SVENSK STANDARD
SS-ISO 23466:2020

Designkrav för termisk isolering av reaktorkylsystems huvudkomponenter och rörledningar i tryckvattenreaktorer (ISO 23466, IDT)

Design criteria for the thermal insulation of reactor coolant system main equipments and piping of PWR nuclear power plants (ISO 23466, IDT)

Svenska Institutet för Standarder

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Den internationella standarden ISO 23466:2020 gäller som svensk standard. Detta dokument innehåller den officiella engelska versionen av ISO 23466:2020.

The International Standard ISO 23466:2020 has the status of a Swedish Standard. This document contains the official English version of ISO 23466:2020.

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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.

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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.

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

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

$$Q = q \times A \quad (3)$$

$$h = h_c + h_r \quad (4)$$

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