INTERNATIONAL STANDARD

ISO 23466

First edition
2020-10

Design criteria for the thermal insulation of reactor coolant system main equipments and piping of PWR nuclear power plants

Critères de conception du calorifuge des composants primaires principaux et des tuyauteries du circuit primaire principal des centrales nucléaires REP

Reference number
ISO 23466:2020(E)

Published in Switzerland

Contents

Page

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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 voluntary nature of standards, 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.

This document was prepared by Technical Committee ISO/TC 85, *Nuclear energy, nuclear technologies, and radiological protection*, Subcommittee SC 6, *Reactor Technology*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Design criteria for the thermal insulation of reactor coolant system main equipments and piping of PWR nuclear power plants

1 Scope

This document specifies the basic requirements of thermal insulation design of reactor coolant system (RCS) equipment and piping.

Among thermal insulation of various RCS equipment and piping, the following two kinds of thermal insulations are described in detailed based on common design logic and requirements:

— thermal insulation of reactor pressure vessel (RPV);

— thermal insulation of RCS piping and other equipment.

This document is valid for two types of thermal insulation:

— metallic thermal insulation;

— non-metallic thermal insulation.

This document mainly applies to nuclear power plants with pressurized water reactor (PWR). For other reactor types, this document can be taken as reference.

2 Normative references

The following standards 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 standards (including any amendments) applies.

ISO 7345, *Thermal performance of buildings and building components — Physical quantities and definitions*

ISO 9229, *Thermal insulation — Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 7345, ISO 9229 and the following apply.

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

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

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

3.1
metallic thermal insulation
thermal insulation with metallic material as the primary insulating material

Note 1 to entry: The metallic thermal insulation is composed by large number of thermal insulation panels. Each thermal insulation panel is surrounded by outer cladding and filled by inner metallic reflective foils/sheets. The geometry of inner packed foils/sheets can be embossed structure or liners in parallel.

Note 2 to entry: The typical geometry of metallic thermal insulation is shown in Annex A. The geometry mentioned in Annex A can be referred by designers.

3.2
non-metallic thermal insulation
thermal insulation with non-metallic material as the primary insulating material

Note 1 to entry: Geometry of non-metallic thermal insulation can be divided into three categories:

— Thermal insulation composed by large number of thermal insulation panels. Each thermal insulation panel is surrounded by outer cladding and filled by inner non-metallic insulating material.

— Layers of non-metallic insulating thermal insulation materials strapped together.

— Thermal insulation mattresses (composed by non-metallic insulating material wrapped in fibre clothing).

Note 2 to entry: The typical geometry of non-metallic thermal insulation is shown in Annex B. The geometry mentioned in Annex B can be referred by designers.

3.3
chimney effect
air circulation between the inner and outer side of thermal insulation originating from heat source

EXAMPLE If clearance and extensive heat exchange paths exist between thermal insulation and the insulated equipment/piping, external cold air would continuously enter from the lower part due to the density and pressure difference between inside and outside of the thermal insulation. The incoming airflow will be heated and thus travels upward to the top of thermal insulation and eventually exits from the upper part.

3.4
thermal bridge
channel with extremely large heat flow due to direct connection between inner/outer surface of thermal insulation and the material with great heat conductivity of the insulated structure

4 General design procedure

4.1 General requirements

The design procedures of thermal insulation shall be comprehensively considered to fulfil all functionalities. The safety class, quality assurance classification and seismic category requirements, which are specified by equipment specification or other relevant documents, shall be satisfied. The design of thermal insulation should take into account the following processes:

— reactor safety considerations;

— material selection;

— design and test of thermal behaviour;

— design and test of mechanical properties, including seismic and vibration resistance, etc.

In addition, other requirements about installation, removing, maintenance, in-service inspection and replacement shall also be considered during the design process of thermal insulation.

4.2 Reactor safety considerations

The design of thermal insulation shall meet the safety requirements specified in the local regulations, codes and standards where the product is manufactured and used. Thermal insulation shall be carefully selected, and its application shall guarantee the fulfilment of its safety functionalities and to minimize interference with other safety functionalities in the event of thermal insulation deteriorating. Meanwhile, the safety requirements of RCS components shall also be considered and specified in the data sheets of thermal insulation.

As a design output of thermal insulation and a design input of safety facilities, the debris source caused by thermal insulation in the event of breaking shall not affect the normal operation of the emergency core cooling system (ECCS), pit strainer and other safety facilities. Quantity and granulometry of debris shall be considered. This consideration applies to the whole thermal insulation system rather than a single local thermal insulation.

For thermal insulation areas where workers may get in contact with or get close to, the outer surface temperature of thermal insulation shall be limited to guarantee human safety.

For thermal insulation, which belong to a nuclear safety related class or provide reactor safety functionalities, the following requirements can be selectively implemented in the design of thermal insulation to meet the functional requirements of the safety system. For thermal insulation, which belong to non-nuclear safety class, the following requirements are not mandatory.

— Under normal service condition or anticipated events, thermal insulation shall withstand corresponding loads and perform all the functionalities during design lifetime.

— Under seismic conditions, thermal insulation shall have its impact on the insulated and adjacent components minimized.

— If any safety functionality needs to be performed by thermal insulation itself, reliable realization of such functionalities shall be ensured.

4.3 Material selection

4.3.1 General requirements

Thermal insulation materials shall meet the reactor safety requirements specified in the local regulations, codes and standards where the product is manufactured and used. Debris source caused by the material itself shall meet relevant requirements given in 4.2.

Thermal insulation materials mainly include primary insulating material, outer cladding/encapsulating material, support/fixation material, etc. Radiation induced material performance degradation over its design lifetime shall be considered during material selection. The maximum service temperature of all materials shall be higher than the design or operating temperature of the insulated equipment and piping. The maximum service temperature shall have appropriate margins.

4.3.2 Primary insulating material

The primary insulating material will have a direct impact on the safety requirement, thermal behaviour, mechanical properties and geometry of the thermal insulation. Therefore, selection of primary insulating material may be carried out firstly. The primary insulating material can be one of the following two types:

a) metallic insulating material;

b) non-metallic insulating material.

As per the classification of primary insulating material, types of thermal insulation should also be classified as metallic and non-metallic thermal insulation.

Metallic insulating material achieves its functionality by virtue of the suppressed heat radiation due to low surface emissivity. Thus, surface brightened metallic material with low surface emissivity may be selected. Austenitic stainless steel is recommended. If the risk of potential hydrogen production and its impact on reactor safety are evaluated and measurements are capable to control the hydrogen concentration under limit, aluminum and galvanized steel are also applicable.

Metallic insulating material shall meet requirements given in relevant standards with regard to chemical composition and properties (including mechanical properties, physical properties and corrosion-resistant properties, etc.), and have good processing performance.

Non-metallic insulating material achieves its functionality by virtue of the suppressed heat convection due to the porous interior structure. Materials such as fibre, microporous material, etc. are recommended.

Non-metallic insulating material and the products made by the non-metallic insulating material shall have good radiation resistance. Such resistance should be validated by irradiation test. No obvious embrittlement, pulverization, contraction and thermal conductivity increasing shall occur over the design lifetime.

Over its design lifetime, non-metallic insulating material shall also be able to resist steam, moisture, fungi, disintegration and fire under service conditions.

Any noxious or harmful effect (formaldehyde emission, carcinogenicity and other possible harmful factors) caused by the non-metallic material shall be limited in accordance with the local regulations, codes and standards where the product is manufactured and used. Strict control of organic binder shall be imposed for non-metallic materials.

For equipment and piping insulated and contacted directly with non-metallic insulation, the tendency of stress corrosion cracking shall be evaluated. No mass production is allowed unless this tendency is proved to be trivial. For non-metallic insulating material applied for austenitic steel components, the level of leachable chloride, fluoride, sodium and silicate ions as well as pH value of leached water shall be strictly limited.

4.3.3 Outer cladding/encapsulating material

The outer cladding/encapsulating material is used for manufacturing the cladding shell, encapsulating panel or other outer protective parts for the primary insulating material. During the design lifetime, the material shall have enough strength to withstand loads acting on the cladding/encapsulating parts. In order to satisfy sealing requirement under different service conditions, processes including riveting, fillet welding, intermittent welding, and seal welding can be adopted for the cladding shell and encapsulating panel assembling. If the outer cladding/encapsulating material is different from the primary insulating material or the adjacent equipment/piping material in contact, the influence of corrosion and other negative tendency caused by the contact between different types of materials shall be evaluated and the tendency shall be proved to be trivial before mass production.

4.3.4 Support/fixation material

The support/fixation material is used for manufacturing support frame, support leg, strap or other parts for supporting and fixing the thermal insulation. During the design lifetime, the material shall have enough strength to withstand loads acting on the support/fixation parts. If the support/fixation material is different from the primary insulating material or the adjacent equipment/piping material in contact, the influence of corrosion and other negative tendency caused by the contact between different types of materials shall be evaluated and the tendency shall be proved to be trivial before mass production.

4.4 Design and test of thermal behaviour

4.4.1 Design of thermal behaviour

In the design of thermal behaviour, the surface temperature or heat productivity of insulated equipment and piping may be considered as the design input, the heat loss limit of insulated equipment and piping may be set as design objective. This heat loss limit is generally specified in the equipment specification or other corresponding documents and mainly described by the following parameters:

— heat flux of thermal insulation outer surface;

— temperature of thermal insulation outer surface;

— heat loss of thermal insulation.

After the above design input and objective are provided and specified, the design thickness of thermal insulation shall be determined by theoretical method. Calculation of the design thickness is based on Formula (1) or Formula (2). Formula (1) applies to the calculation under heat transfer through flat wall, while Formula (2) applies to the calculation under heat transfer through cylinder wall. Also, Formula (3) gives the calculation method of heat flux from heat loss. The design thickness of the insulation can then be determined. Formula (3) can also be used to verify the heat flux calculation result by checking the compatibility with heat loss limit.

The thermal conductivity coefficient λ in Formula (1) and Formula (2) can be obtained from standards or heat transmission test described in 4.4.2. For the heat transfer coefficient, h, both heat convection transfer coefficient, h_c, and heat radiation transfer coefficient, h_r, of the thermal insulation outer surface shall be taken into account, as shown in Formula (4). Appropriate safety margin shall be considered for the design thickness.

It shall be noted that the calculated design thickness is the net thickness of the primary insulating material, excluding outer cladding, encapsulating or any other material without thermal insulating functionality.

The following formulae are only applicable to basic theoretical calculation. Other methods with corrected/optimized factors or empirical formulae are also allowed depending on the actual design and application conditions of the thermal insulation.

$$q = \Delta T / \left(\frac{\delta}{\lambda} + \frac{1}{h} \right) \tag{1}$$

$$q = \Delta T / \left(\frac{d_o}{2\lambda} \times \ln \frac{d_o}{d_i} + \frac{1}{h} \right) \tag{2}$$

$$Q = q \times A \tag{3}$$

$$h = h_c + h_r \tag{4}$$

where

- q is the heat flux of thermal insulation;
- ΔT is the temperature difference between inner and outer surfaces of thermal insulation;
- λ is the thermal conductivity coefficient of thermal insulation;
- δ is the design thickness of thermal insulation under heat transfer through flat wall;
- d_o is the design outer diameter of thermal insulation under heat transfer through cylinder wall;
- d_i is the design inner diameter of thermal insulation under heat transfer through cylinder wall;
- h is the heat transfer coefficient of thermal insulation outer surface;
- h_c is the heat convection transfer coefficient of thermal insulation outer surface;
- h_r is the heat radiation transfer coefficient of thermal insulation outer surface;
- Q is the heat loss of thermal insulation;
- A is the heat transfer area of thermal insulation.

The shape and the direction of the thermal insulation, the ambient temperature and the ventilation condition should all be considered when calculating the heat convection transfer coefficient of outer surface. The different calculation methods can be adopted based on certainty conditions. The heat radiation transfer coefficient shall be consistent with the primary insulating material properties.

In addition, thermal expansion induced displacement of thermal insulation and insulated equipment and piping should be considered, expansion and contraction during start-up and shutdown of the reactor should also be considered. Obvious effects of the functionalities of typical insulation parts due to thermal stress or deformation shall be verified by corresponding analyses.

Calculation only by theoretical formulae is acceptable if the geometry and heat transfer conditions are simple. If various heat transfer influence factors exists or the shape of insulation is complex and irregular, finite element method or other verified equivalent analysis method should be used to calculate the heat flux, temperature distribution and heat loss.

If the heat exchange paths between inner and outer side of thermal insulation are unavoidable, chimney effect shall be accounted for thermal behaviour prediction.

For factors hard to model or quantify (e.g. ventilation and chimney effect), conservative assumption regarding such factors should be considered to ensure the analysis results are enveloped with sufficient confidence.

4.4.2 Test of thermal behaviour

After the primary insulating material has been selected, the thermal conductivity coefficient should be obtained by heat transmission test. This heat transmission test can be performed on the material itself or on typical thermal insulation panel. In order to obtain the thermal conductivity coefficient as close to the actual in-service condition as possible, the unidirectional heat transmission test for typical thermal insulation panel is preferred.

Heat transmission test with simulated actual service condition can be performed before thermal insulation design is finalized for suppliers involved in the design of thermal insulation for the first time. Such a test should also be performed if a new geometry, a new material or a new process is introduced without previous experiences for the mass production. Heat transfer calculation results for thermal behaviour design can be validated by such a test.

Main factors (including hot surface temperature, ambient temperature, nearby ventilation condition, etc.) that effect the heat transfer behaviour of the thermal insulation should be simulated in this test. The geometry, material and manufacturing process of the heat transmission test specimens shall be representative of the actual products.

4.5 Design and test of mechanical properties

4.5.1 Design of mechanical properties

In the design of mechanical properties of thermal insulation, the loads under different design conditions may be considered as design input, the fulfilment of different functionalities or structural integrity requirement under various conditions may be set as design objective.

The design input includes, but not limited to, the following loads:

— the mass of the thermal insulation and its accessories;

— the loads due to thermal expansion and contraction of the thermal insulation itself;

— the loads due to vibration;

— the loads due to seismic condition and other external hazards (if any);

— the loads caused by other adjacent equipment interfaced with the thermal insulation (if any);

— the loads due to pre-service inspection (if any);

— the loads due to the thermal expansion and contraction of insulated equipment and piping (if any);

— additional loads caused by safety functionalities performed by the thermal insulation itself (if any).

Combination of different loads can be applied in consistent with certain design requirements. The combination of loads shall represent the most severe load under this condition.

The mass of the thermal insulation and its accessories, the loads due to the thermal expansion and contraction of the thermal insulation itself, and the loads due to vibration shall be combined for the calculation.

If the whole or part of the thermal insulation belongs to anti-seismic related category, loads due to seismic condition shall be additionally combined.

Other kinds of loads can be selectively combined according to the functionalities and service conditions of the specific parts of thermal insulation.

The above listed loads are typical examples, the actual loads and their combinations to be considered in the design of thermal insulation should be determined based on the safety class and seismic category of thermal insulation as well as the local design standard applied by the designer.

The design objective of the mechanical properties shall meet the requirements given in 4.2.

To evaluate the design objective of mechanical properties, calculation shall be carried out to verify the strength of relatively weak parts of the thermal insulation, e.g. connections (welds, bolts, lockers, etc.), cantilever or other beam-like supports, lifting lugs or other geometries for installations, etc. The calculation and the result should represent the most severe conditions.

The calculation of tensile, compressive, shear, bending stress and their combinations at the abovementioned weak parts under various loads shall be carried out to verify the strength. The calculated stress value shall be less than the allowable stress of the selected material itself. The value of the allowable stress is determined by the mechanical properties calculation standard applied by the designer and the service condition for thermal insulation.

A detailed design of thermal insulation geometries shall be determined according to the evaluation results of the mechanical properties (e.g. type and dimension of welds, number and specification of bolts, geometry and dimension of supports, etc.).

Calculation only by theoretical formulae is acceptable if the geometry details and loading conditions are simple. If multiple loading inputs exist or the shape of insulation is complex and irregular, finite element method or other verified equivalent analysis method should be used to calculate the stress, strain and displacement.

For factors hard to model or quantify (e.g. complicated geometry details and loading conditions), conservative assumption regarding such factors can be considered to ensure the analysis results are enveloped with sufficient confidence.

4.5.2 Test of mechanical properties

After the design of thermal insulation panels and its connections, supports, fixation geometries are finalized, the following tests of typical mechanical properties can be selectively conducted:

— mechanical properties test of thermal insulation connecting joints (including threaded-connection, welded joint, locker, etc.);

— locking mechanisms test of lockers;

— vibrational test of typical thermal insulation panel and associated connecting and support/fixation geometries;

— verification test of integrity maintenance of a single thermal insulation panel subject to external load.

According to the design requirements, functionalities and the anti-seismic category of thermal insulation under earthquake condition, analysis or test can be carried out to verify its anti-seismic capability. Such analysis or test is not mandatory if thermal insulation belongs to non-seismic category.

For thermal insulation with debris source limit under LOCA condition, verification test of impact resistance and the actual debris amount of typical thermal insulation panel can be selectively carried out. Such tests adopt simulated LOCA load.

For the above tests, the geometry of test specimens shall be representative of actual products.

4.6 Additional requirements

In addition to the requirements in 4.1 to 4.5, the following requirements shall also be met.

The overall shape of thermal insulation should be similar to the shape of insulated equipment and piping. On the premise that the requirements of overall heat loss are satisfied, the outer surface of insulated equipment and piping can be entirely or partially covered by thermal insulation depending on accessibility or other reasons. If any direct gap or heat exchange path exists between inner and outer side of thermal insulation, special attention shall be paid to minimize possible chimney effect and thermal bridge effect. Such requirement shall be emphasized for the design of joints and penetrations.

According to different requirements of mechanical properties, geometry, installation and operation, the support/fixation parts can be set selectively.

It is generally not recommended to weld the support/fixation parts directly on the insulated equipment and piping. If any part of thermal insulation needs to be connected with insulated equipment and piping (in the form of welding, drilling, tapping, etc.), evaluations on the influence of the connection form on the joints shall be performed.

Negative influences on thermal insulation functionalities caused by surface condensate water or other possible external fluid shall be avoided.

The geometry design shall meet the installation requirements for different thermal insulation parts. Such requirements include installation timing, subsequence, accessibility, and operation space for installation tools and workers.

The geometry design shall ensure the penetrations of the insulated equipment or piping be able to pass through the thermal insulation and shall not affect functionalities of the penetrations.

The geometry design shall meet the requirements for in-service inspection accessibility and maintenance feasibility (if required) of the thermal insulation itself and the insulated equipment and piping.

According to the need of insulated equipment and piping, the ambient condition, the accessibility for in-service inspection and the maintenance requirements, two types of thermal insulation can be selected, removable or non-removable. The removable thermal insulation panel shall meet the following requirements:

— Easy for quick removal and re-installation and labelled with permanent marks.

— Be with enough rigidity to avoid deformation and damage during numerous removal, re-installation and overhaul operations.

— Be equipped with parts which are for handling, lifting or dismantle (such as folded or unfolded handle). The mass of a single removable panel shall be less than the operation limit of individual maintenance worker. The recommend maximum mass is 25 kg.

5 Design requirements of RPV thermal insulation

5.1 General requirements

According to the covering range, RPV thermal insulation can be divided into two parts, closure head thermal insulation and reactor vessel thermal insulation.

Depending on their radiation dose, different primary insulating material may be selected for the above two parts of RPV thermal insulation.

Metallic thermal insulation should be mainly used for reactor vessel thermal insulation. For few locations with complicated shape or penetrations surrounding zone, non-metallic insulating material can be used for filling, but it is recommended to use a metallic cladding.

Both metallic and non-metallic thermal insulation should to be used for closure head thermal insulation. The in-service radiation dose shall be taken as the key consideration for material selection. Cumulative material property degradation caused by radiation dose received over the whole design lifetime shall be considered for material selection.

The design lifetime of RPV thermal insulation shall be determined by its repair and replacement conditions. For non-repairable and irreplaceable thermal insulation, its design lifetime shall be the same as that of RPV.

In addition to requirements given in Clause 4, the design of RPV thermal insulation shall also be consistent with the remainder of Clause 5.

5.2 Safety requirements

For RPV thermal insulation, which belong to nuclear safety related class or with reactor safety functionalities, the following safety related design can be selectively performed to meet the functional requirements of safety system. For RPV thermal insulation, which belong to non-nuclear safety class, the following requirements are not mandatory.

During or after any condition (including normal service condition and design basis accidents), the thermal insulation structural integrity shall be kept and not affect functionalities of the insulated and adjacent components. Especially, RPV thermal insulation shall not prevent the intended functionalities of safety related systems. The safety related systems include but not limited to RPV and its connected piping, ex-core detectors, ECCS, etc.

If RPV thermal insulation is designed with additional safety functionalities, such safety functionalities shall be completely realized under corresponding conditions.

A type of RPV thermal insulation with RPV external cooling safety functionality is described in Annex C. The design recommendations given in Annex C can be referred by designers.

A type of RPV thermal insulation with radiation shield safety functionality is described in Annex D. The design recommendations given in Annex D can be referred by designers.

5.3 Material selection

The metallic material shall be radiation-resistant and no obvious material property degradation caused by neutron radiation and gamma rays is allowed during the whole design lifetime.

The immersion of metallic material in boric water, sodium hydroxide or tri-sodium phosphate under specific concentration over short period of time shall be allowed with its functionality remain unaffected.

The metallic reflective sheet and foil used in the thermal insulation shall be flat, bright and with low emissivity.

Non-metallic insulating material with low thermal conductivity and density is recommended.

5.4 Thermal behaviour requirements

The thermal conductivity coefficient of a single thermal insulation panel can be obtained from standards or heat transmission test. The test method according to ISO 8990 should be used. Other equivalent test methods may be used.

Heat transmission test with simulated actual service condition may be performed before thermal insulation design is finalized for suppliers involved in the design of thermal insulation for the first time. Such a test should also be performed if a new geometry, a new material or a new process is introduced without previous experiences for the mass production. Heat transfer calculation results for thermal behaviour design can be validated by such a test. The requirements of such a heat transmission simulation test shall be consistent with 4.4.2.

5.5 Mechanical properties and structural requirements

In addition to the requirements in 5.1 to 5.4, the following requirements shall also be met.

When dynamic analysis is required for RPV thermal insulation, both equivalent static method and modal response spectrum method may be used. No resonance shall occur during reactor operation. Loads and their combinations used in the dynamic analysis should be determined based on the safety class and seismic category of thermal insulation as well as the design standard applied by the designer.

After installation, appropriate gaps can be reserved between the panels on hot surfaces to allow for free expansion. Alternatively, expansion joints may be applied to permit the thermal expansion movement of thermal insulation. When clamps are used for connection or fixation, thermal expansion difference shall be considered.

Closure measures (such as laps, Z-shaped seals and seal ring, etc.) shall be taken to close the panel-panel or the panel-penetration geometry gap to prevent thermal bridges.

For RPV thermal insulation, which belong to anti-seismic related category, anti-seismic and anti-vibration measures (such as anti-vibration damping component) shall be set.

6 Design requirements of thermal insulation of RCS piping and other equipment

6.1 General requirements

Depending on different service conditions and functionality requirements, either metallic or non-metallic thermal insulation may be used for thermal insulation of RCS piping and other equipment.

The design lifetime of metallic thermal insulation shall be determined by its repair and replacement condition. For non-repairable and irreplaceable metallic thermal insulation, its design lifetime shall be the same as for insulated equipment and piping. The design lifetime of non-metallic thermal insulation shall be in consistent with those specified in the equipment specification.

Removable thermal insulation shall be used at locations of the piping and equipment where in-service inspection and maintenance are required (such as welds, nozzles, manholes, hand holes).

In addition to requirements given in Clause 4, the design of thermal insulation of RCS piping and other equipment shall also be consistent with the remainder of Clause 6.

6.2 Safety requirements

For RCS piping and other equipment thermal insulation, which belong to nuclear safety related class or with reactor safety functionalities, the following safety related design may be selectively performed to meet the functional requirements of safety system. For thermal insulation, which belong to non-nuclear safety class, the following requirements are not mandatory.

For thermal insulation of piping, the quantity and morphology features of LOCA induced debris source shall be considered. The area affected by LOCA shall be verified. Analysis of thermal insulation debris movement can also be carried out, if necessary.

6.3 Material selection

The primary insulating materials should have low thermal conductivity, low density, good formability and easy to construct and to maintain.

When metallic thermal insulation is used, the material requirements shall be consistent with the requirements given in 4.3 and 5.3.

When non-metallic thermal insulation is used, the chemical, physical properties and form of the non-metallic primary insulating materials shall meet the requirements specified in the local regulations, codes and standards where the product is manufactured and used.

In addition to the requirements given in 4.3, non-metallic insulating material shall also meet the following requirements:

— Non-metallic insulating material and its product shall have good chemical stability including acid resistance, alkali resistance, moisture resistance and steam resistance. No obvious aging is allowed in the design lifetime.

— Both organic content in non-metallic insulating material and slag content in fibrous material shall be strictly controlled. Limit of such content should be specified in the design technical document.

When carbon steel is used for the support/fixation, the surface of carbon steel shall undergo anti-corrosive treatment. Stainless steel should be used for support/fixation where direct contact occurs between stainless steel equipment/piping and support/fixation.

6.4 Thermal behaviour requirements

For flat surface, or cylindrical surface of equipment or piping with diameter greater than 1 000 mm, the thermal conductivity coefficient of the primary insulating materials used in thermal insulation design should be tested according to ISO 8302. For cylindrical surface of equipment or piping with diameter no more than 1 000 mm, the thermal conductivity coefficient of the primary insulating materials used in thermal insulation design should be tested according to ISO 8497. Other equivalent test methods may be used.

Heat transmission test with simulated actual service condition may be performed before thermal insulation design is finalized for suppliers involved in the design of thermal insulation for the first time. Such a test should also be performed if a new geometry, a new material or a new process is introduced without previous experiences for mass production. Heat transfer calculation results for thermal behaviour design can be validated by such a test. The requirements of such a heat transmission simulation test shall be consistent with 4.4.2.

6.5 Mechanical properties and structural requirements

In addition to the requirements in 6.1 to 6.4, the following requirements shall also be met.

The support/fixation shall be adjustable. Appropriate measures shall be taken to prevent loosening.

For non-removable thermal insulation with large thickness, design with staggered layers with all layers using the same material is recommended.

For vertical piping, stop rings shall be set at the end of non-removable thermal insulation layer to prevent slipping.

For vertical equipment and piping, or piping with horizontal angle greater than 45°, a number of bearing rings may be set along the axial direction to distribute the mass of thermal insulation. For thermal insulation made by fibrous material, measurements shall be taken to prevent collapse due to self-mass and vibration.

The outer shell of thermal insulation can be connected with rivets or self-tapping screws. The spacing of rivets or self-tapping screws shall be specified in the design document.

When strapping geometry is applied, the strapping material, number of straps and (or) strapping spacing shall be specified. Thermal insulation with more than two layers should be strapped layer by layer. For the strapping located on the equipment head, movable or fixed rings may be used to fix the layers in a radial way. Spiral winding is prohibited.

Annex A
(informative)

Geometry description of metallic thermal insulation

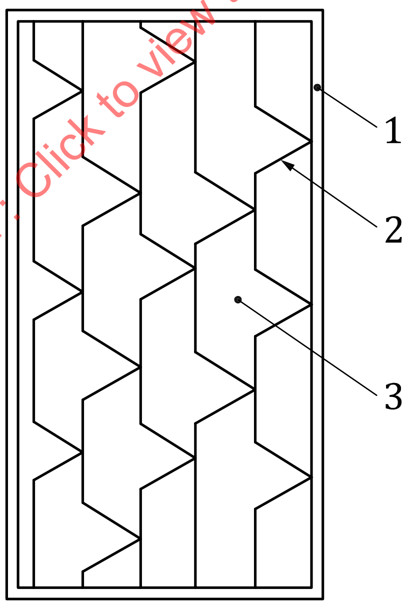
A.1 General

Metallic thermal insulation is composed by large number of thermal insulation panels. A single thermal insulation panel is composed by outer metallic cladding and inner packed metallic insulating layers. Austenitic stainless steel is commonly used for the metallic thermal insulation

The outer metallic cladding is an enclosed cubic shell composed by several rigid steel panels. The outer cladding should withstand all loads on the thermal insulation panel and provide enclosure and protection for inner packed metallic insulating layers.

The inner packed metallic insulating layers are composed by several reflective foils/sheets. With low surface emissivity, the heat radiation transfer should be suppressed. The reflective foils/sheets can be of embossed or parallel liners geometry. For foils/sheets with embossed geometry, the corrugated foils/sheets can be arranged to form separated air spaces between adjacent layers or outer cladding to suppress heat convection transfer.

The geometry of typical metallic thermal insulation panel is shown in Figure A.1 and Figure A.2.



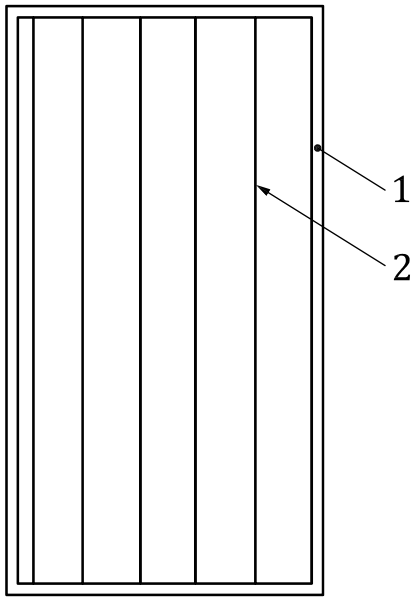
Key

1 outer cladding

2 embossed inner packed reflective foils/sheets

3 separated air spaces

Figure A.1 — Geometry schematic of typical metallic thermal insulation panel with embossed inner packed reflective foils/sheets



Key

1 outer cladding

2 parallel inner packed reflective foils/sheets

Figure A.2 — Geometry schematic of typical metallic thermal insulation panel with parallel inner packed reflective foils/sheets

Annex B
(informative)

Geometry description of non-metallic thermal insulation

B.1 General

The non-metallic thermal insulation can have the following types of geometries:

— composed by thermal insulation panels;

— strapped by layers of insulating material;

— thermal insulation mattresses.

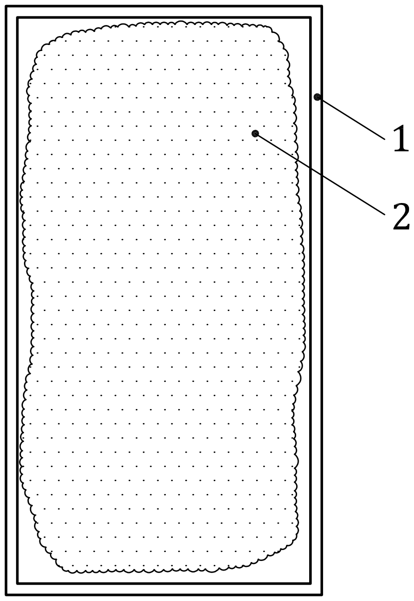
B.2 Non-metallic thermal insulation composed by thermal insulation panels

The non-metallic thermal insulation is composed by a large number of thermal insulation panels. A single thermal insulation panel consists of outer metallic cladding and inner packed non-metallic insulating material. Austenitic stainless steel is commonly used for the outer cladding.

The outer metallic cladding is an enclosed cubic shell composed by several rigid steel panels. The outer cladding should withstand all loads on the thermal insulation panel and provide enclosure and protection for inner packed non-metallic insulating material.

The inner packed non-metallic insulating material is commonly composed by fibre material. The amount of glass fibre is huge and the diameter of each fibre is small. Such properties create a porous media filled with air within the closure. Ensure that the air is well isolated and kept steady by the closure. Thus heat convection and conduction are suppressed.

The geometry of typical non-metallic thermal insulation panel is shown in Figure B.1.



Key

1 outer cladding

2 inner packed non-metallic insulating material

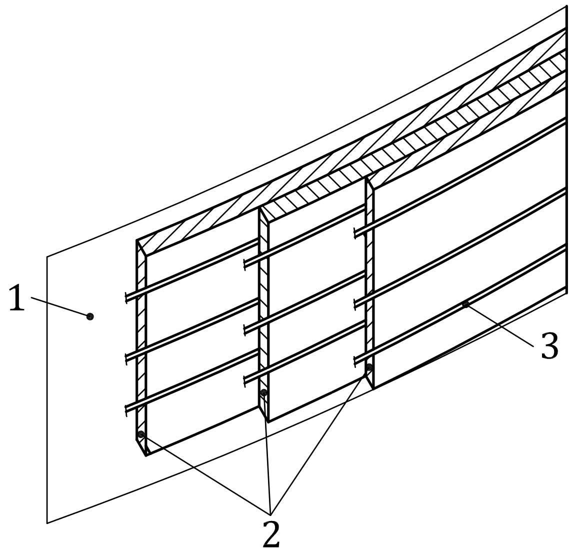
Figure B.1 — Geometry schematic of non-metallic thermal insulation panel

B.3 Non-metallic thermal insulation composed by strapped layers

Non-metallic thermal insulation composed by strapped layers is mainly applied to the equipment head or piping. Layers of non-metallic insulating material can be fabricated as flexible sheets. The layers are covered and strapped along the surface shape of insulated equipment and piping.

The non-metallic insulating material used herein is the same as described in B.2.

The geometry of typical strapped non-metallic thermal insulation is shown in Figure B.2.



Key

1 outer surface of insulated equipment and piping

2 layers of non-metallic insulating material

3 straps

Figure B.2 — Geometry schematic of thermal insulation composed by strapped non-metallic layers

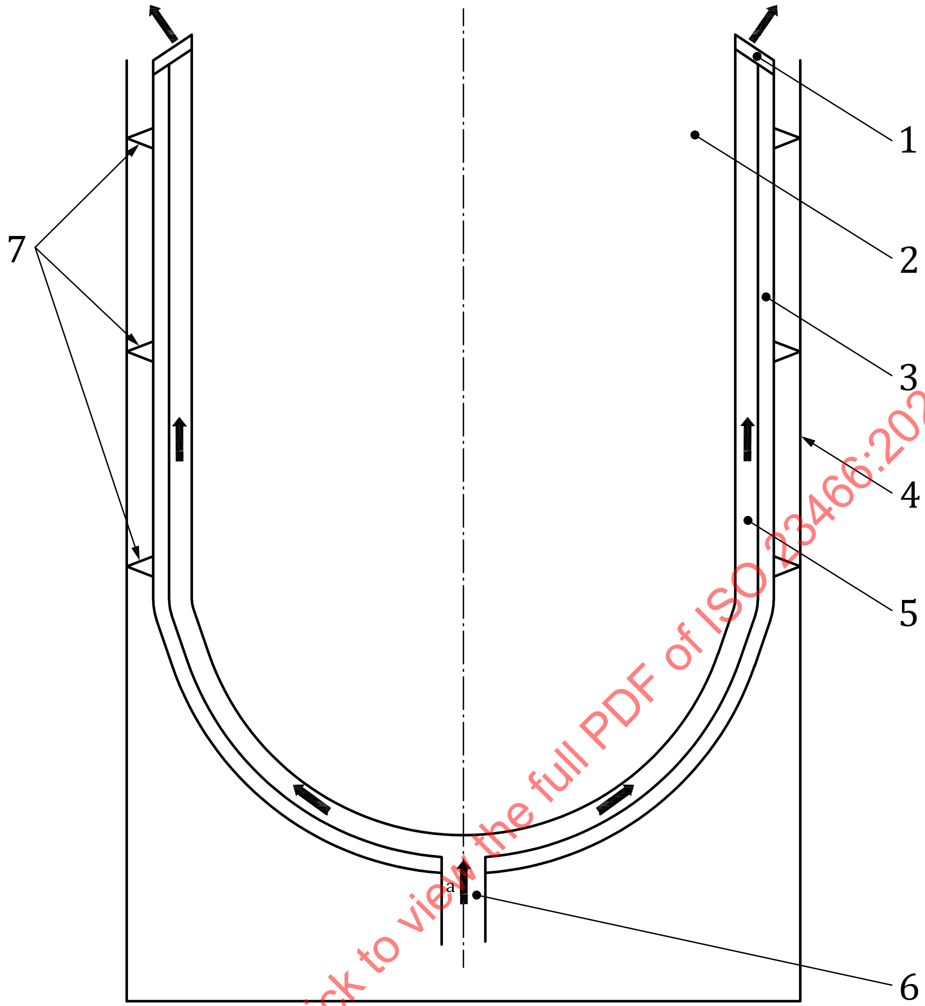
Annex C
(informative)

Type of RPV thermal insulation with RPV external cooling safety functionality

C.1 General

A type of RPV thermal insulation with RPV external cooling safety functionality is shown in Figure C.1. During severe accident of reactor core melting, the thermal insulation should keep its integrity so that an annular flow passage between the RPV outer surface and the thermal insulation is formed. The cavity cooling water will be injected into this annular flow passage through the injection pipeline at the bottom of RPV thermal insulation to cool the RPV. After heated, the cavity cooling water turns to steam/water mixture and exhausts through the water-steam vent at the upper part of thermal insulation. Such RPV external cooling safety functionality can avoid RPV meltdown during severe accident of reactor core melting.

To withstand loads caused by cavity cooling water injection and boiling, supports are generally required to increase the mechanical rigidity of thermal insulation. The supports can be installed and fixed to the reactor cavity wall and floor.



Key

1 cavity cooling water vent
2 RPV
3 thermal insulation
4 reactor cavity wall
5 annular flow passage between RPV and thermal insulation
6 cavity cooling water inlet
7 thermal insulation supports

[a] Arrows represent the movement direction of cavity cooling water.

Figure C.1 — Type of RPV thermal insulation with RPV external cooling safety functionality

C.2 Design recommendations

In order to ensure RPV external cooling safety functionality, the design of RPV thermal insulation should consider the following recommendations:

— RPV thermal insulation and its support should form a reliable low resistance flow passage with adequate cross sectional area to ensure continuous and fluent flow of cavity cooling water for RPV heat removal.

— In addition to the loads given in 4.5.1 and 5.5, RPV thermal insulation support and joints should also have their structural integrity held under the static fluid load and dynamic boiling load of cavity cooling water.

— Heat conduction by thermal insulation supports connected to the reactor cavity wall and floor should not cause the operation temperature of reactor cavity wall and floor to exceed their service temperature limit.

— The annular flow passage should be designed with leakage prevention to ensure that the actual mass flow of cavity cooling water to meet relevant requirements.

— To effectively reduce heat loss during normal operation and form a reliable annular flow passage under severe accident, the cavity cooling water inlet and outlet vent should be designed with passive self-opening functionality (i.e., opened by water buoyancy or water/steam mixture pressure). The inlet and outlet vent should have adequate cross-sectional area to reduce pressure drop, avoid debris clogging and keep clear flow passage. Under normal operation, the water inlet and outlet vent should be self-closed.

— Analysis on mechanical properties should be performed under the special case of reactor core cooling. Stress and deformation analysis on the thermal insulation and its supports should be calculated for evaluation.

