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Cathodic protection of steel in concrete

Protection cathodique de l'acier dans le béton

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

The committee responsible for this document is ISO/TC 156, *Corrosion of metals and alloys*.

This second edition cancels and replaces the first edition (ISO 12696:2012), of which it constitutes a minor revision with the following changes:

— figures for MnO_2, NaOH (0,5 M) in Table A.1 have been updated;

— general editorial corrections throughout the document.

Introduction

This document applies to cathodic protection of steel in concrete, with the concrete atmospherically exposed, buried or immersed.

Because the criteria of protection for steel in buried or immersed concrete are those applicable to cathodic protection of steel in atmospherically exposed concrete, this revision of EN 12696:2000 incorporates cathodic protection of steel in buried and immersed concrete. The provision of cathodic protection current can often be more economically provided to steel in buried and immersed concrete by using buried or immersed anode systems detailed in International Standards for buried and immersed steel structures, rather than the anode systems that are suitable for applications to steel in atmospherically exposed concrete. Therefore, reference is made to other International Standards in this respect while the cathodic protection performance criteria for steel in concrete are defined in this document for all exposures.

There are other electrochemical treatments intended to provide corrosion control for steel in concrete. These techniques include re-alkalization and chloride extraction and are not incorporated into this document. CEN/TS 14038-1:2004 and CEN/TS 14038-2:2011 have been published.

Cathodic protection of steel in concrete is a technique that has been demonstrated to be successful in appropriate applications in providing cost effective long-term corrosion control for steel in concrete. It is a technique that requires specific design calculations and definition of installation procedures in order to be successfully implemented. This document does not represent a design code for cathodic protection of steel in concrete, but represents a performance standard for which it is anticipated, in order to comply with this document, a detailed design and specification for materials, installation, commissioning and operation will be prepared.

Cathodic protection of steel in concrete

1 Scope

This document specifies performance requirements for cathodic protection of steel in cement-based concrete, in both new and existing structures. It covers building and civil engineering structures, including normal reinforcement and prestressed reinforcement embedded in the concrete. It is applicable to uncoated steel reinforcement and to organic-coated steel reinforcement.

This document applies to steel embedded in atmospherically exposed, buried, immersed and tidal elements of buildings or structures.

NOTE 1 Annex A gives guidance on the principles of cathodic protection and its application to steel in concrete.

NOTE 2 This document, while not specifically intended to address cathodic protection of steel in any electrolyte except concrete, can be applied to cathodic protection of steel in other cementitious materials such as are found, for example, in early 20th century steel-framed masonry, brick and terracotta clad buildings. In such applications, additional considerations specific to these structures are required in respect of design, materials and installation of cathodic protection; however, the requirements of this document can be applied to these systems.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 1504 (all parts), *Products and systems for the protection and repair of concrete structures — Definitions, requirements, quality control and evaluation of conformity*

EN 14629, *Products and systems for the protection and repair of concrete structures — Test methods — Determination of chloride content in hardened concrete*

EN 14630, *Products and systems for the protection and repair of concrete structures — Test methods — Determination of carbonation depth in hardened concrete by the phenolphthalein method*

IEC 60502-1, *Power cables with extruded insulation and their accessories for rated voltages from 1 kV (Um = 1,2 kV) to 30 kV (Um = 36 kV) — Part 1: Cables for rated voltages of 1 kV (Um = 1,2 kV) and 3 kV (Um = 3,6 kV)*

IEC 60529, *Degrees of protection provided by enclosures (IP Code)*

IEC 61140, *Protection against electric shock — Common aspects for installation and equipment*

IEC 61558-1, *Safety of power transformers, power supplies, reactors and similar products — Part 1: General requirements and tests*

IEC 61558-2-1, *Safety of power transformers, power supplies, reactors and similar products — Part 2-1: Particular requirements and tests for separating transformers and power supplies incorporating separating transformers for general applications*

IEC 61558-2-2, *Safety of power transformers, power supplies, reactors and similar products — Part 2-2: Particular requirements and tests for control transformers and power supplies incorporating control transformers*

IEC 61558-2-4, *Safety of transformers, reactors, power supply units and similar products for supply voltages up to 1 100 V — Part 2-4: Particular requirements and tests for isolating transformers and power supply units incorporating isolating transformers*

IEC 61558-2-13, *Safety of transformers, reactors, power supply units and similar products for supply voltages up to 1 100 V — Part 2-13: Particular requirements and tests for auto transformers and power supply units incorporating auto transformers*

IEC 61558-2-16, *Safety of transformers, reactors, power supply units and similar products for voltages up to 1 100 V — Part 2-16: Particular requirements and tests for switch mode power supply units and transformers for switch mode power supply units*

IEC 62262, *Degrees of protection provided by enclosures for electrical equipment against external mechanical impacts (IK code)*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 8044 and EN 1504 (all parts) and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— IEC Electropedia: available at http://www.electropedia.org/

— ISO Online browsing platform: available at http://www.iso.org/obp

3.1
zone
part of a cathodic protection system

Note 1 to entry: Anode systems may be divided into separate zones to supply current to a fully continuous reinforcement mesh. Alternatively, a single anode zone may supply current to separate, electrically isolated, zones within the reinforcement system. Zones may comprise an individual anode zone for each reinforcement zone or exposure condition. As the current provision to each of the zones in each of these alternatives can be separately measured, all of them are generically called “cathodic protection zones” and specifically “anode zones” or “cathode zones”.

3.2
humectant
hygroscopic material, i.e. a substance that promotes the retention of moisture

Note 1 to entry: It may be applied to the surface of a galvanic anode to keep the concrete-anode interface moist.

4 General

4.1 Quality management systems

The design, the installation, the energizing, the commissioning and the long-term operation of all of the elements of cathodic protection systems for steel in concrete shall be fully documented.

NOTE ISO 9000 constitutes a suitable quality management systems standard which can be utilized.

Each element of the work shall be undertaken in accordance with a fully documented quality plan.

Each stage of the design shall be checked and the checking shall be documented.

Each stage of the installation, energizing, commissioning and operation shall be the subject of appropriate visual, mechanical and/or electrical testing, and all testing shall be documented.

All test instrumentation shall have valid calibration certificates traceable to national or European standards concerning calibration.

The documentation shall constitute part of the permanent records for the works.

4.2 Personnel

Each aspect of the cathodic protection system design, installation, testing of the installation, energizing, commissioning and long-term operational control shall be under the supervision of personnel with appropriate qualifications, training, expertise and experience in the particular element of the work for which they are responsible.

NOTE Cathodic protection of steel in concrete is a specialist multidiscipline activity. Expertise is required in the fields of electrochemistry, concrete technology, civil and/or structural engineering and cathodic protection engineering.

Personnel who undertake the design, supervision of installation, commissioning, supervision of operation, measurements, monitoring and supervision of maintenance of cathodic protection systems shall have the appropriate level of competence for the tasks undertaken. EN 15257 specifies a suitable method which may be utilized for assessing the competence of cathodic protection personnel.

The competence of cathodic protection personnel to the appropriate level for tasks undertaken should be demonstrated by certification in accordance with EN 15257 or by another equivalent prequalification procedure.

4.3 Design

This document does not represent a design code, but is a performance standard.

Cathodic protection systems for steel in concrete shall be the subject of detailed design.

The design shall, as a minimum, include the following:

a) detailed calculations;

b) detailed installation drawings;

c) detailed material and equipment specifications;

d) detailed method statements or specifications for installation, testing, energizing, commissioning and operation;

e) structures containing prestressing shall be assessed for their susceptibility to hydrogen embrittlement and for risk of stray currents.

Annex B lists items that should be considered in the detailed design.

5 Structure assessment and repair

5.1 General

For cathodic protection (or cathodic prevention) of new structures, see 5.12.

The assessment of an existing structure, including its material condition, its structural integrity and whether and how to repair it, shall be performed in accordance with EN 1504 (all parts).

When cathodic protection is proposed as the repair/protection method, or part of it, for a structure, additional investigation shall be undertaken in order to

a) confirm the suitability of cathodic protection, and

b) provide system-design input information. See Annex B.

These investigations shall include, but shall not be limited to, those in 5.2 to 5.10.

5.2 Records

All available drawings, specifications, records and notes shall be reviewed to assess the location, quantity, nature (e.g. normal, galvanized, epoxy-coated, prestressed) and continuity of the reinforcement and any additional steel, the constituents and quality of the concrete.

The available information shall be confirmed and supplemented by site survey and laboratory tests, as specified in 5.3 to 5.8.

5.3 Visual inspection and delamination survey

Visual survey data shall be collected to ascertain the type, causes and extent of defects, and any features of the structure or its surrounding environment, which could influence the application and effectiveness of cathodic protection. Areas which have been previously repaired, and the repair methods and materials, shall be identified.

All areas of the structure which require to be cathodically protected shall be checked for delamination of the concrete cover.

Defects, such as cracks, honeycombing or poor construction joints, which could permit significant water penetration, and which could in turn impair the effectiveness or durability of the cathodic protection system, shall be recorded.

Where necessary, the inspection and survey of buried or immersed elements will be facilitated by excavation and or cofferdams.

5.4 Chloride analysis

If required, values and distributions of the chloride content of the concrete shall be determined in accordance with EN 14629.

5.5 Carbonation depth measurement

If required, distribution of carbonation depths shall be measured in accordance with EN 14630.

5.6 Concrete cover and reinforcement location

Concrete cover distribution and embedded steel and reinforcement size and position measurements shall be carried out in order to assess whether the anode/cathode spacing will be adequate for the particular anode system envisaged, and to identify dense regions of steel or reinforcement which may require high current density. Shielding of the steel to be protected, caused by embedded metal meshes, metal fibres or plates, plastic sheets or non-conductive repair materials, which could impair the efficiency of cathodic protection, shall be assessed. Possible short-circuits between reinforcing steel and impressed current anodes shall be assessed.

For buried or immersed structures or zones, the concrete cover may be less significant if the anode system is to comprise anodes buried or immersed and located some distance from the structure.

5.7 Reinforcement electrical continuity

Drawings of reinforcement and other steel elements shall be checked for continuity which shall then be proven on site by measuring the electrical resistance and/or potential difference between bars in locations remote from each other across the structure. Testing shall be as specified in 7.1 for the purpose of confirming cathodic protection feasibility and providing design information. This shall include at least an assessment of the following on a representative basis:

a) electrical continuity between elements of the structure within each zone of the cathodic protection system;

b) electrical continuity of reinforcement within elements of the structure;

c) electrical continuity of metallic items, other than reinforcement, to the reinforcement itself.

At the subsequent repair and installation stage, reinforcement and other steel electrical continuity shall be further checked in accordance with the methods, and to the extent specified in 7.1.

5.8 Steel/concrete potential

Representative areas, both damaged and apparently undamaged, shall be surveyed for reinforcement/steel corrosion activity, using portable reference electrodes conforming to 6.3.2. Measurements shall be taken, preferably on an orthogonal grid, at a maximum spacing of 500 mm.

NOTE 1 It is not necessary to carry out a steel/concrete potential survey of the entire structure. It is appropriate to survey, in more detail, those areas where reference electrodes are planned to be permanently installed, in order to place them in most anodic and other suitable locations.

Continuity of the reinforcement and steel within any steel/concrete potential survey area is essential and shall be checked, using the method in 7.1 before the steel/concrete potential survey.

Measurements in any areas identified as delaminated, in the survey specified in 5.3, should be interpreted with caution, because delamination can produce readings inconsistent with the level of corrosion of the reinforcement or other embedded steel.

NOTE 2 ASTM C876, RILEM TC 154 report (2003)[9] and Concrete Society Technical Report 60[10] provide guidance with respect to steel/concrete potential measurements and interpretation.

5.9 Concrete electrical resistivity

The impact of variations in concrete resistivity on the cathodic protection system shall be considered. There is no firm guidance on limits of electrical resistivity with respect to cathodic protection, but the designer shall consider whether full protection can be achieved where required for the ranges and absolute values of concrete resistivity found on the structure.

NOTE RILEM TC 154 Report (2000)[11] and Concrete Society Technical Report 60[10] provide guidance with respect to concrete electrical resistivity measurements and interpretation.

5.10 Repair

5.10.1 General

All operations comprising repair shall be performed in accordance with EN 1504 (all parts), except where stated otherwise in this subclause.

NOTE Installation of cathodic protection to an existing structure may be associated with other forms of repair work, such as strengthening, patching or coating, as determined in accordance with EN 1504 (all parts). In this subclause, the term “repair” signifies reinstatement of the damaged/deteriorated concrete to provide an uninterrupted path for the flow of cathodic protection current prior to the installation of cathodic protection, as well as reinstatement at locations where concrete has been removed to provide access to reinforcement and other steel, to install cable connections and monitoring sensors, etc.

5.10.2 Concrete removal

All repair materials from previous installations with significantly different electrical resistivity from the parent concrete shall be broken out.

Typically, these repair materials with an electrical resistivity outside the range of approximately half to twice that of the parent concrete, when measured under the same conditions as the parent concrete, should be removed in order to allow relatively uniform current distribution to reinforcement. For example, predominantly epoxy-based repair materials will have very high resistivity values and may

shield reinforcement within or behind them from cathodic protection. Concrete reinforced with metallic fibres may have very low electrical resistivity and the fibres may form an electrical short-circuit path between the anode and the steel.

For impressed-current cathodic protection systems, any tying wire, nails or other metal components visible on the concrete, that might contact the anode system or might be too close to the anode for optimum anode/cathode spacing, shall be cut back and the concrete shall be repaired.

NOTE Any metallic objects electrically isolated from the cathodic protection cathode circuit may corrode and may require to be electrically bonded to the reinforcement or removed.

The removal of physically sound chloride-contaminated or carbonated concrete prior to applying cathodic protection is not necessary.

5.10.3 Reinforcement preparation

Any loose corrosion product particles shall be removed from the exposed reinforcement or other steel to ensure good contact between the steel and the repair material, but there is no need to clean the reinforcement or other steel, to be embedded in concrete, to bright metal.

Neither insulating nor resistive primers or coatings shall be used.

5.10.4 Concrete reinstatement

Concrete reinstatement shall be in accordance with EN 1504 (all parts), except where stated in this subclause.

Concrete shall be reinstated using cementitious materials. Repair materials containing metal (either fibre or powder) shall not be used, especially in the case of impressed current systems. The electrical resistivity characteristics and mechanical properties of the repair materials shall be compatible with the original concrete. Proprietary curing membranes shall not be used prior to subsequent anode installation over the repair area. Alternative curing methods shall be used.

The electrical resistivity of concrete repair materials shall be similar to that of the parent concrete.

NOTE Typically, these repair materials will have an electrical resistivity within the range approximately half to twice that of the parent concrete when measured under the same conditions as the parent concrete. However, the electrical resistivity of the parent concrete will be that of an aged material (age >20 years), whereas the electrical resistivity of the repair material will reflect the properties at a relatively young age; it is anticipated that there will be a significant ageing effect over time. Also, measurements made in the laboratory on prisms will not represent the conditions of the structure. A good quality repair made with materials known to be compatible with cathodic protection installations has been found to be more important than arbitrary resistivity limits.

5.11 Cementitious overlay

For cathodic protection systems employing anode systems as outlined in 6.2.2.2, following repair as specified in 5.10, and anode installation in accordance with 7.5, 7.6 and 7.7, a cementitious overlay shall be applied over appropriate types of installed anode. All materials and application methods shall be in accordance with EN 1504 (all parts). The average bond strength between the existing concrete and overlay shall be greater than 1,5 MPa and the minimum shall be greater than 1,0 MPa.

If the substrate concrete cohesive strength fails at lower values than 1,5 MPa average and 1,0 MPa minimum, the use of a cementitious overlay may be inappropriate.

Overlay application may be combined with concrete repair.

The electrical resistivity of anode overlays may exceed twice that of parent concrete subject to the anode within the overlay being able to pass its design current at the design voltage, in an overlay of this resistivity, in all atmospheric and exposure conditions applicable to the structure.

The selected material, thickness and placement method shall be compatible with each other, with the anode material and the exposure of the structure.

The potential between the anode and reinforcement/steel (cathode) shall be monitored to detect short-circuits. Curing membranes shall be removed from the parent concrete/substrate or shall have sufficiently degraded to avoid adversely influencing the performance of the cathodic protection system.

5.12 New structures

In the case of a new structure, if cathodic protection as a preventive system is to be included in the original construction, the following issues shall be assessed in the design, specification and construction procedures, in addition to the requirements of the remainder of this document and of the standards governing the design and construction of the new structure:

a) provision and checking of reinforcement/steel electrical continuity, in accordance with 7.1;

b) adequate securing and protection of monitoring sensors and all cables and their connections, to avoid damage or disturbance during concrete placement and vibration;

c) connection, location or insulation of other metallic fixtures, fixings or other items, so as to avoid undesirable influences from the cathodic protection system;

d) in the case of impressed current anodes cast into the concrete structure, provision of sufficient rigid insulating spacers and attachments to secure the anodes in position and prevent the creation of short-circuits during concrete placement and vibration. The potential monitoring between anode and reinforcement/steel (cathode) shall be used to detect short-circuits during concrete placement.

6 Cathodic protection system components

6.1 General

The cathodic protection system shall include an anode system intended to distribute the cathodic protection current to the surfaces of the embedded steel to be protected. Impressed current cathodic protection systems shall further incorporate positive and negative direct current cables between the anode and the steel, respectively, and the DC power supply, which is the source of the cathodic protection current.

For galvanic anode systems, direct permanent metallic connections shall be provided between the anode and the steel, except where monitoring that requires current interruption is installed.

Reference electrodes, other electrodes and other sensors are key elements of cathodic protection systems and constitute the performance monitoring system within cathodic protection systems. The data from the electrodes and sensors may be interrogated and displayed by portable instrumentation or permanently installed instrumentation of either the automatic or manual type.

The entire cathodic protection system shall be designed, installed and tested to be suitable for its intended life in its intended environment.

Both impressed current and galvanic anode cathodic protection systems require monitoring provisions in order to determine the performance and comply with this document.

NOTE Galvanic anode systems may be used without monitoring systems or methods to measure their performance. Such systems do not comply with this document.

6.2 Anode systems

See Annex C.

The anode system shall be capable of supplying the performance required by the cathodic protection design (see 4.3). The anode system's calculated or anticipated life shall be sufficient for the design life incorporated into the design, with, where necessary, planned maintenance or replacement of the anode system or parts of the system at periods designated in the design.

For anodes embedded into or applied to the surface of the concrete, the anode current density shall conform to the design and shall not exceed such values resulting in a performance reduction of either

a) the concrete at the anode/concrete interface, or

b) the anode, during the design life of the anode.

The design and/or the selection of the anode material shall consider likely variations in cathode current density requirements, steel distribution, concrete electrical resistivity and any other factors likely to result in uneven distribution of current demand or current discharge from the anode and the possibility of this resulting in an early failure of isolated parts of the anode system.

NOTE 1 A variety of anode systems have been developed, tested and demonstrated in long-term field applications to be suitable for use embedded in concrete or applied to the concrete primarily (but not exclusively) in the cathodic protection of steel in atmospherically exposed concrete. The requirements for such anodes are unique for usage of cathodic protection in concrete, as the anodes have to be installed or applied and distributed across the concrete surface or within the concrete, as required, to meet the design distribution and magnitude of current. The anode is therefore in close contact with the highly alkaline concrete pore water. In operation, the anodic electrochemical reactions at the anode/concrete interface are oxidizing, producing acidity.

NOTE 2 The anode systems described in this document are in two categories. Anode systems which have been in use for a minimum of 5 years and which have extensive, generally successful, track records are covered in 6.2.1 and 6.2.2. It is not intended that the use of other, perhaps newer or less well proven, anode materials is to be precluded as this would restrict the necessary and advantageous development of new, possibly improved, anode materials. Anodes are listed non-exclusively in Annex C.

It is likely that new and effective anode materials will be developed for cathodic protection of steel in concrete. It is not the purpose of this document to preclude their use. It is recommended that the use of any anode should only be undertaken where performance can be demonstrated by laboratory testing, trials and/or past projects.

It is suggested that new anode materials for cathodic protection of steel in concrete should be the subject of rigorous laboratory testing and, wherever possible, extended and/or accelerated field trials prior to commercial non-trial applications.

NOTE 3 There is an established test method for accelerated life testing of anodes embedded in concrete, NACE/TM 0294[12] and for organic-based conductive-coating anodes.[13]

Anode systems used for the protection of steel in buried or immersed concrete are detailed in European Standards EN 12473, EN 12954, EN 12495, EN 12474 and ISO 13174.

6.2.1 Conductive coating anode systems

6.2.1.1 Organic coatings

These coatings are used as impressed current anodes.

The anode system shall comprise an organic conductive coating (solvent based or water soluble, containing a carbon conductor) and a series of conductors (primary anodes) fixed to the concrete surface or integrated into the coating, in order that the conductors can distribute current within the coating. The conductors shall be of material able to resist anodic reactions, e.g. platinum-coated or platinum-clad titanium or niobium which may be copper cored, or mixed metal-oxide-coated titanium.

The combination of conductive coating and primary anodes shall be demonstrated by trials or past projects to enable the design anode performance to be achieved. The spacing of primary anodes within the conductive coating shall be such that it can be calculated or demonstrated that the variation in anode current output attributable to the resistance, within the coating, between primary anodes, does not exceed ±10 % of the average current output measured as a ±10 % voltage drop.

The particular application technique selected shall be demonstrated by trials or past projects to enable the design anode performance to be achieved.

The adhesion of the coating to the concrete, subject to appropriate surface preparation and the above application technique, shall be suitable to achieve the full design life of the anode system.

Data shall be provided determining the wet and/or dry film thickness requirements to achieve the required dry film conductivity.

See Annex C for further information.

6.2.1.2 Thermally sprayed metallic coatings

The anode system shall comprise a thermally sprayed metallic coating of Zn, Al-Zn, Al-Zn-In or Ti.

The Zn coatings are used both as impressed current anodes and as galvanic anodes; the Al-Zn and Al-Zn-In alloy anodes are used as a galvanic anode. Ti is used as an impressed current anode with a catalytic spray to lower the anode-to-concrete interfacial resistance.

When thermal sprayed metallic coatings are used as galvanic anodes, they may be applied directly to the reinforcement/steel where it is exposed, as well as predominantly to the sound concrete surface.

A humectant may be applied to thermal sprayed metallic coatings used as galvanic anodes to enhance their performance.

To avoid atmospheric corrosion and prolong the lifetime of the anode, an organic top-coating may be applied to the thermal sprayed metallic layer.

The combination of metallic coating and connectors shall be demonstrated by trials or past projects to enable the design anode performance to be achieved.

The particular application technique selected shall be demonstrated by trials or past projects to enable the design anode performance to be achieved.

The adhesion of the coating to the concrete, subject to appropriate surface preparation and the above application technique, shall be suitable to achieve the full design life of the anode system.

Data shall be provided for determining the application process requirements to achieve the required film thickness and conductivity.

Metallic connectors (of Cu, Cu-Zn-alloys, Ti or steel) mechanically bonded to the concrete surface shall be installed prior to metallic coating application.

See Annex C for further information.

6.2.2 Activated titanium anode systems

6.2.2.1 General

These anodes are used as impressed current anodes.

The anode system shall comprise a substrate of titanium[14] and an electrocatalytic coating containing oxides of platinum group metals, platinum, iridium or ruthenium along with oxides of titanium,