

^D As modified in accordance with Section 9.

being conducted. Fingerprinting results should be traceable to the respective batch number of each tested component.

8. Phase 1 Tests

8.1 *Permeability*—The permeability of the polymeric lining materials should be determined in accordance with Test Method E96/E96M, Procedure BW, modified as follows:

8.1.1 Liquid-grade and paste-grade polymeric lining materials should be tested separately.

8.1.2 The thickness for each type of material should be the intended thickness as defined by the lining manufacturer or the project specifications. Suggested film thicknesses are presented in Table 1. Since test results are reported per unit of thickness, actual test thickness is not considered critical.

8.2 *Immersion Environment Testing*—Test specimens of the lining material should be conditioned in an Atlas cell immersion environment to evaluate the lining material when exposed to immersion service at a stipulated temperature. Both water-to-air and water-to-water heat transfer configurations should be replicated in the test. The evaluation should include visual examination, flex testing, reverse impact testing, adhesion testing and hardness assessment. Test specimen exposure should be performed in accordance with Test Method C868, modified as follows:

8.2.1 At the discretion of the organization responsible for the test program, immersion test panels may be pre-irradiated in accordance with 9.3.

8.2.2 The Atlas cell test duration should be 180 days with interruption at 30-day intervals for examination of the test panels. Exposure should be terminated prior to 180 days if the lining has degraded to the extent that it is no longer viable for the testing described below.

8.2.3 Test panels should be 8 in. (20 cm) square by 1/8-in. (3-mm) thick carbon steel plates. Each panel should be uniquely identified for traceability throughout testing and examination. Panel identification should indicate the following:

8.2.3.1 The top (vapor phase) and bottom (liquid phase) halves of the panel should be differentiated by marking.

8.2.3.2 For those panels exposed to water on both sides, the side exposed to the cooler and warmer water should be differentiated by marking.

8.2.4 Typical Atlas cell configurations are presented in Fig. 1 and Fig. 2. Each Atlas cell should be fitted with the necessary probes and electrodes to evaluate the performance of the lining materials using alternating current (AC) impedance techniques. The Atlas cells shown schematically in Fig. 1 and Fig. 2 involve a single test panel. Combined configurations that accommodate multiple panels may be used. An Atlas cell diameter of at least 5 in. (13 cm) should be used.

8.2.5 When applicable to the intended service condition, the test solution should be constantly agitated with air bubbling as described in Test Method C868.

8.2.6 Test panels of both thinner (for example, ≤ 25 mils (0.6 mm)) and thicker (for example, > 25 mils (0.6 mm)) lining systems should be tested. The thinner lining system includes one or more coats of liquid-grade materials. The thicker lining system may also include paste-grade materials. Surface prepa-

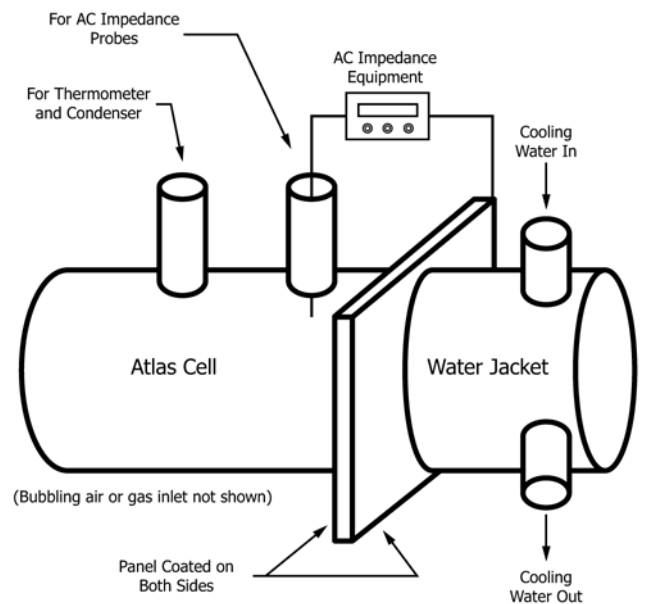


FIG. 1 Atlas Cell—Water to Water

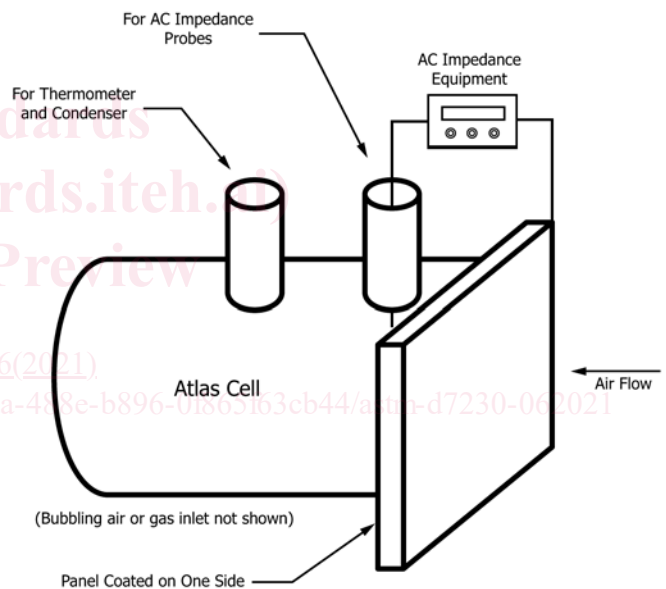


FIG. 2 Atlas Cell—Air to Water

ration and application of lining materials should be in accordance with the lining manufacturer's instructions and the requirements of the test specification. Panel preparation and lining material application should be fully documented in accordance with Specification D5139.

8.2.6.1 For water-to-air testing, the applied lining should be on one side only (the side ultimately exposed to the cell environment). The other side of the panel should be unlined in accordance with Test Method C868.

8.2.6.2 For water-to-water testing, both sides of the panel should be coated with the same system and thickness or as stipulated by the test specification. Different thicknesses on the test plate may influence lining performance in a cell exposure.

8.2.7 Before installation onto the Atlas cell, each panel should be photographed.