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Method for the justification of fire partitioning in water cooled nuclear power plants (NPP)

Méthode de justification de l'efficacité de la sectorisation incendie des centrales nucléaires utilisant l'eau comme fluide caloporteur

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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).

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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.

This corrected version of ISO 18195:2019 incorporates the following corrections:

— In 5.4.5.4, a few formatting corrections were made;

— In 6.4.7, Figure 13 has been corrected and the key modified accordingly.

Introduction

This document is intended to provide a technical specification to verify the adequacy of the performance of fire partitions in nuclear power plants. The intended audience of this document are fire safety engineers and project designers. Nuclear authorities are also concerned considering that this method is to be used in the process of fire hazard nuclear safety demonstration. The method presented herein includes a combination of standardized testing and ad hoc testing with numerical and empirical calculations. Users of this document are expected to be appropriately qualified and competent in the fields of fire safety engineering, risk assessment and fire resistance standardization.

This document specifies a new methodology to Nuclear Power Plant (NPP) designers, fire safety professionals and nuclear safety authorities. This methodology aims to verify the adequacy of the performance of fire barriers in nuclear power plants in order to avoid fire propagation. This method is a potential tool for risk-informed, performance-based assessment.

NOTE This method is based on the EPRESSI method developed by EDF in collaboration with Efectis France fire safety laboratory in France for EPR reactors[39].

Method for the justification of fire partitioning in water cooled nuclear power plants (NPP)

1 Scope

The document provides:

— guidelines for determining the thermal effects to consider on fire barriers inside a given room;

— guidelines for determining the global performance of the fire barriers based on standard test characterization;

— guidelines for assessing the need for additional tests to verify the robustness of the solution.

Requirements of applicable standards, numerical tools validation and verification (V&V), and the expected qualification of fire resistance laboratories are detailed.

The limitations of the method's applicability and scope are discussed.

The purpose and justification of this document is to describe a new methodology for the verification of the efficiency of fire barriers, which is initially based on a standardized fire resistance test.

The significance of this work relates to the fact that the present methodology will enhance the level of safety by providing more realism to hazards analysis in combination with standardized test data. It completes the standard ISO-fire rating required for justifying the performance.

The most relevant benefit of this method concerns the determination of the global performance of a barrier in a fire of extended duration compared to the classification given by the ISO-fire rating.

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.

ISO 12749-2, *Nuclear energy, nuclear technologies, and radiological protection — Vocabulary — Part 2: Radiological protection*

ISO 12749-3, *Nuclear energy, nuclear technologies, and radiological protection — Vocabulary — Part 3: Nuclear fuel cycle*

ISO 12749-4, *Nuclear energy, nuclear technologies, and radiological protection — Vocabulary — Part 4: Dosimetry for radiation processing*

ISO 12749-5, *Nuclear energy, nuclear technologies, and radiological protection — Vocabulary — Part 5: Nuclear reactors*

ISO 13943, *Fire safety — Vocabulary*

ISO/IEC 17025, *General requirements for the competence of testing and calibration laboratories*

3 Terms, definitions, symbols and abbreviated terms

For the purposes of this document, the terms and definitions given in ISO 13943, ISO 12749-2, ISO 12749-3, ISO 12749-4, and ISO 12749-5 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 Terms and definitions

3.1.1
credited combustible
part of the potential combustible material that will actually participate to the fire development

3.1.2
design basis fire
fire which may break out in any fire source of the plant and which has the severest consequences (duration, severity)

Note 1 to entry: For a given room, it is a fire taking into account all available fuel in this room liable to burn. Its characteristics are calculated taking into account the characteristics of the rooms and fuels.

3.1.3
fire volume
volume inside a building, composed or one or several rooms and designed to prevent the extension of a fire through its boundaries

Note 1 to entry: One of the means of preventing the extension of the fire is to keep it within a limited volume, either physically, by partitions opposing the fire propagation, either spatially, by boundaries associated with the remoteness of the components, with active protection systems (sprinklers), or with passive protection systems (structural features, cable wraps).

3.1.4
fire cell
fire volume (3.1.3) consisting of one or more rooms, bounded by separations guaranteeing that a fire occurring inside cannot extend to the outside or that one occurring on the outside cannot spread to the inside for a given period of time

Note 1 to entry: The boundaries of a fire cell may be either fire-resistant physical barriers, wall, ceiling and floor or *spatial separation* (3.1.15) through openings with a certain configuration and distance rules between combustible sources guaranteeing geographical separations with adjacent rooms and other fire areas. The non-propagation assumption has to be verified (by fire influence studies).

3.1.5
fire compartment
fire volume (3.1.3) consisting of one or more rooms, bounded by material *partitions* (3.1.10) whose fire resistance guarantees that a fire occurring inside cannot extend to the outside or that one occurring on the outside cannot spread to the inside for a given period of time

Note 1 to entry: All the partitions of a fire compartment shall be fire-resistant physical barriers, walls, ceilings, or floors.

3.1.6
fire resistance rating
time during which the fire *partitioning elements* (3.1.9) (partitions, walls, floors, doors, dampers, caulking of penetrations, enclosures of cable racks, etc.) can fulfil their assigned role, despite the effect of a standard fire

3.1.7
low heat load threshold
LHLT
threshold which is introduced to avoid calculations in case of rooms that have too small quantity of combustible material and are neither PFL nor PFG

Note 1 to entry: See 5.4.5.3.

3.1.8
“neither PFG nor PFL” criterion
criterion that is met when the quantity of combustible material is not sufficient to generate a significant fire and does not present risks for spreading to secondary fire sources

Note 1 to entry: By extension, a room is said to be “neither PFG nor PFL” when the concentration of combustible masses in it is not enough to generate a widespread fire (with no necessity of further verification).

3.1.9
partitioning elements
features (partitions, fire walls, ceilings, floors, ducts, seals of openings such as doors, shutters, dampers, hatches as well as seals of cable bushings and piping sleeves) which make up a *partition* (3.1.10)

3.1.10
partition
set of *partitioning elements* (3.1.9) which fully bound the relevant area by *physical separation* (3.1.13)

3.1.11
possibility of a fire getting generalized
PFG criterion
criterion for a fire source when its burning is likely to result in flashover and a generalized fire

Note 1 to entry: By extension, a room is said to be PFG when a fire breaking out in an unfavourable part of the room may result in flashover and generalized fire in the whole room.

3.1.12
all possible fires remaining localized
PFL criterion
criterion for a fire source when its burning shall not result in flashover or propagate to other parts of the *room* (3.1.14)

Note 1 to entry: A fire meeting this criterion remains localised and goes out spontaneously. By extension, a room is said to be PFL when a fire breaking out at the most unfavourable part of the room cannot result in flashover nor propagate to other parts of the room; it remains localised and goes out spontaneously.

Note 2 to entry: The hypothesis of a fire source or room being PFL assumes a single fire source representation but the non-propagation to other fire sources inside or outside the room need a confirmation using a spread temperature threshold (STT).

3.1.13
physical separation
installation of two items of equipment in two distinct *rooms* (3.1.14) of which at least one is inside a *fire compartment* (3.1.5), or protection of one of them by an insulating thermal casing to prevent the simultaneous loss of both items of equipment due to a single fire

3.1.14
room
<common meaning> single volume identified by the user inside the building with no structural separation assumed inside

Note 1 to entry: Its boundaries may or may not be completely closed.

3.1.15
spatial separation
installation of two items of equipment in different *rooms* (3.1.14) or at an adequate distance free of any fuel to prevent fire from spreading

3.1.16
spread temperature threshold
STT
threshold that is considered in the method to determine if there is a risk of spreading of a PFL fire source into a PFG fire source

Note 1 to entry: The STT applies to the hot gas layer (see 5.4.5.4).

3.1.17
standard time temperature curve
temperature-time curve used for the relevant fire resistance standard tests

Note 1 to entry: In the scope of document, this curve is defined according to ISO 834-1:1999, Figure 7. The curve follows the Formula $T = T_0 + 345 \log (8t + 1)$ with t the time (min) and T_0 the initial temperature.

3.2 Symbols

Symbol	Meaning	Unit
A	surface (structures)	m^2
Ao_i	surface of the vertical opening i of the room	m^2
AT	total surface of the walls of the room (excluding surface of openings)	m^2
β_1, β_2	pyrolysis rate coefficients	$kg \cdot s^{-1}$
α	growth factor (heat release rate)	$kJ \cdot s^{-3}$
D	equivalent diameter: $D = \sqrt{4S/\pi}$	m
Ho_i	maximum height of the vertical opening i of the room = distance between the top of the opening and the floor of the room	m
ΔH_C	heat of combustion of a fuel	$kJ \cdot kg^{-1}$
$K\beta$	product of the extinction coefficient of the flame K and a correction factor β	m^{-1}
L	length of the rack	m
M	mass of combustible cables	kg
$\dot{m}$	mass loss rate (= rate of pyrolysis)	$kg \cdot s^{-1}$
$\dot{m}_{max}$	maximum mass loss rate: $\dot{m}_{max} = \frac{\dot{Q}_{max}}{\Delta H_C}$	$kg \cdot s^{-1}$
n_{rack}	number of racks	
$\dot{Q}$	heat release rate	kW
$\dot{Q}_{max}$	maximum heat release rate of the fire source	kW
S	surface (liquid pool)	m
S_t	stoichiometric ratio of a fuel	g_{o2}/g_{fuel}
t	time	s
t_d	Time where the performance curve starts to decrease	s or h
T, θ	temperature	°C or K
T_0	initial ambient temperature	°C or K

Symbol	Meaning	Unit
T_{cor}	correlated temperature gap estimated in the process of material behaviour modelling.	°C or K
$T_{num,i}$	calculated temperature at point "i" (i is an occurrence of experiment/calculation comparison : instant, location)	°C or K
$T_{exp,i}$	experimental temperature at point "i".	°C or K
T_{max}	Maximum temperature at time t_d for a performance curve	°C or K
ΔT_{local}	gap of temperature from initial temperature at a certain location (defined by the applied standard) during a fire resistance test	°C or K
$\Delta T_{average}$	gap of an average temperature (defined by the applied standard) from initial temperature during a fire resistance test	°C or K
$\theta_g(t)$	temperature condition at time t, following an increase law for material performance	°C
ε	emissivity: $\varepsilon_{material}$: emissivity of a material surface. $\varepsilon_{furnace}$: emissivity of a furnace surface	—
X_{O2}	oxygen ratio in the entering air	g_{o2}/g_{air}

3.3 Abbreviated terms

CFD	computational fluid dynamics
HRR	heat release rate
MLR	mass loss rate
MQH correlation	MacCaffrey - Quintiere - Harkleroad correlation
NPP	nuclear power plant
UL	underwriters laboratories

4 Method for justification of nuclear safety fire partitioning: global approach

4.1 Objective of the method

The present method is a tool made available for engineers to check whether the fire resistance performance of the fire partitioning elements in buildings is adequate to resist the design basis fire to which they could be exposed, independently of manual firefighting considerations.

As a prerequisite, prevention against the risks of fire in PWRs is based on the principle of separation of buildings into fire volumes, which are bounded by fire resistant walls. First, the fire protection design basis shall establish the minimum fire resistance rating of the fire partitioning elements.

NOTE Numerical values, empirical correlations or mathematical laws can be fixed by the document, recommended with possibility of change (rec.), or given as example (e.g.). If no indication is given, they are considered as fixed.

4.1.1 The basis of design: standard fire resistance tests

The fire resistance rating of fire partitioning elements is determined by a standard test, in accordance with the regulation and with the standardization.

For other products not covered by standard tests, such as fire resistant housings or enclosures, the fire resistance test may be carried out according to specific procedures. Regardless of the test method employed, the thermal stress applied to the product shall be that of the standard time/temperature curve.

The fire resistance rating of a product is based on national, European or International standards or, when no standard applies, on plant designer specifications respecting the same performance criteria considered in similar standards.

— Thermal effects of the standard fire temperature curve.

— Measurement and qualitative systems for the performance criteria check.

— Temperatures: on elements, on exposed and unexposed surface or inside elements: ambient or surface.

— Electrical equipment functionality test system.

— Pilot flames or a layer of cotton for ignition verification.

— Fixed gauge tubes to check openings through the partitioning elements.

Furthermore, these tests require the use of standardized equipment and a description of its support and assembly. Extensions to the performance checks of different products are made on the basis of these references. Each of these criteria and measurements shall be taken into consideration during the analysis of the product in order to build its performance curve (see Clause 6).

NOTE The fire resistance rating of fire partitioning elements is determined by a standard test, in accordance with the regulation and with the standardization. For instance the rating may be given from the decision of European Commission 2000/367/CE and 2003/629/CE. Depending of the country, alternative standards could be used when needed by the Authority Having Jurisdiction.

The performance can concern:

— R: load-bearing capacity;

— E: integrity;

— I: insulation

— C: self-closing;

— S: smoke leakage;

— W: radiation;

— DH: smoke screen.

The rated time is given in minutes. For example, REI 120 refers to a structure which guaranties load-bearing capacity, integrity and insulation for 120 min. These tests are carried out and approvals delivered by a laboratory approved by the national authorities.

4.1.2 Aim, limitations, and precautions

4.1.2.1 Aim

The method applies to fire barriers qualified with a fire resistance standard.

The present methodology can be adapted to any other standard fire temperature curves and testing conditions, such as those specified by ASTM, UL or any national standardized curve used for qualification.

From European or international standardization (ISO 834 or EN 1363) the fire resistance test is based on a standard time/temperature fire temperature curve with a fast temperature rise, representative of flashover conditions in organic solid fires. The temperature increase is represented by the logarithmic curve, following Formula (1):

$$T - T_0 = 345 \ \log(8t + 1) \tag{1}$$

where

t is the time in min;

T_0 is initial ambient temperature (see Figure 1).

The current methodology extends the performance assessment of a fire resistant product to a longer duration compared to that of the rating assessment. The methodology set up remains within the framework of the fire resistance test, namely a flashover or similar in terms of temperature and pressure distribution.

Unlike the current method of verification of robustness of fire partition elements, it will be the responsibility of the operator to demonstrate that fire resistance tests are representative of operational conditions.

4.1.2.2 Limitations

The aim of the method does not cover certain fire scenarios. For example:

— a fire with a very small heat release rate, in case where the fire barriers includes components likely not to react (e.g.: intumescing elements) or to be activated (e.g.: thermal fuse). Note that additional tests performed at low temperature (see Euroclass "s" classification) may be performed to solve this issue. Of course very small fires are less challenging from a fire hazard point of view and specific demonstration may be proposed for those cases.

— a fire combined with severe pressure conditions (shock wave, blast, etc.): different standards are necessary to evaluate component performance under these conditions.

4.1.2.3 Precautions

Precautions include the following:

— a very fast growth capable of generating thermal shocks greater than those given by the conventional curve (mainly represented by a temperature rise time in °C/min): it can be for example assumed that, based on the recorded sampling time during ISO-fire tests, the maximum temperature rise is limited to 329 °C /min. This should be compared to the maximum temperature increase over 1 minute during the real scenario. Same approach may be performed for any other conventional curves (ASTM, Hydrocarbon, etc.). Nevertheless, this aspect is controlled by the method through the fire temperature curve slope considerations (see 4.2).

— a confined fire excessively ventilated and isolated with a fire load composed on material with high combustion heat is capable to produce very high temperatures (greater than those obtained with the conventional curve during the period tested) : fire behaviour of the partition element in such situation should be assessed using the adapted conventional temperature – time curve. Nevertheless this aspect is controlled by the method through the fire temperature curve maxima considerations (see 4.2).

Additional hose stream tests are sometimes required and are performed at the end of the fire tests for verifying the performance of the products with high-pressure water jet on the exposed phase (for example ASTM E2226[40]). The current methodology is based only on the fire behaviour of the product during the fire test period without taking into account the hose stream tests, which is consistent with the fire resistance ISO standards.

The performance criteria defined for the standard fire resistance rating are also used for assessing performance in the current method. Any adaptation shall be justified.

NOTE The methodology described below is not intended to determine whether a qualification criterion is relevant or not.

4.1.3 Minimum requirements concerning the qualification of the method practitioners

The following method shall be applied by qualified and well-informed practitioners.

The first part of the method (see Clause 5) is appropriate for fire safety engineers with an adequate knowledge of fire safety science and the applicable codes. The organisation shall apply the principles of ISO 9001.

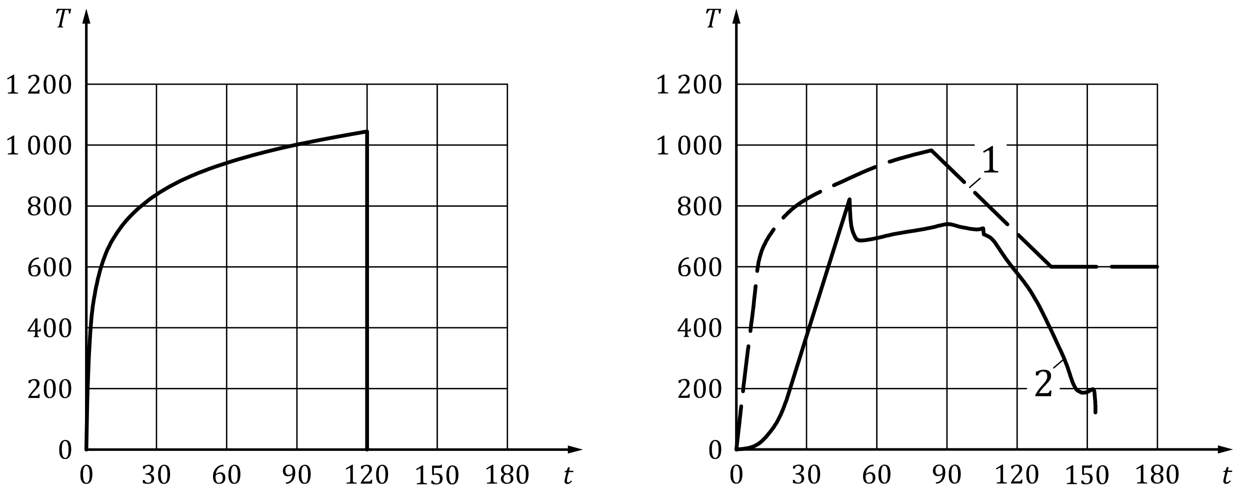
A fire safety laboratory is required for section on determining barrier performance (see Clause 6). As the method requires knowledge and experience not only in the application of standard fire tests, but also in more complex instrumentation processes and engineering models, the capability of the laboratory teams has to be confirmed.

The fire laboratory meet the requirements of ISO/IEC 17025 or an equivalent national alternative for the relevant fire tests.

4.2 General principle of the method

For one room, different design fire scenarios are defined. Each of them leads to one temperature-time curve. The design basis fire temperature curve of the room is a temperature/time curve equal or superior, in each plotted point, to any possible fire conditions concerning the room.

Fire resistance tests are carried out to assess the ability of a given fire barrier to resist the conventional fire (see Figure 1). They do not necessarily reflect its behaviour in a real fire where thermal stress may be, for instance, sharper but shorter or weaker but longer. The present methods consists of creating a set of time/temperature curves that represent the thermal stress a given fire barrier can successfully withstand. This set of curves constitutes the performance diagram of the given fire barrier.



a) ISO 834 (2h rating)   **b) Method application**

Key

t time in min

T temperature in °C

1 fire barrier performance curve

2 room fire curve

Figure 1 — ISO 834 versus method application

The method process consists of:

— setting up performance curves for each fire barrier (one or several curves constituting the fire performance diagram of the barrier);

— setting up the design basis fire temperature curve for each room;

— comparing the design basis fire temperature curve of a given room with the performance curves of the fire barriers in the room;

A fire barrier will be qualified for a given room only if all the following criteria are met by at least one performance curve belonging to the fire performance diagram:

— the maximum slope of the fire temperature curve is less than the maximum thermal gradient of the performance curve;

— the area delimited by the fire temperature curve is smaller than the area delimited by the fire resistance performance curve. Qualitatively, this means the heat of the fire is less than the heat the element can withstand;

— the maximum temperature of the fire temperature curve is less than the maximum temperature of the fire resistance performance curve.

Considering that the design basis fire temperature curve starts with the growth stage of the fire, which presents the maximum slope, at least one fire resistance performance curve of the equipment shall encompass the fire temperature curve of the room to fulfil these criteria (see Figure 2). If not, the equipment will not be validated for the room and a different strategy will be necessary: choice of an element with better fire resistance properties, addition of other means of protection, elimination of combustible loads in the room, etc.

NOTE 1 When comparing the curves, one can translate the design basis fire temperature curve on the time axis in order to demonstrate that it is below a fire resistance performance curve (see Figure 2). In those cases, one shall be careful to fulfil condition 1.