



# Standard Practice for Evaluating Biofouling Resistance and Physical Performance of Marine Coating Systems<sup>1</sup>

This standard is issued under the fixed designation D6990; 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 ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

## 1. Scope

1.1 This practice establishes a practice for evaluating degree of biofouling settlement on and physical performance of marine coating systems when panels coated with such coating systems are subjected to immersion conditions in a marine environment. Guidance for preparation or exposure and handling of test specimens can be found in related ASTM standards as noted below (see Section 2).

1.2 This practice and related exposure methodologies are designed as tools for the relative assessment of coating performance, and in no way are to be used as an absolute indicator of long-term performance under all conditions and in all environments. There can be high variability among and within exposure sites with respect to water quality and population or species of fouling organisms, and coating performance may vary with these and other properties.

1.3 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.4 *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.* A specific hazard statement is given in Section 6.

## 2. Referenced Documents

### 2.1 ASTM Standards:<sup>2</sup>

Recommended ASTM Methods and Practices for evaluation of antifouling coatings via panel exposure under a variety of exposure conditions:

- D3623 Test Method for Testing Antifouling Panels in Shallow Submergence
- D4938 Test Method for Erosion Testing of Antifouling Paints Using High Velocity Water
- D4939 Test Method for Subjecting Marine Antifouling Coating to Biofouling and Fluid Shear Forces in Natural Seawater
- D5479 Practice for Testing Biofouling Resistance of Marine Coatings Partially Immersed
- D5618 Test Method for Measurement of Barnacle Adhesion Strength in Shear
- G141 Guide for Addressing Variability in Exposure Testing of Nonmetallic Materials

## 3. Terminology

### 3.1 Definitions of Terms Specific to This Standard:

3.1.1 *biofilm*, *n*—matrix-enclosed populations of microorganisms adherent to each other or to surfaces, or both, or interfaces.

3.1.2 *biofouling adhesion*, *n*—qualitative or quantitative force required for the successful and complete removal of marine fouling attached to the antifouling coating surface (for example, reference Test Method D5618 for barnacles).

3.1.3 *corrosion eruptions*, *n*—build up of oxides, exiting through protective paint film.

3.1.4 *damage*, *n*—limited destruction of portions of paint film due to impact with a foreign article.

3.1.5 *digging*, *n*—a term used to describe hard fouling macroorganisms that are growing “into” the coating. That is, where its calcareous shell penetrates/breaks through the coating surface causing physical damage to the coating.

3.1.6 *macroorganism*, *n*—organisms large enough to be seen with the naked eye and thus would be noted when growing on submerged surfaces.

3.1.7 *microorganism*, *n*—organisms too small to be seen with the naked eye, which generally include bacteria, protozoa, fungi and microalgae (sometimes collectively called “slime”).

3.1.8 *peeling*, *n*—the phenomenon manifested in paint films where a portion of a film, when pulled, can be removed in strips or relatively large intact pieces, or both.

<sup>1</sup> This practice is under the jurisdiction of ASTM Committee D01 on Paint and Related Coatings, Materials, and Applications and is the direct responsibility of Subcommittee D01.45 on Marine Coatings.

Current edition approved June 1, 2011. Published June 2011. Originally approved in 2003. Last previous edition approved in 2005 as D6990–05. DOI: 10.1520/D6990-05R11.

<sup>2</sup> 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.

3.1.9 *silt, n*—sedimentary material consisting especially of mineral particles intermediate in size between those of sand and clay.

3.1.10 *softness, adv*—the phenomenon manifested by paints in transferring some of its pigmentation to a foreign item or substance, upon encountering friction on its surface.

3.1.11 *wearing, n*—gradual loss of the paint film caused by use or exposure to the environment.

#### 4. Summary of Practice

4.1 Test specimens or panels are coated with marine coating systems and exposed to marine immersion conditions for a specified amount of time and under specific sets of conditions as agreed upon by the producer and user. See 2.1 for published ASTM standard methods and practices that provide guidance for exposure of coating systems.

4.2 Coating systems are evaluated in terms of fouling rating (percent of coverage of the coating system by biofouling organisms), and physical deterioration rating (percent area of the coating system affected by physical coating failure(s)). These data are useful in assessing and comparing effectiveness of antifouling coating systems.

#### 5. Significance and Use

5.1 This practice is designed to provide guidance to a panel inspector for quantitative and consistent evaluation of coating performance from test panels coated with marine antifouling coating systems. The practice assesses performance of coating systems based on both antifouling and physical properties.

5.2 The user is cautioned that the results are representative for the specific region and time of year in which the specimens are immersed. It shall be noted that interpretation of results will depend on the geographical location where the test is conducted, whether the coated specimens are exposed either totally or partially immersed, under static or dynamic conditions, and position and orientation.

5.3 Simultaneous testing of a proven standard antifouling coating system (known to minimize fouling accumulation, for example, containing biocide or active agent(s) to prevent fouling settlement/growth) in the specific marine environment shall be included as a reference to assist in interpretation of results. In addition, a negative control (inert surface susceptible to heavy fouling) shall be included on a regular basis. For the exposure to be valid, the surface of the negative control should show heavy fouling relative to the standard system(s).

5.4 Marine coating systems that produce positive results relevant to the standard system(s) show potential for use in protecting underwater marine structures.

5.5 The format can be utilized independent of exposure protocol and coating type, and provides the end user with a consistent practice and format for reporting of performance rating.

#### 6. Safety Precautions

6.1 **Warning**—Certain marine coating systems contain toxic materials (biocides) that may cause skin and eye irritation

on contact as well as adverse physiological effects if ingested or inhaled. In the preparation, application, and general handling of panels coated with various types of marine paints, the use of appropriate protective clothing and equipment is required consistent with local, state, federal government regulations and recognized industrial and technical standards.

#### 7. Procedure—Evaluation of Fouling Present on Test Surface

7.1 Controls should be exposed and assessed at the same time as the test materials. More information about the use of control materials in weathering tests can be found in Guide G141. (See also 5.3.)

7.2 Retrieve test panels and any negative controls and reference coatings from immersion site. Note and record the visual percentage coverage by biofilm or silt, or both, or lack thereof in accordance with the guidelines provided below.

7.3 Prior to inspection, it is recommended that panels be rinsed (see below and 7.3.2 for more information) in order to remove silt (may interfere with observation of attached forms) and unattached forms. Alternatives to rinsing such as either gentle agitation of the panels or not rinsing the panels at all may be done but must be specified in the final reports. Whichever preparation is chosen, it must be documented and performed on all panels equally and at each inspection. If rinsed, the test panel surface is to be wetted using low-pressure water. For example, use household water pressures from garden hose sized-nozzles measuring 9.5 to 13 mm ( $\frac{3}{8}$  to  $\frac{1}{2}$  in.) in the form of a gentle shower spray or non-forceful flow to allow for a reliable inspection of what is attached to the coating/panel. Nozzles that cause water to be forcefully applied to the panel shall not be used. **Warning**—Risk in rinsing panels is that subsequent biofouling attachment may be affected. Alternatively, panels may be gently agitated in water to remove loose/unattached bacterial biofilm or silt deposits, or both. **Warning**—Risk in not rinsing panels is that silt or slime, or both, may interfere with assessment of biofouling attachment on complete panel surface.

7.3.1 Test panels shall not be allowed to dry during the entire inspection period. A holding tank is useful for accomplishing this.

7.3.2 Rinse water and holding tank water, shall be taken from the immersion site.

7.3.3 Efforts shall be made to minimize the length of time panels remain removed from the normal immersion site, and to not touch the coated surfaces.

7.4 Populations and types of organisms will vary by test site. Some examples of biofouling microorganisms include barnacles, oysters, mussels, bryozoans (arborescent and encrusting), hydroids, tubeworms, tunicates, sponges, and various types of algae. Each type of fouling organism directly attached to the test surface shall be reported by (1) the estimated percentage of the panel area covered by all of the same type of biofouling (for example, colonial forms), (2) the frequency (number of individuals for the larger and solitary organisms; for example, barnacles, mussels, oysters, tube worms, and some tunicates), and (3) the range of size for the

individual organisms (for larger, solitary organisms). See [Appendix X1](#) for guidance on estimating percent cover and [Fig. X2.1](#) for a suggested sample antifouling inspection report form.

7.4.1 Make a note of any fouling organisms found to be growing into the paint film, also referred to as “digging.”

7.4.2 Note that percentage cover of algae and arborescent bryozoans shall be based on the area covered by the “hold fast” and not the area covered by the “strands” or colony. The type of algae (for example, brown, red, green) shall also be recorded if known.

7.4.3 Only attachment of primary biofouling settlement (that is, biofouling attached directly to the coating system) shall be recorded. Notes on secondary fouling (biofouling attached to other fouling organisms) can be made if desired, but shall not factor into the generation of a “fouling rating.”

7.4.4 Percent cover by mud tube-building amphipods shall be reported as a footnote in [Fig. X2.1](#), but shall NOT factor into the generation of a “fouling rating.”

7.4.5 *Partial Immersion Test Panels Only*—Panels exposed in accordance with Practice [D5479](#) are partially immersed. The non-immersed area will be subject to splash and may show some fouling attachment, but the area is not included in the determination of a fouling rating. Therefore, the fouling rating is calculated based on the fully immersed surface area, counting the immersed surface area as 100 %.

7.4.6 In addition, antifouling performance of coating systems is often different in the immediate waterline vicinity. Therefore, an estimate of coverage along the first 50 mm (2 in.) of the test panel shall also be made and can then be contrasted with the overall coverage. Fouling occurring in the “above the waterline” area, if any, is not considered when generating a “fouling rating.”

7.5 Discount biofouling attachment within 13 mm ( $\frac{1}{2}$  in.) from all edges of the test panel.

## 8. Procedure—Evaluation of Physical Deterioration/Performance of Test Surface

8.1 Prior to the original exposure, inspect all test panels for possible physical deterioration. Record findings. Continue observation of predetermined damage during future inspections. See [Fig. X2.2](#) for a suggested sample physical performance inspection report form.

8.2 Evaluate individual physical performance failure, qualitatively and quantitatively, for each test specimen. Observations of erosion, wearing, blistering, alligatoring, checking, cracking, chipping, peeling, flaking, and damage shall be made. For additional information and guidance for evaluating any of the previous physical deteriorations, refer to Sections [2](#) and [3](#). Record the percent surface area affected by each physical parameter.

8.2.1 Observations of physical deterioration shall be performed for each coat visible to the inspector (for example, topcoat, intermediate, primer). The percent surface area affected by each physical parameter shall be estimated based on the visible area of each coat.

8.3 Discount any physical failures within 13 mm ( $\frac{1}{2}$  in.) from all edges of the test panel.

8.4 Observations of physical deterioration cannot be performed on panel surface areas covered by hard fouling. At the time of inspection do not count this area in the generation of the physical deterioration rating (PDR); see also [11.2](#). At the end of the panel test period, a final evaluation of physical deterioration rating can be performed after removal of hard fouling in order to determine whether physical deterioration has occurred under areas that had been covered by hard fouling.

## 9. Procedure—Evaluation of “Softness” of Marine Coating System

9.1 Evaluation of “softness” is intended for marine coating systems (excluding silicone coating systems), and is an indicator of a coating’s pigment erosion characteristics. It is measured on a subjective scale of 10 to 0 (see [9.2.1](#)), dependent on the amount of pigment transferred from the coating to a cotton swab.

9.2 After rinsing the test panels (see [7.2](#)), rub a wet cotton swab, exactly 10 strokes in a back and forth motion, over the wet test surface. The cotton swab is held at one of its ends with the thumb and index finger. The cotton swab is positioned at  $45^\circ$  to the coating surface and sufficient pressure is applied so that the cotton swab stem just starts to bend. The strokes shall be made continuously in a back and forth motion, in the same linear pattern, approximately 50 mm (2 in.) in length. Use of proper protective equipment, such as gloves, is recommended.

9.2.1 Softness shall be evaluated on the following subjective scale, where:

- 10 = no pigment transferred to a cotton swab,
- 8 = trace amount of pigment transferred to a cotton swab,
- 6 = slight amount of pigment transferred to a cotton swab,
- 4 = moderate amount of pigment transferred to a cotton swab,
- 2 = severe amount of pigment transferred to a cotton swab, and
- 0 = complete removal of pigment transferred to a cotton swab.

9.3 Softness measurements can be performed anywhere 13 mm ( $\frac{1}{2}$  in.) or more away from all edges of the test panel. In the case of partially immersed panels, avoid taking measurements in the area affected by partial immersion.

9.4 When a large change in “softness” is observed in any subsequent inspection cycle, the inspector will take a second or even third softness grading at a different location of the test panel to ascertain a true, consistent, or, possibly, averaged value.

9.5 The appropriate layer of paint film (that is, topcoat, intermediate coat, or primer coat) on which softness testing was performed shall be recorded and noted in the report.

## 10. Interferences

10.1 The presence of “loose” detritus or bacterial slimes, or both, which include microorganism attachment and silt settlement, shall be reported based on the estimated percentage of the panel area covered excluding: (a) percentage of panel

area covered by macrofouling, and (b) percentage of panel area where the antifouling film is no longer present due to previous physical failure.

10.1.1 “Loose forms” of fouling settlement shall be reported using only the more predominant of the two, silt or bacterial, present on the surface. In addition, the severity or accumulation on top of the surface shall be designated as light, medium, or heavy.

10.1.2 In practice, it is impossible to ascertain total silt or bacterial slime coverage until this “loose” film has been rinsed off, exposing the existing paint surface or low height macrofouling forms, or both, which may have been obscured by the “loose forms.”

10.2 When evaluating the type and percentage coverage of microfouling organisms, be sure to distinguish between the fouling adherent to the surface and the unattached fouling. Neither fouling attached to other fouling, nor unattached fouling shall be included in the fouling rating.

## 11. Calculations

11.1 Grading for antifouling performance of the marine coating system—generation of a fouling rating (FR). The range of FRs is from 0 to 100.

11.1.1 The fouling rating for a coating system free of adherent biofouling settlement shall be recorded as 100.

11.1.2 The fouling rating for a paint film free of macrofouling settlement but partially or totally covered by microfouling growth (adherent slime) shall be recorded as 99, irrespective of the percent area covered by the “adherent slime.”

11.1.3 Upon settlement of macrofouling forms, the total sum of percentage of area covered by macrofouling shall be deducted from 100. The fouling rating, then, essentially reflects non-fouled area.

11.2 Grading of physical performance of the marine coating system—generation of a physical deterioration rating (PDR). The range of PDRs is 0 to 100.

11.2.1 The physical deterioration rating for a coating system free of physical deterioration shall be recorded as 100.

11.2.2 Separate physical deterioration ratings are applied to each layer of intact coating.

11.2.3 Upon determining physical deterioration(s), the sum of all reported percentages of deterioration will be deducted from 100, and the result will reflect the physical deterioration rating of the remaining intact film for each coat.

11.2.4 Topcoat, intermediate, and primer of the marine coating system shall be graded independently from one another. The lowest rating shall be taken as the PDR for the paint system.

11.3 To calculate the percentage coverage by “loose forms,” note what percentage of the panel area is free of bacteria or silt. Upon rinsing the surface, the sums of percentages covered by macrofouling, plus percentages of missing paint film plus area free of “loose forms” coverage, deducted from 100 will provide the amount covered by bacteria or silt, or both.

## 12. Inspection Report

12.1 **Appendix X2** provides sample comprehensive inspection reports. Required general information includes:

12.1.1 Testing Facility name, address, phone number, body of water in which panels were immersed,

12.1.2 Name of customer for whom test is being conducted,

12.1.3 Size and shape of test substrate,

12.1.4 Material out of which substrate was made,

12.1.5 Type of exposure (reference associated ASTM method numbers as appropriate). Include orientation of panel, and depth of exposure,

12.1.6 Initial date of immersion and total number of months of exposure at time of latest inspection cycle,

12.1.7 Identification of panel series,

12.1.8 Individual panel identification,

12.1.8.1 In the event that a specific test panel is to have more than a single surface inspected, the descriptive location (for example, front, back) shall be shown immediately following the identification of the specific test panel.

12.1.9 Date of inspection,

12.1.10 Inspector’s name or initials,

12.1.11 Original color of marine coating on panel (prior to test exposure) and color at time of each inspection, and

12.1.12 Brief description of handling procedures from **7.3** (panel rinsing).

12.2 Required information concerning coating performance includes:

12.2.1 *Antifouling Performance Ratings* (refer to **Fig. X2.1**):

12.2.1.1 Report fouling rating and biofilm/silt fouling as described in Sections **7 – 11**, including percent cover information for each type of macroorganism and algae.

12.2.1.2 The inspector shall report percent cover of all macroorganisms occurring at the test site, and shall not limit their reporting to those listed in the sample report provided in **Fig. X2.1**. All organisms from a particular genus may be reported together. For example, percent cover by barnacles may include more than one species of barnacle.

12.2.2 *Physical Deterioration Ratings* (refer to **Fig. X2.2**):

12.2.2.1 Report physical deterioration ratings as described in Sections **8 – 11** for each layer of exposed paint.

12.2.3 *Softness of the Marine Coating* (refer to **Fig. X2.2**):

12.2.3.1 Report softness rating as described in Sections **9 – 11** for each layer of exposed paint.

12.3 *Optional Information in Report*:

12.3.1 Additional information may be included in the report dependent upon the needs of the producer and user. Optional variables could include, but are not limited to:

12.3.1.1 Color photos of each panel at each inspection are strongly recommended. Additional recommendation includes labeling each panel with, at a minimum, the test site, coating name/code name, date of exposure, and date of inspection.

12.3.1.2 Recommendations for frequency of panel inspection or photographs, or both.

12.3.1.3 Range of water temperature, salinity and pH at the test site (reporting period to be determined between evaluator and producer).

12.3.1.4 A record of average occurrence of fouling at the test site on a monthly basis over one year.

12.3.1.5 Orientation of rack/panel(s) to sun and tide.

12.3.1.6 Comments on color change.

12.4 *Additional Guidance:*

12.4.1 Providing cumulative performance data reports on a quarterly basis is suggested.

12.4.2 It is desirable to devise a reporting format where, for a given panel, cumulative periodic inspections can be viewed simultaneously and in chronological order.

**13. Keywords**

13.1 antifouling coating; antifouling performance; biofouling; coating physical performance; fouling rate; physical performance; evaluation; film physical performance

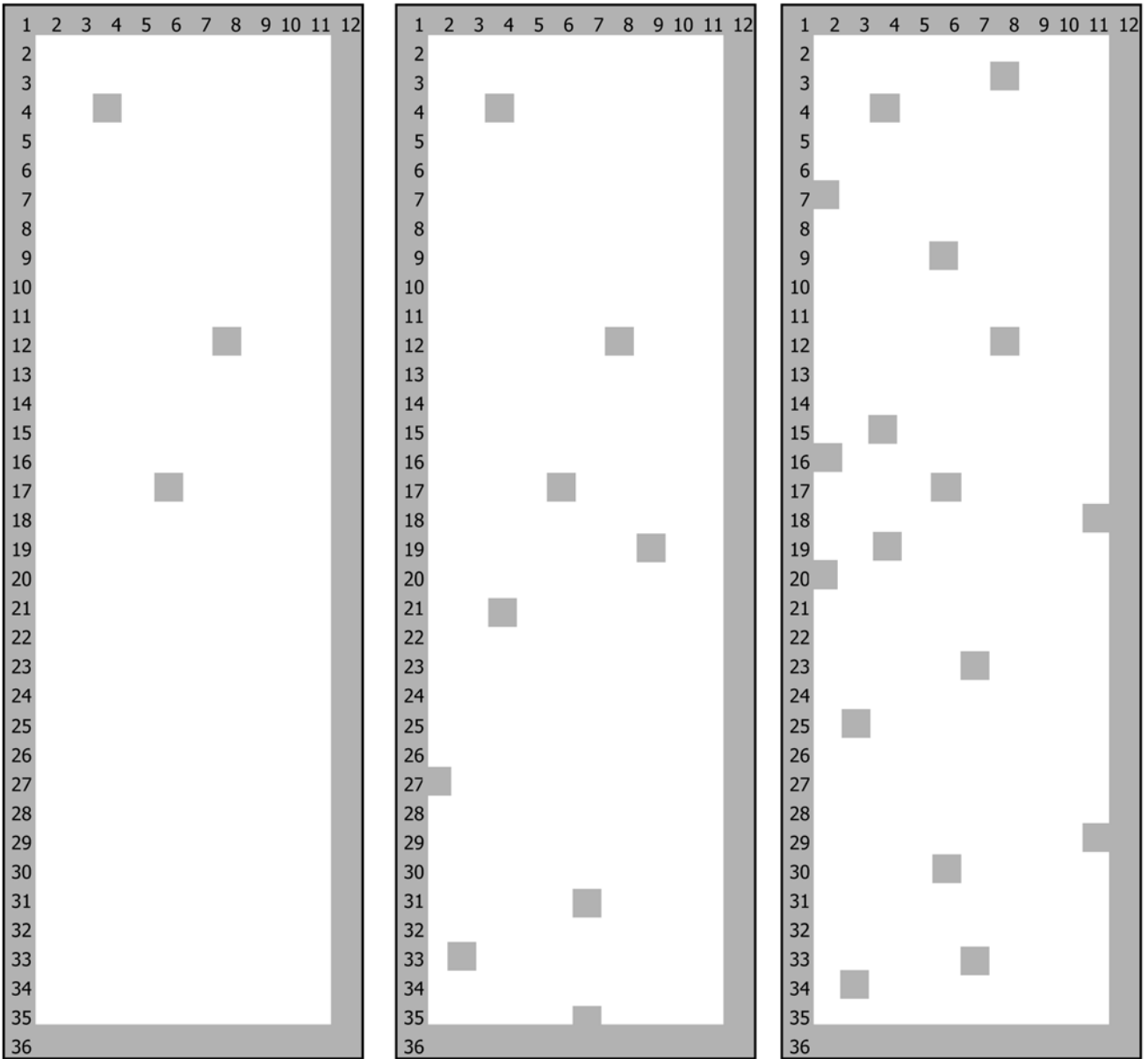
**APPENDIXES**

**(Nonmandatory Information)**

**X1. EXTENT DIAGRAMS**

X1.1 Each 12 by 36 segment represents a test specimen or panel coated with an antifouling coating system and immersed in a marine environment. The percentage listed below each

diagram indicates the total area covered by the shaded area. The shaded area is representative of biofouling coverage.

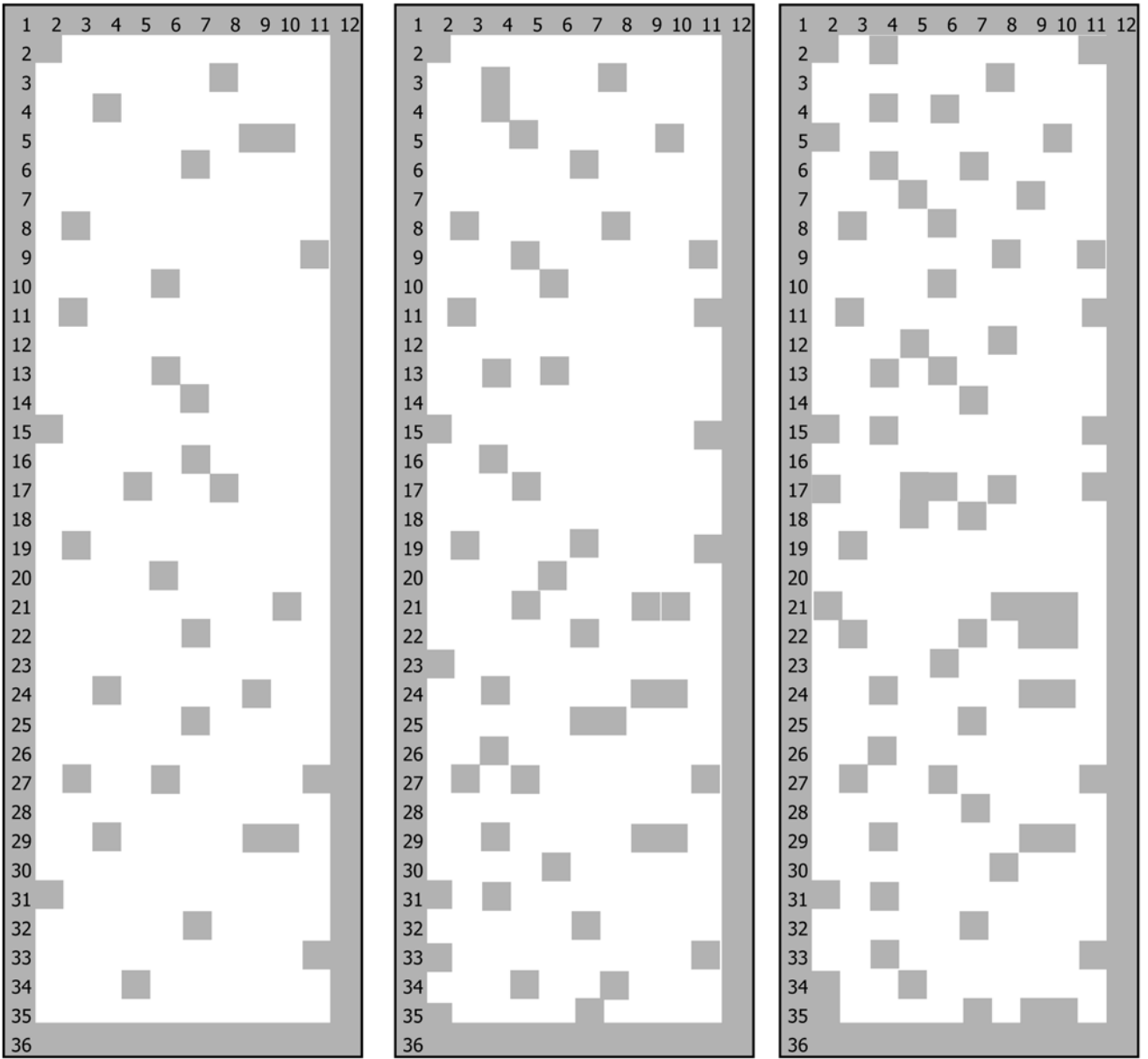


1%

3%

5%

FIG. X1.1 Biofouling Coverage 1 %, 3 %, and 5 %

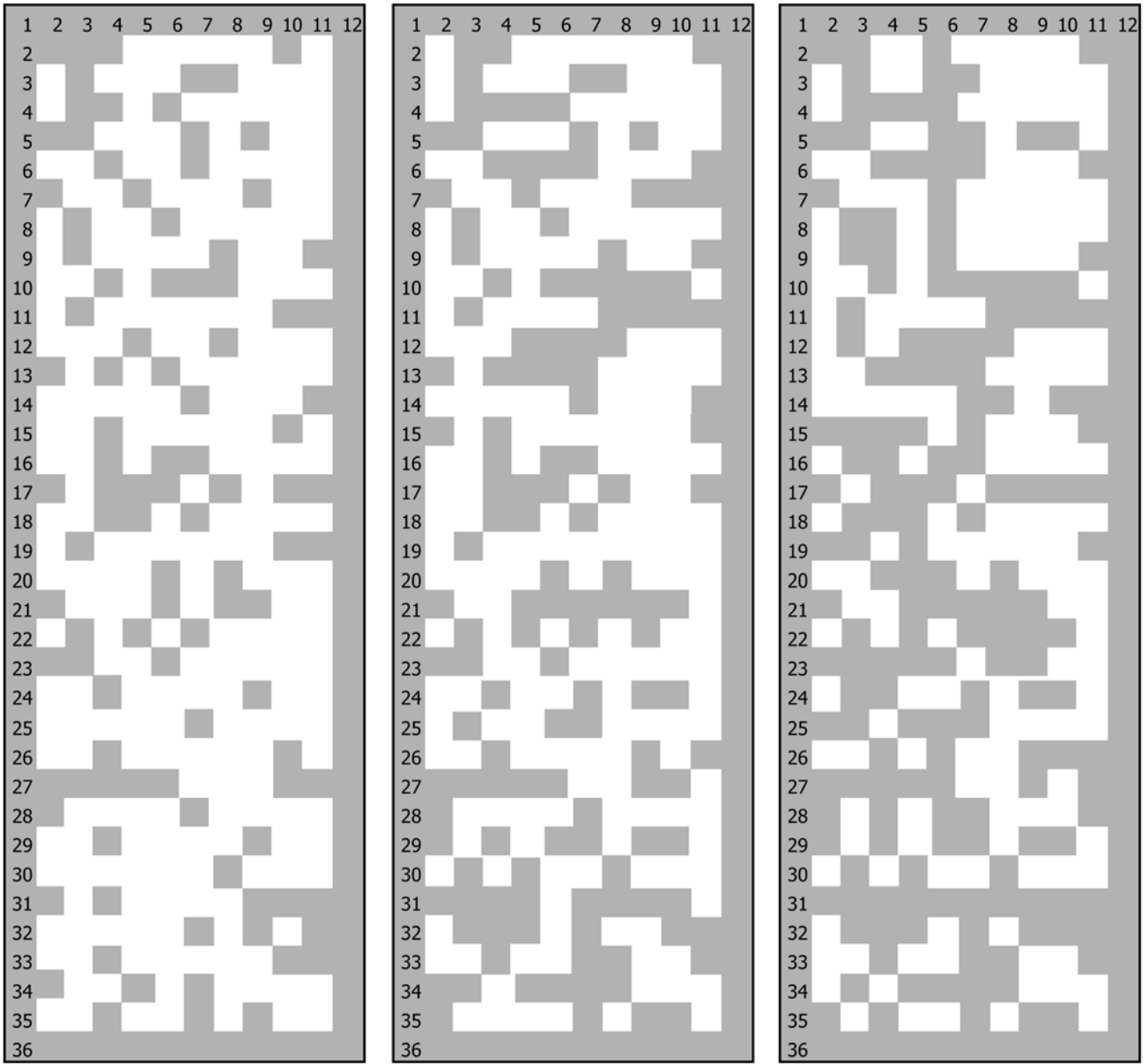


10%

15%

20%

FIG. X1.2 Biofouling Coverage 10 %, 15 %, and 20 %



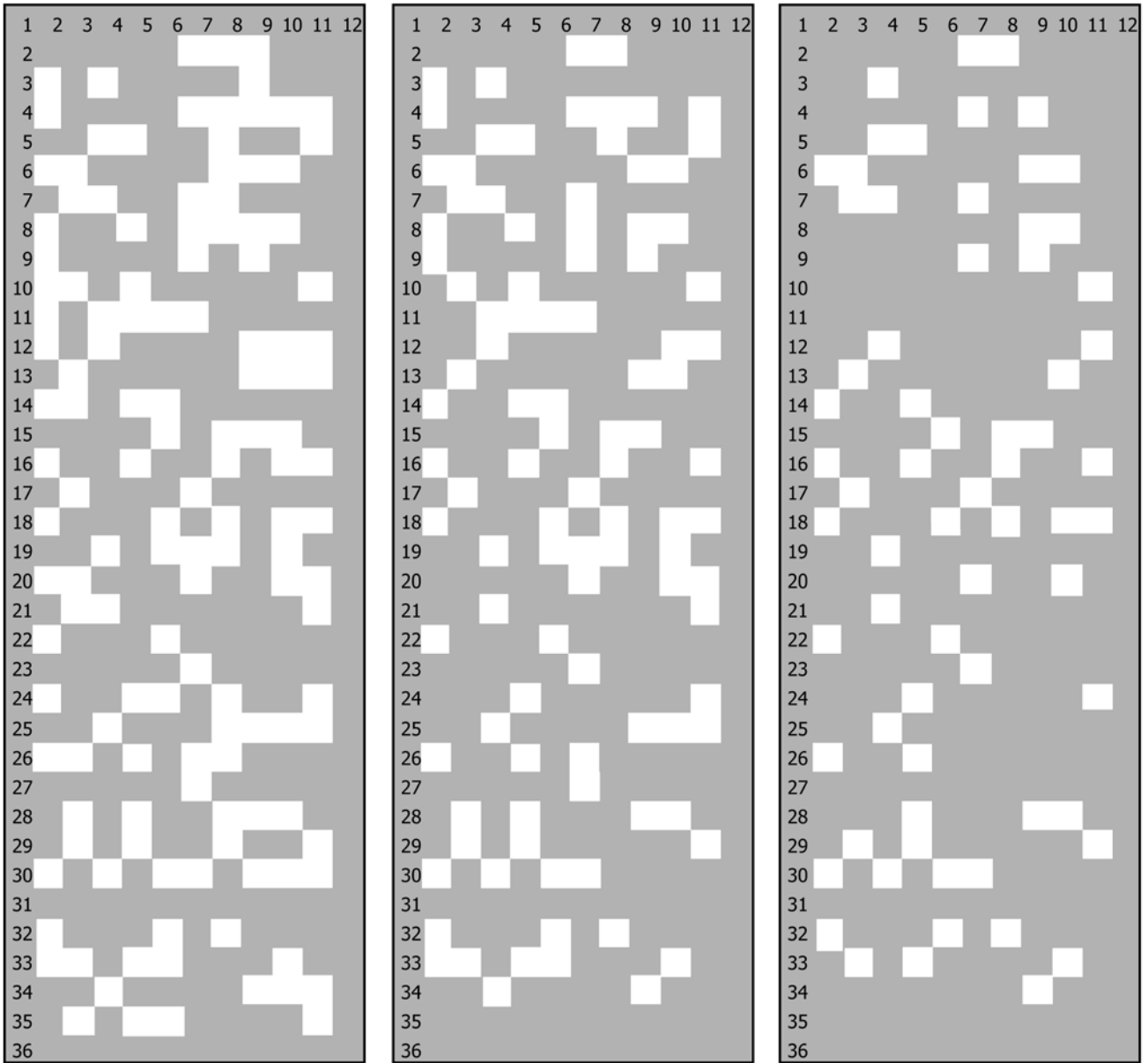
30%

40%

50%

FIG. X1.3 Biofouling Coverage 30 %, 40 %, and 50 %





60%

70%

80%

FIG. X1.4 Biofouling Coverage 60 %, 70 %, and 80 %

**X2. REPORT FORMS**





**NAME OF MARINE EXPOSURE TESTING FACILITY**  
ADDRESS INFORMATION, PHONE, AND OTHER CONTACTS

**TEST CONDUCTED FOR "NAME OF COATING PRODUCER, CLIENT" IN BODY OF WATER, LOCATION, STATE**

Series ID: (Series Number)  
Substrate: (e.g., Fiberglass or Metal)  
Panel Size and Shape: (e.g., length x width mm, Flat, Rectangular)  
Type of Exposure: (e.g., ASTM method # or brief description)

Date of Initial Exposure: (mm/dd/yy)  
Date of Inspection: (mm/dd/yy)  
Total Exposure Time to Date: (## of Months)  
Inspector: (name(s))

**ESTIMATE OF FILM PHYSICAL PERFORMANCE**

PANEL ID	Original Panel Color	Present Panel Color	DAMAGE		Wearing % Cover	Blistering % Cover	Corrosion % Cover	Peeling % Cover	Chipping % Cover	Flaking % Cover	Checking % Cover	Cracking % Cover	Alligating % Cover	Softness Rating (10-0)	PHYSICAL DETERIORATION RATING (PDR)		
			Type	% Cover											Top Coat A.F.	Inter-coat Tie	Primer A.C.

Legend      **Physical Deterioration Rating (PDR):** 100 = 0 % fouling; 99 = 1 % fouling; 90 = 10 % failure; ... 10 = 90 % fouling; 0 = 100 % fouling.  
**Softness Rating:** 10 = No pigment transfer; 8 = Trace amount; 6 = Slight amount; 4 = Moderate amount; 2 = Severe amount; 0 = Complete Removal of pigment.

- Notes**
- 1) At time of inspection all panels are rinsed and kept wet with water from test site.
  - 2) Panel edges (13 mm) and mounting holes are not considered in the film physical ratings.
  - 3) A unique damage to or performance of panel(s) may be noted here.
  - 4) Each physical performance rating applies to the antifouling (A.F.), tie, and anticorrosive (A.C.) coats.

**FIG. X2.2 Estimate of Film Physical Performance**

### X3. COATING PERFORMANCE INSPECTION PROTOCOLS

X3.1 Portions of the currently published Test Method **D3623** provide guidance for rating coating system performance during antifouling coating panel testing. The panel inspection protocol has been lifted from Test Method **D3623**, modified, and is now published as a separate method – Practice D6990. In the near future, the ASTM Marine Coatings subcommittee

will ballot changes to Test Method **D3623** (removing the inspection protocol). Changes will also be made to Test Methods **D4938**, **D4939**, **D5618**, and Practice **D5479**. Essentially, these methods will now refer to Practice D6990 for coating performance inspection protocols (panel testing).

### X4. ASTM STANDARDS FOR REFERENCE ONLY

X4.1 The following ASTM standards may provide the reader with useful information on evaluating physical performance of marine coating systems. The method references are provided only for the convenience of the reader. The reader is not required to specifically apply these methods to the ratings and reporting assigned under this method, but is encouraged to utilize the descriptions, definitions, and pictures provided in the methods to assist in understanding coating physical performance.

D16 Terminology for Paint, Related Coatings, Materials, and Applications

D660 Test Method for Evaluating Degree of Checking of Exterior Paints

D661 Test Method for Evaluating Degree of Cracking of Exterior Paints

D662 Test Method for Evaluating Degree of Erosion of Exterior Paints

D714 Test Method for Evaluating Degree of Flaking (Scaling) of Exterior Paints

D4538 Terminology Relating to Protective Coating and Lining Work for Power Generation Facilities

*ASTM International takes no position respecting the validity of any patent rights asserted in connection with any item mentioned in this standard. Users of this standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, are entirely their own responsibility.*

*This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, at the address shown below.*

*This standard is copyrighted by ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959, United States. Individual reprints (single or multiple copies) of this standard may be obtained by contacting ASTM at the above address or at 610-832-9585 (phone), 610-832-9555 (fax), or service@astm.org (e-mail); or through the ASTM website (www.astm.org). Permission rights to photocopy the standard may also be secured from the Copyright Clearance Center, 222 Rosewood Drive, Danvers, MA 01923, Tel: (978) 646-2600; <http://www.copyright.com/>*