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REQUIREMENTS FOR COATINGS OF NUCLEAR POWER PLANT CONTAINMENTS

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Abstract

During an accident in a nuclear power plant, conditions in the reactor containment will be characterized by elevated temperature and pressure, as well as the presence of radiation environment. Water spray, with or without chemical additives, may be used in the primary containment to suppress the consequences of the incident, to scavenge radioactive products, and to return the containment to near-ambient conditions. It is important, that the coatings used will not have an unfavourable effect on accident management. Furthermore, it shall be demonstrated that coatings will not come off to an extent which would block flow paths and endanger core cool ability or removal of residual heat. It must also be proved, that under accident conditions chemical changes, if any, in coating material do not create new risk factors.

This publication presents the detailed requirements for coatings inside the containment. The requirements are given for the following issues specified in Guides YVL 4.1 and YVL 4.2:

- radiation resistance
- ease of decontamination (decontaminability)
- chemical resistance
- durability under operating conditions
- durability under postulated accident conditions
- fire technical properties.

The requirements are based on the standards referred and on the Nordic TBY-criteria.

Only coatings which have passed tests demonstrating the meeting of these requirements can be used on concrete and steel structures inside the containment. Results from the Nordic project TBY-Technical Regulations for Surface Treatment can be utilized for approval of coatings.

This publication will be applied for both new work and maintenance.

HÄKKÄ-RÖNNHOLM Eva. Requirements for coatings of nuclear power plant containments. STUK-YTO-TR 210. Helsinki 2004. 24 s.

Avainsanat: ydinvoimalaitos, suojarakennus, onnettomuus, onnettomuustilanne, pinnoite, laadunvalvonta, testaus

Tiivistelmä

Onnettomuustilanteissa kohdistuu suojarakennuksen sisäpuolisten rakenteiden pinnoitteisiin kuormituksia, jotka poikkeavat olennaisesti normaalisti käytön aikana esiintyvistä kuormituksista. Pinnoitteiden tulee olla sellaisia, että niistä ei aiheudu ylimääräistä haittaa onnettomuustilanteen hallitsemiselle. Tästä syystä tulee osoittaa mm., että pinnoitteiden irtoamista ei tapahdu siinä määrin, että virtausteitä voisi tukkeutua ja sydämen jäähdytys tai jälkilämmön poisto näin vaarantuisi. Lisäksi tulee osoittaa, että onnettomuustilanteissa pinnoitemateriaalin mahdolliset kemialliset muutokset eivät synnytä uusia riskitekijöitä.

Tässä julkaisussa esitetään ydinvoimalaitoksen suojarakennuksen sisäpuolisia pinnoitteita koskevat yksityiskohtaiset vaatimukset ohjeissa YVL 4.1 ja YVL 4.2 esitetyille suunnitteluvaatimuksille, jotka ovat

- säteilynkestävyys,
- dekontaminoitavuus,
- kemiallinen kestävyys,
- kestävyys käyttöolosuhteissa ja
- kestävyys oletetuissa onnettomuustilanteissa.

Pinnoitteita koskevat yksityiskohtaiset vaatimukset perustuvat viitteissä mainittuihin standardeihin ja pohjoismaisiin TBY-kriteereihin.

Suojarakennuksen sisäpuolisina pinnoitteina voidaan käyttää vain pinnoitteita, jotka täyttävät tässä julkaisussa esitettyjen testien vaatimukset. Pohjoismaisen TBY-projektin yhteydessä tehtyjä testejä voidaan hyödyntää pinnoitteiden hyväksymisessä.

Foreword

This publication has been prepared at VTT in co-operation with an executive group for the follow-up and instruction of implementation of the project. The members of the executive group represented Teollisuuden Voima Oy, Fortum Power and Heat Oy, Paintco Ky and Teknos Oy. Senior inspector Heikki Saarikoski from STUK has supervised the project. At VTT group manager Eva Häkkä-Rönnhom has been responsible for the project.

This publication supersedes the publication STUK-YTO-TR 179 (in Finnish).

Contents

1 Attestation of conformity

The paint manufacturer shall attest the conformity of the coating system. The evaluation of conformity involves the manufacturer and a third party.

1.1 Quality management system

The manufacturer shall have a documented quality management system. The system has to be certified according to ISO 9001-series or the manufacturer must have a quality control contract with an independent organization approved by the developer.

The factory production control shall be operated according to the documented system given in the quality manual. The traceability of the products must be ascertained.

1.2 Tests according to this publication

The testing shall be performed either by the manufacturer or by an independent laboratory approved by the licensee. All tests must be reported as given in respective clauses.

Tasks of manufacturer

The manufacturer may perform the following tests or he may use an approved laboratory to perform these tests:

- chemical composition of coating (clause 2)
- chemical durability at operational conditions (clause 5)
- durability at operational conditions: initial tests for adhesion (clause 6)
- durability at operational conditions: abrasion resistance (clause 7).

Tasks of third party

The following tests must be performed by an independent laboratory approved by the licensee:

- radiation (gamma) resistance (clause 3)
- decontamination (clause 4)
- durability at simulated Design Basis Accident (DBA) conditions (clause 8)
- behaviour at fire (clause 9).

2 Chemical composition of coatings

Coatings and coating systems to be used in power plant containments must not contain more than a total of 1% by weight of lead, mercury, copper, cadmium, cobalt, antimony, chlorides and fluorides as measured of the dried coating. Analysis certificates from suppliers or independent laboratories, stating the actual concentrations and detection limits of the above substances, will be required. These analyses shall normally be carried out in connection with type testing of the coatings. A guarantee given by the paint manufacturer, that none of the above substances is added during the manufacturing process, will not be sufficient for approval.

3 Radiation (gamma) resistance

3.1 Determination according to standard ASTM D 4082

The radiation tolerance of the coatings shall be evaluated. The radiation tolerance can be determined according to standard ASTM D 4082-95 *Standard test Method for Effect of Gamma Radiation on Coatings for Use in Light-Water Nuclear Power Plants*.

The test method given in standard ASTM D 4082 is designed to provide a uniform test to assess the suitability of coatings used in nuclear power plants under continuous radiation exposure for 40-year lifetime of the facilities, including radiation during a DBA (Design Basis Accident). There may be local factors such as variations concerning surface preparation, application and curing of coatings, that may affect the performance of coating system exposed to radiation. The performance of coatings at DBA-conditions shall additionally be evaluated according to clause 8.

3.2 Test specimens

Concrete specimens

The concrete specimens shall be prepared in accordance with standard ASTM D 5139-90 *Standard Specification for Sample Preparation for Qualification Testing of Coating to be Used in Nuclear Power Plants* unless otherwise agreed.

The concrete blocks shall be allowed to cure for at least 28 days before coating.

The following information shall be documented:

- composition of concrete (i.e. concrete aggregate, type of cement, water/cement-ratio, additives)
- grade of concrete (compression strength).

The standard ASTM D 5139 gives as the minimum size for the concrete test specimens 50 mm × 50 mm × 100 mm. If agreed, also thinner concrete specimens can be used, i.e. 25 mm × 50 mm × 100 mm.

The edges of the concrete specimens are recommended to be chamfered up to 6.5 mm maximum.

The recommended surface preparation method for the concrete samples is light sweep blasting. When relevant, the following standards may be applied:

- ASTM D4258-83(1999) *Standard Practice for Surface Cleaning Concrete for Coating*,
- ASTM D 4259 88(1999) *Standard Practice for Abrading Concrete*.

The upper and/or lower ends of the concrete blocks shall be left uncoated. A suitable hanger compatible with the testing apparatus shall be fixed at the mid-point of the upper end of the block where applicable.

Number of test specimens shall be at least 2.

Steel panels

The steel panels shall be of hot rolled carbon steel (yield stress min. 235 N/mm^2) or the steel quality can in due form agreed to be changed to correspond the testing practise in Finland or to the actual case.

The size of steel panels is 50 mm × 100 mm × 5 mm.

The steel panels shall be blast-cleaned. The preparation grade is specified to fulfil the requirements of the actual coating system.

Number of test panels shall be at least 2.

Coating of test specimens

All test samples shall be coated from one side with the full coating system according to written instructions given by the coating manufacturer. All the other sides of the test specimens shall be protected with suitable coating. The film thickness range shall be representative of the specified work for which the testing is being conducted. The procedures and conditions used for the test sample preparation shall be documented.

As minimum the documentation shall include:

- preparation times and dates
- surface preparation details
- coating sequence
- individual dry film thickness ranges of each coat (coatings on steel) or specified thickness range (coatings on concrete)
- total thickness range
- environmental conditions
- product identification (trade name, batch number).

3.3 Test method

The irradiation procedure is according to standard ASTM D 4082-95.

- The gamma energy field at the position of the test specimen shall be 1×10^6 rads/h, or greater.
- The total accumulated dose shall be 1×10^8 rads [1] (= 1×10^6 J/kg = 1×10^6 Gy), unless otherwise specified.
- Specimens shall be in air during exposure to gamma source, depending on the intended service as prescribed by the owner.

3.4 Assessment and reporting of results

The test specimens shall be examined and documented immediately after irradiation for the following defects:

- chalking ISO 4628-6
- cracking ISO 4628-4
- blistering ISO 4628-2
- flaking ISO 4628-5.

Any observation of unusual appearance or deterioration shall also be reported.

3.5 Acceptance criteria

Unless otherwise specified, cracking, blistering and flaking, are not permitted.

1) (Gy): A gray, like the rad, measures the radiation absorbed by a person or animal. One gray is equal to 1 J of absorbed radation per kilogram (of person or animal). Gy = 1 J kg^{-1}, 1 Gy = 100 rads.

4 Ease of decontamination (decontaminibility)

4.1 Determination according to ISO 8690

The contamination with radionuclides and the ease of decontamination varies for different of coatings. Also the decontamination methods may be different. This test method ISO 8690 is designed to obtain data allowing the comparison of ease of decontamination of different surface materials.

The purpose of this test is to assess the ease of decontamination of surfaces under laboratory conditions. Further decontamination tests under simulated service conditions may be agreed about. In such case actual contamination and decontamination chemicals are used.

4.2 Test specimens

The test specimens are steel panels coated with the coating system as given in clause 3 Radiation resistance.

The size of the test panels is (50 +10/–2) mm × (50 +10/–2) mm.[2)] The thickness of the test specimens should be between 3 and 10 mm. The thickness shall be ascertained with the testing laboratory.

Unless otherwise specified, 10 ordinary irradiated and 10 unirradiated test specimens are needed. These test specimens shall be kept in conditions and cleaned as given in standard ISO 8690.

4.3 Contamination and decontamination solutions

Contamination solutions

The test shall be contaminated by the radionuclides ^{137}Cs and ^{60}Co, contained in separate solutions. The solutions shall be in accordance with standard ISO 8690 (i.e. an evaporated 100 µl sample produces a pulse rate of not less than 200 000 pulses per minute; an activity concentration of 0.2 MBq/ml will usually sufficient to fulfil the requirement). If using other contamination solutions, this shall be separately agreed about.

Decontamination agent

Demineralized water (maximum conductivity 3 µS/ml) shall be used as decontamination agent.

4.4 Procedure (contamination and decontamination)

According to standard ISO 8690 the specific pulse rate of each contamination solution is determined (pulse/minute/millilitre).

Contamination is performed with both contamination solutions for five (5) irradiated and five (5) unirradiated test specimens according to standard ISO 8690.

Then, the test specimens are decontaminated and the residual pulse rate is determined. The results are calculated as presented in standard ISO 8690:

- five (5) equally contaminated test specimens are decontaminated simultaneously with demineralized water using the test arrangements given in the standard
- after drying, the residual pulse rate of the test specimens is determined
- the arithmetic mean of the residual pulse rates of the five test specimens of each group is calcuclated separately for both radionuclides ^{137}Cs and ^{60}Co (standardized mean pulse rate)

2) When tested at VTT, the recommended size is (50 ± 2) mm × (50 ± 2) mm, thickness 3–10mm.

- final result FRP (final residual pulse rate) is calculated as the arithmetic mean of standardized mean residual pulse rates for ^{137}Cs and ^{60}Co.

4.5 Assessment of ease of decontamination and reporting the results

The ease of decontamination is assessed according to Table I. This assessment is valid only when the contamination is carried out using the radionuclides ^{137}Cs and ^{60}Co.

Table I. Assessment of the ease of decontamination.

Final residual pulse rate (FRP), pulses/minute	Ease of decontamination
FRP < 3 500	Excellent
3 500 ≤ FRP < 15 000	Good
15 000 ≤ FRP < 60 000	Fair
60 000 ≤ FRP	Poor

The test report shall include the information and data specified in standard ISO 8690, Annex D.

4.6 Acceptance criteria

The ease of decontamination shall be at least “Good” (Table I).

5 Chemical durability at operational conditions

5.1 Scope

The purpose of determination of chemical durability by immersion is to evaluate the resistance of coatings against saponification, demineralized water and some chemicals. If other chemicals are to be used in the nuclear power plants containment, the resistance of the coating against these chemical shall be determined separately.

5.2 Test specimens

Concrete specimens

The concrete specimens shall be prepared in accordance with standard ASTM D 5139-90 *Standard Specification for Sample Preparation for Qualification Testing of Coating to be Used in Nuclear Power Plants* unless otherwise agreed.

The concrete blocks shall be allowed to cure for at least 28 days before coating.

The following information shall be documented:

- composition of concrete (i.e. concrete aggregate, type of cement, water/cement-ratio, additives)
- grade of concrete (compression strength).

The standard ASTM D 5139 gives as the minimum size for the concrete test specimens 50 mm × 50 mm × 100 mm.

The edges of the concrete specimens are recommended to be chamfered up to 6.5 mm maximum.

The recommended surface preparation method for the concrete samples is light sweep blasting. When relevant, the following standards may be applied:

- ASTM D4258-83(1999) *Standard Practice for Surface Cleaning Concrete for Coating*,
- ASTM D 4259 88(1999) *Standard Practice for Abrading Concrete*.

The number of test specimens shall be specified and it shall be at least 2: one specimen for adhesion measurements and one for visual assessment of coating.

Steel panels

The steel panels shall be of hot rolled carbon steel (yield stress min. 235 N/mm^2) or the steel quality can in due form agreed to be changed to correspond the testing practise in Finland or to the actual case.

The minimum size of steel panels is 100 mm × 150 mm × 5 mm.

The steel panels shall be blast-cleaned. The preparation grade is specified to fulfil the requirements of the actual coating system.

The number of test specimens shall be specified and it shall be at least 2: one specimen for adhesion measurements and one for visual assessment of coating.

Coating of test specimens

All test samples shall be coated from one side with the full coating system according to written instructions given by the coating manufacturer. All the other sides of the test specimens shall be protected with suitable coating. The film thickness range shall be representative of the specified work for which the testing is being conducted.

The procedures and conditions used for the test sample preparation shall be documented.

As minimum the documentation shall include:

- preparation times and dates
- surface preparation details
- coating sequence
- individual dry film thickness ranges of each coat (coatings on steel) or specified thickness range (coatings on concrete)
- total thickness range
- environmental conditions
- product identification (trade name, batch number).

5.3 Resistance to saponification

Coating systems that are intended to be painted directly on to concrete must be tested for their re-

Table II. Chemical resistance testing: chemicals and test parameters.

Chemical	Concentration	Temperature °C	Test time h	Coatings on concrete	Coatings on steel *
Sulphuric acid †	245 g/l	23	24	X	X
Nitric acid	5%	23	2	X	
Hydrochloric acid *	5%	23	2 *	X	
Citric acid	5%	23	2	X	X
Boric acid	6%	23	2 *	X	X
Borax	10%	23	2	X	
Sodium hydroxide	250 g/l	23	24	X	X
Ferro(II)-sulphate	10%	23	2	X	
Ethanol	95%	23	0.1	X	X
Acetone	100%	23	0.1	X	X
Hydrazine	15%	23	2 *	X	

† Sulphuric acid, density 1.84 g/m^3

* Not relevant for zinc rich primers on steel surfaces

sistance to saponification. The test panels shall be immersed in a saturated calcium hydroxide solution ($Ca[OH]_2$) at 50°C for three months.

5.4 Resistance to demineralised water

Testing for resistance to demineralised water is carried out at 40°C for six months. The electrical conductivity of the water must be less than 2 mS m^{-1} at +25°C for the duration of the test period. The water shall be replaced if at any time during the test it becomes turbid or coloured or its conductivity exceeds 2 mS m^{-1} (at +25°C). The conductivity of the water shall be determined during the test and the results of the determinations shall be reported. The test method shall be according to standard ISO 2812-2, method 1 (immersion method).

5.5 Resistance to chemicals

The resistance of the coating systems to chemicals shall be determined to all chemicals that the systems may be exposed to. This applies also to the chemicals used for decontamination surfaces.

The chemical resistance shall be determined at least to the extent given in Table II.

5.6 Assessment and reporting of results

After removing the samples from the test solution, the test specimens are evaluated immediately (within 2 hours) and repeat the evaluation until at least 24 hours have passed for the following properties and defects:.

- blistering ISO 4628-2
- flaking ISO 4628-5
- cracking ISO 4628-4
- stickiness and softening (testing by moderate finger pressure)
- adhesion ISO 4624 (notice details in clause 6.1).

5.7 Acceptance criteria

- Blistering max 2(S4). Blisters shall be limited to intact blisters that are completely surrounded by sound coating bonded to the surface
- No flaking, cracking or softening
- No stickiness may occur, the surface must be tack-free when tested by moderate finger pressure
- Adhesion, concrete structures: The type of breakage shall be cohesion breakage of concrete. The following values are valid:
  - floors min. 2.5 MPa
  - walls, pillars, beams, ceilings min. 1.5 MPa
- Adhesion, steel structures:
  - no adhesion break to substrate allowed unless pull-off values are 5 MPa or greater
  - for cohesion break of coating min. 3 MPa.

6 Durability at operational conditions/initial tests for adhesion

6.1 Testing according to ISO 4624

The adhesion of the coating shall be determined with appropriate initial tests.

The adhesion is determined with pull-off test according to standard ISO 4624. The tensile stress shall be applied in a direction perpendicular to the plane of the coated surface. The test results are not reproducible unless coaxial alignment of the tensile forces is ensured.

The test apparatus used shall be a hydraulic pull-off apparatus, where the test cylinder is pulled off the surface using hydraulic pressure to provide the force.

The diameter of test cylinder shall be min. 20 mm for concrete surfaces and 10–20 mm for steel surfaces.

Before testing, cuts around the test cylinder are made through cured adhesive and the coating to the substrate round the circumference of the test cylinder. The internal diameter of the cutting device shall not exceed the diameter of the test cylinder by more than 2 mm. For cutting, also a sharp knife may be used.

At least three determinations shall be carried out for each test specimen.

6.2 Test specimens

Concrete specimens

The concrete specimens shall be prepared in accordance with standard ASTM D 5139-90 *Standard Specification for Sample Preparation for Qualification Testing of Coating to be Used in Nuclear Power Plants* unless otherwise agreed.

The concrete blocks shall be allowed to cure for at least 28 days before coating.

The following information shall be documented:

- composition of concrete (i.e. concrete aggregate, type of cement, water/cement-ratio, additives)
- grade of concrete (compression strength) and density of concrete.

The size of the specimens shall be such, that three adhesion determinations from each test specimen can be performed. Suitable size is for instance 300 mm × 300 mm × 50 mm.

The recommended surface preparation method for the concrete samples is light sweep blasting. When relevant, the following standards may be applied:

- ASTM D4258-83(1999) *Standard Practice for Surface Cleaning Concrete for Coating*,
- ASTM D 4259 88(1999) *Standard Practice for Abrading Concrete*.

The number of test specimens shall be specified and it shall be at least 2.

Steel panels

The steel panels shall be of hot rolled carbon steel (yield stress for instance 235 N/mm^2) or the steel quality can in due form agreed to be changed to correspond the testing practise in Finland or to the actual case.

The minimum size of steel panels is 100 mm × 150 mm × 5 mm.

The steel panels shall be blast-cleaned. The preparation grade is specified to fulfil the requirements of the actual coating system.

The number of test specimens shall be specified and it shall be at least 2.

Coating of test specimens

All test samples shall be coated from one side with the full coating system according to written instructions given by the coating manufacturer. The film thickness range shall be representative of the specified work for which the testing is being conducted. The procedures and conditions used for the test sample preparation shall be documented.

The procedures and conditions used for the test sample preparation shall be documented.

As minimum the documentation shall include:

- preparation times and dates
- surface preparation details
- coating sequence
- individual dry film thickness ranges of each coat (coatings on steel) or specified thickness range (coatings on concrete)
- total thickness range
- environmental conditions
- product identification (trade name, batch number).

6.3 Assessment and reporting of results

The test results are reported according to standard ISO 4624. The report shall include the following information at minimum:

- the type and identification of the product(s) tested
- a reference to the standard used
- the type of instrument and the diameter of the dolly
- the type of cutting tool employed to cut around the dolly
- the results of the test as indicated in ISO 4624.

6.4 Acceptance criteria

Concrete structures

The type of breakage shall be cohesion breakage of concrete. The following values are valid:

- floors min. 2.5 MPa
- walls, pillars, beams, ceilings min. 1.5 MPa.

Steel structures

- no adhesion break to substrate allowed unless pull-off values are 5 MPa or greater
- for cohesion break of coating min. 3 MPa.

7 Durability at operational conditions / abrasion resistance

7.1 Testing according to ISO 7784-2

The resistance to abrasion of coatings for floors shall be determined.

The abrasion resistance is determined according to standard ISO 7784-2 (so called Taber method). This method gives information of the ability of the coating to withstand mechanical stress during use.

7.2 Test specimens

Only steel panels are used, typically used substrate is metal (steel) sheet.. The shape and size of the test panels shall be such that they can be fitted correctly on the apparatus. They shall have a central hole of diameter 6.35 mm. Typical size is 100 mm × 100 mm. The test panels shall be plane and free from distortion, otherwise the wear of the coating will not be uniform.

All test samples shall be coated from one side with the full coating system according to written instructions given by the coating manufacturer. The film thickness range shall be representative of the specified work for which the testing is being conducted. The procedures and conditions used for the test sample preparation shall be documented.

As minimum the documentation shall include: ASTM D 5139 (*Standard Specification for Sample Preparation for Qualification Testing of Coating to be Used in Nuclear Power Plants*),

- preparation times and dates
- surface preparation details
- coating sequence
- individual dry film thickness ranges of each coat
- total thickness range
- environmental conditions
- product identification (trade name, batch number).

The number of test specimens shall be specified and it shall be 3 at minimum.

7.3 Test method

The test is performed according to standard ISO 7784-2 as follows:

- The abrasion wheel shall be a rubber wheel type CS-17
- The load on the wheels is adjusted to 1000 g.
- For resurfacing the abrasion wheels, an S-11 abrasive disc is used.
- The weight loss mg/1000 cycles is calculated.

The determinations are performed for three test panels.

7.4 Assessment and reporting of results

The results are reported according to standard ISO 7784-2. The report shall include the following information:

- identification of specimens
- conditioning of test panels before testing
- wheel load and the type of abrasive rubber wheel used
- date of testing and conditions during testing
- individual test results: weight loss mg/1000
- mean value of weight loss mg/1000 cycles.

7.5 Acceptance criteria

The mean value of weight loss must be less than 175 mg/1000 cycles.

8 Durability at simulated Design Basis Accident (DBA) conditions

8.1 Determination according to ASTM D 3911

The durability of coatings during design basis accident (DBA) shall be evaluated. The durability at DBA-conditions can be determined according to standard ASTM D 3911-95.

The method gives information concerning the general ability of coating to remain intact and not become debris at DBA-conditions which could compromise engineered safety systems. Variations in actual surface preparation and curing of the coating materials may require additional testing as deemed necessary by the specifying or qualifying agency, or both, if it is anticipated that the variations may adversely affect the performance of the coating system during a DBA.

The standard ASTM D 3911 describes the conditions and apparatus for temperature-pressure testing.

8.2 Test specimens

The preparation of test specimens is described in clause 3, radiation (gamma) resistance.

The number of test specimens is 4. Two of the specimens are irradiated in accordance with clause 3 prior to testing.

8.3 Test method

The test procedure is given in standard ASTM D 3911.

The testing parameters (temperature–time–pressure) shall be according to the safety analysis report (SAR) identified by the owner for the specific containment. The curves described in standard ASTM D 3911 may be used if they represent conditions equal to or more severe than those of DBA conditions anticipated. [3)]

Steam is used initially to achieve the desired thermal chock and to raise the test chamber and its environment to the prescribed test conditions. The inlet steam shall not be directed on the test specimens. The duration of steam injection should be minimized and where inlet steam temperatures exceed 188°C initial steam injection shall be no longer than 15 min.

Unless otherwise specified, deionized water shall be used.

8.4 Assessment and reporting of results

The test specimens are examined and evaluated within 4 h and again after 14 days following removal from test chamber for the following defects:

- blistering ISO 4628-2
- cracking ISO 4628-4
- flaking ISO 4628-5.

Moreover, any observations of unusual appearance shall be reported.

Disregard the condition of the edges and the plane areas within 6 mm from the edges of the steel or concrete test surfaces, and the top and bottom ends of the concrete surfaces.

8.5 Acceptance criteria

The following criteria represent the minimum standards for acceptance:

- No flaking is permitted
- Cracking is not considered a failure unless accompanied by flaking or loss of adhesion
- Blisters shall be limited to intact blisters that are completely surrounded by sound coating bonded to the surface

The licensee shall review the report generated according to clause 8.4 for coating acceptability.

8.6 Alternative methods

If alternative methods to ASTM D 3911 are used, these must be accepted by the licensee.

3) Examples of testing parameters according to ASTM 3911:

- Boiling water reactor: max 171ºC/4.83 bar
- Pressure water reactor: max 152ºC/4.14 bar

Total time of testing 7 days.

9 Behaviour at fire

9.1 Classification according to EN 13501-1

Regulations and guidelines for fire classification of coating materials are given in The National Building Code of Finland, part E1 (Fire safety of buildings). The classification procedure given in standard ISO 13501-1 is applied. For nuclear power plant containments, only coatings for floors are to be classified.

9.2 Test methods

For classification of the coating materials the following test are applied:

- ISO 9239-1 *Reaction to fire test for floorings- Part 1: Determination of the burning behaviour using a radiant heat source.*
- ISO 11925-2 *Reaction to fire tests – Ignitability of building products subjected to direct impingement of flame – Part 2: Single-flame source test.*

9.3 Test specimens

All test samples (concrete slab) shall be coated from one size with the full coating system according to written instructions given by the coating manufacturer. The film thickness range shall be representative of the specified work for which the testing is being conducted. The procedures and conditions used for the test sample preparation shall be documented.

As minimum the documentation shall include: ASTM D 5139 (*Standard Specification for Sample Preparation for Qualification Testing of Coating to be Used in Nuclear Power Plants*,

- preparation times and dates
- surface preparation details
- coating sequence
- individual dry film thickness ranges of each coat
- total thickness range
- environmental conditions
- product identification (trade name, batch number).

The number and size of test specimens is:

ISO 9239-1

- 230 mm × 1050 mm for substrate thickness ≤ 19 mm
- 230 mm × 1025 mm for substrate thickness > 19 mm
- number of test specimens 6.

ISO 11925-2

- 90 mm × 250 mm × max 60 mm
- number of test specimens 6.

9.4 Assessment and reporting of results

The test results are reported according to the test method standards ISO 9239-1 and 11925-2.

The content and form of the classification report is given in detail in standard EN 13501-1.

9.5 Acceptance criteria

The fire class for flooring materials shall be class D_{fl}-s1 according to EN 13501-1.

10 Summary of tests

Summary of the tests of coatings for nuclear power plant containments are given in Table III.

Table III. Tests and test specimens required for evaluating coating performance in nuclear power plant containments.

Test	Clause	Size (mm × mm × mm) and number of test specimens		Irradiation of specimens
		Concrete	Steel	
Radiation resistance	3	i.e. 100 × 50 × 25 2 pieces	100 × 50 × 5 2 pieces	All
Decontamination	4	—	(50 +10/–2) × (50 +10/–2) × (3…5) * 10 +10 pieces	10 pieces
Chemical durability	5	100 × 50 × 50	100 × 150 × 5	
• resistance to saponification	5.2 and 5.3	2 pieces	2 pieces	No
• resistance to demineralised water	5.2 and 5.4	2 pieces	2 pieces	No
• chemical resistance	5.2 and 5.5	2 pieces	2 pieces	No
Initial test for adhesion	6	i.e. 300 × 300 × 50 2 pieces	100 × 150 × 5 2 pieces	No
Abrasion resistance	7	—	100 × 100 × 5 3 pieces	No
Durability at DBA conditions	8	i.e. 100 × 50 × 25 4 pieces	100 × 50 × 5 4 pieces	2 concrete specimens 2 steel specimens
Behaviour at fire	9			
• ISO 9239-1		230 × 1025 × (30…50) 6 pieces	—	No
• ISO 11925-2		90 × 250 × max 60 6 pieces	—	No

* When tested at VTT, the recommended size is (50 ± 2) mm × (50 ± 2) mm, thickness 3–10 mm.

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