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Fire safety engineering — Requirements governing algebraic formulae —

Part 7:
Radiation heat flux received from an open pool fire

Ingénierie de la sécurité incendie — Exigences régissant les formules algébriques —

Partie 7: Flux de chaleur rayonné reçu d'un feu en nappe ouvert

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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.

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).

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For an explanation of 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 www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 92, *Fire safety*, Subcommittee SC 4, *Fire safety engineering*.

A list of all parts in the ISO 24678 series can be found on the ISO website.

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 24678-7:2019 incorporates the following corrections:

Figure 1: "ISO 23932" has been corrected to "ISO 23932-1:2018". The box titled "selection of engineering methods" has been highlighted.

Figure A.2: The symbol *m*&, estimation of mass burning rate, has been corrected to $\dot{m}''$.

B.3.1.2, Formula B.2: first parenthesis, under the squared root, "x+1/x−1" has been corrected to read "x−1/x+1".

B.3.1.2, Formula B.5: second denominator "r" has been corrected to "r^2".

B.3.3.2.1, Figure B.11 a): The black triangles have been removed.

B.3.3.3.1, Figure B.12: The black rectangle has been removed.

B.3.3.3.1, Figure B.13: "1" has been removed from inside the figure.

B.3.3.3.1, Figure B.14: The horizontal line has been removed.

Introduction

This document is intended to be used by fire safety practitioners involved with fire safety engineering calculation methods. It is expected that the users of this document are appropriately qualified and competent in the field of fire safety engineering. It is particularly important that the users understand the parameters within which particular methodologies can be used.

Algebraic formulae conforming to the requirements of this document are used with other engineering calculation methods during fire safety design. Such a design is preceded by the establishment of a context, including the fire safety goals and objectives to be met, as well as performance criteria when a trial fire safety design is subject to specified design fire scenarios. Engineering calculation methods are used to determine if these performance criteria are met by a particular design and if not, how the design needs to be modified.

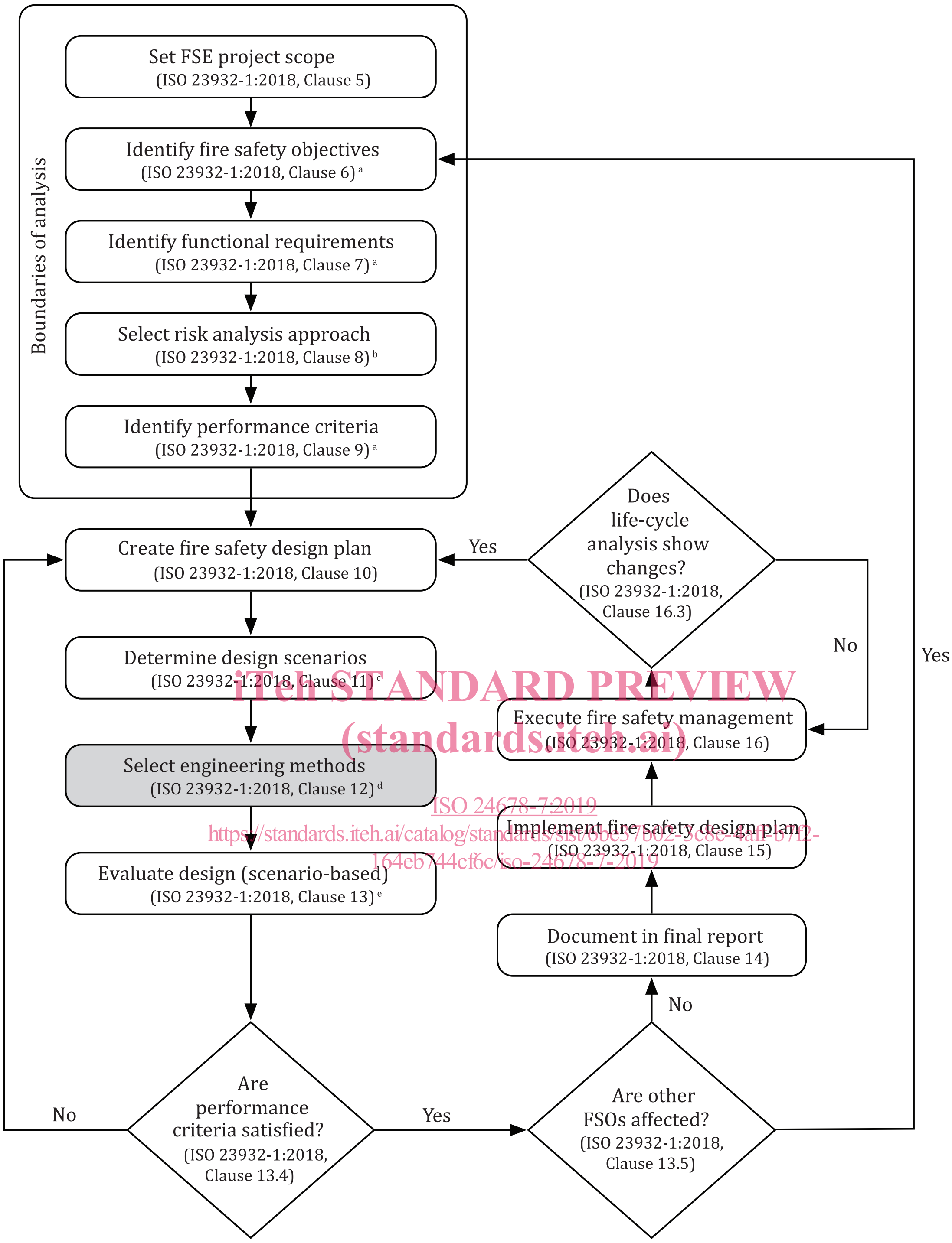
The subjects of engineering calculations include the fire safety design of entirely new built environments, such as buildings, ships or vehicles as well as the assessment of the fire safety of existing built environments.

The algebraic formulae discussed in this document can be useful for estimating the consequences of design fire scenarios. Such formulae are valuable for allowing the practitioner to quickly determine how a proposed fire safety design needs to be modified to meet performance criteria and to compare among multiple trial designs. Detailed numerical calculations can be carried out until the final design documentation. Examples of areas where algebraic formulae have been applicable include determination of convective and radiative heat transfer from fire plumes, prediction of ceiling jet flow properties governing detector response times, calculation of smoke transport through vent openings, and analysis of compartment fire hazards such as smoke filling and flashover. However, the simple models often have stringent limitations and are less likely to include the effects of multiple phenomena occurring in the design fire scenarios.

The general principles are described in ISO 23932-1, which provides a performance-based methodology for engineers to assess the level of fire safety for new or existing built environments. Fire safety is evaluated through an engineered approach based on the quantification of the behaviour of fire and based on knowledge of the consequences of such behaviour on life safety, property and the environment. ISO 23932-1 provides the process (i.e. necessary steps) and essential elements to conduct a robust performance-based fire safety design.

ISO 23932-1 is supported by a set of available fire safety engineering International Standards on the methods and data needed for all the steps in a fire safety engineering design as summarized in Figure 1 (taken from ISO 23932-1:2018, Clause 4). The set includes ISO 16730-1, ISO 16733-1, ISO 16732, ISO 16734, ISO 16735, ISO 16736, ISO 16737, ISO/TR 16738, ISO 24678-6, ISO/TS 24679, ISO 23932-1, ISO/TS 29761 and other supporting technical reports that provide examples of and guidance on the application of these standards.

Each International Standard supporting the global fire safety engineering analysis and information system includes language in the introduction to tie the standard to the steps in the fire safety engineering design process outlined in ISO 23932-1. ISO 23932-1 requires that engineering methods be selected properly to predict the fire consequences of specific scenarios and scenario elements (ISO 23932-1:2018, Clause 10). Pursuant to the requirements of ISO 23932-1, this document provides the requirements governing algebraic formulae for fire safety engineering. This step in the fire safety engineering process is shown as a highlighted box in Figure 1 and described in ISO 23932-1.



Key

a See also ISO/TR 16576 (Examples).

b See also ISO 16732-1, ISO 16733-1, ISO/TS 29761.

c See also ISO 16732-1, ISO 16733-1, ISO/TS 29761.

d See also ISO/TS 13447, ISO 16730-1, ISO/TR 16730-2 to 5 (Examples), ISO 16734, ISO 16735, ISO 16736, ISO 16737, ISO/TR 16738, ISO 24678-6.

e See also ISO/TR 16738, ISO 16733-1.

NOTE Documents linked to large parts of the FSE process: ISO 16732-1, ISO 16733-1, ISO/TS 24679, ISO/TS 29761, ISO/TR 16732-2 to 3 (Examples), ISO/TR 24679-2 to 4 and 6 (Examples).

Figure 1 — Flow chart illustrating the fire safety engineering design process (from ISO 23932-1:2018)

Fire safety engineering — Requirements governing algebraic formulae —

Part 7: Radiation heat flux received from an open pool fire

1 Scope

The requirements in this document govern the application of a set of explicit algebraic formulae for the calculation of specific characteristics of radiation heat flux from an open pool fire.

This document is an implementation of the general requirements provided in ISO 16730-1 for the case of fire dynamics calculations involving a set of explicit algebraic formulae.

This document is arranged in the form of a template, where specific information relevant to the algebraic formulae is provided to satisfy the following types of general requirements:

a) description of physical phenomena addressed by the calculation method;

b) documentation of the calculation procedure and its scientific basis;

c) limitations of the calculation method;

d) input parameters for the calculation method; and

e) domain of applicability of the calculation method.

Examples of sets of algebraic formulae meeting the requirements of this document are provided in Annexes A and B. Annex A contains a set of algebraic formulae for radiation heat fluxes from a circular or near-circular open pool fire. Annex B contains formulae for configuration factors of a flame to a target.

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 5725 (all parts), *Precision of test methods — Determination of repeatability and reproducibility for a standard test method by inter-laboratory tests*

ISO 13943, *Fire safety — Vocabulary*

ISO 16730-1, *Fire safety engineering — Procedures and requirements for verification and validation of calculation methods — Part 1: General*

ISO 16733-1, *Fire safety engineering — Selection of design fire scenarios and design fires — Part 1: Selection of design fire scenarios*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 13943 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 https://www.iso.org/obp

3.1
pool fire
burning of a horizontal, upward-facing, combustible fuel of liquids, liquefied gases or horizontally placed melting plastic materials

3.2
open pool fire
pool fire (3.1) in open air or in a space that is very large relative to the size of the fire, where the confined effect of the built environment on the behaviour of its flame is negligible

Note 1 to entry: The open pool fire characteristics are dependent on the outside conditions such as wind.

3.3
circular or near circular pool fire
pool fire (3.1) whose geometry can be approximated by a circular shape

Note 1 to entry: In case of an elongated pool, this approximation is valid if the ratio between the longest dimension and the shortest dimension is not greater than 2 to 3[1].

3.4
equivalent diameter
diameter of a circular pool whose plan area is equivalent with rectangular or irregularly shaped pools

3.5
absorption coefficient
the fraction of absorbed radiation intensity per unit length of radiation path.

3.6
radiative fraction
ratio of the radiative heat release rate to the total heat release rate

3.7
mean flame height
time-averaged height of flames above the base of a fire, defined as the elevation where the probability of finding flames is 50 %

3.8
atmospheric transmissivity
ratio of the transmitted radiation intensity after passing through unit length of a participating medium (carbon dioxide, water vapour, dust and fog) to the radiation intensity that would have passed the same distance through clean air

4 Requirements governing the description of physical phenomena

4.1 Radiation heat flux from an open pool fire is a complex thermo-physical and chemical phenomenon that can be highly transient or nearly steady-state. Radiation heat flux depends on the combustible properties, the combustible's geometry and the environment between the radiation source and the "target" that receives the heat flux. The properties of the target need to be considered when further calculations of target behaviour are assessed, e.g. injuries to people, malfunction/damage of a piece of equipment, ignition of a combustible material, deteriorations of structural members. The physical phenomena described in this document are concerned with only the calculations of the radiation heat flux received by a target from an open pool fire.

4.2 General types of pool sources, pool geometry and relative positions of the considered targets (including the position of radiation screens placed between the pool and the targets) shall be described with the aid of diagrams.

4.3 Scenario elements, as determined by ISO 16733-1, to which specific formulae apply shall be clearly identified. Radiation heat flux characteristics to be calculated and their useful ranges shall be clearly identified, including those characteristics inferred by association with calculated quantities, if applicable.

4.4 Physical phenomena (e.g. pool formation during a continuous release, interaction between fire and extinguishing materials) to which specific formulae apply shall be clearly identified.

4.5 Because different formulae describe different pool source radiative flame characteristics (see 4.2) or apply to different scenarios (see 4.3), it shall be shown that if there is more than one method to calculate a given quantity, guidance shall be given on the selection of appropriate methods. An example describing the choice of a method is given in Annex A.

5 Requirements governing the documentation

5.1 The general requirements governing the documentation can be found in ISO 16730-1.

5.2 The process to be followed in performing calculations shall be described through a set of algebraic formulae.

5.3 Each formula shall be presented in a separate clause containing a statement that describes the output of the formula, as well as explanatory notes and limitations unique to the presented formula.

5.4 Each variable in the formula set shall be clearly defined, along with appropriate SI units. Formula versions with dimensionless coefficients are usually preferred.

5.5 The scientific basis for the formula set shall be provided through references to recognized handbooks, peer-reviewed scientific literature or through derivations, where appropriate.

5.6 Examples shall be provided to demonstrate how the formula set is evaluated using values for all input parameters consistent with all the requirements of Clause 5.

6 Requirements governing the limitations

6.1 Quantitative limits on the direct application of the algebraic formula set to calculate output parameters, consistent with the scenarios described in Clause 4, shall be provided.

6.2 Cautions on the use of the algebraic formula set within a more general calculation method shall be provided including checks of consistency with the other relations used in the calculation method and the numerical process employed.

7 Requirements governing the input parameters

7.1 Input parameters for the set of algebraic formulae shall be identified clearly, e.g. mass burning rate, pool diameter, etc.

7.2 Sources of data for input parameters shall be identified or provided explicitly.

7.3 The valid ranges for input parameters shall be listed as specified in ISO 16730-1.

8 Requirements governing the domain of applicability

8.1 One or more collections of measurement data shall be identified to establish the domain of applicability of the set of algebraic formulae. The data shall have a certain level of quality in accordance with ISO 5725(all parts) (e.g. repeatability and reproducibility). The level of quality shall be assessed through a documented standardised procedure.

8.2 The domain of applicability of the algebraic formulae shall be determined through comparison with the measurement data as given in 8.1.

8.3 Potential sources of errors that limit the set of algebraic formulae to the specific scenarios shall be identified, e.g. the assumption of quiescent atmosphere.

Annex A
(informative)

Algebraic formulae for thermal radiation from a circular or near circular open pool fire

A.1 Symbols and abbreviated terms used in this Annex

A_s	plan area of a pool fire source (m^2)
D	equivalent diameter of a pool fire source (m)
E	emissive power of a flame (kW/m^2)
E_{max}	emissive power of the luminous region of a flame (kW/m^2)
E_s	emissive power of smoke (kW/m^2)
F_{12}	configuration factor of a flame to a target (–)
$F_{12,h}$	configuration factor of a flame to a horizontal target (–)
$F_{12,v}$	configuration factor of a flame to a vertical target (–)
g	gravity acceleration (9,81 m/s^2)
H	vertical distance from flame base to a target (m)
k	radiation absorption coefficient of a flame from various fuels (m^{-1})
L	mean flame height (m)
$\dot{m}''$	mass burning rate per unit area ($kg/m^2 \cdot s$)
$\dot{m}''_{\infty}$	mass burning rate per unit area of a sufficiently large pool ($kg/m^2 \cdot s$)
m^*	non-dimensional burning rate (–)
$\dot{q}''$	radiation heat flux to a target (kW/m^2)
$\dot{Q}$	heat release rate (kW)
u_w	wind velocity (m/s)
u^*	non-dimensional wind velocity
X	horizontal distance to a target from the centre of a flame (m)
β	radiation absorption coefficient of a flame taking the diameter as the characteristic length (m^{-1})
χ_r	radiative fraction (–)
ΔH_c	heat of combustion of fuel (J/kg)

θ flame tilt angle (rad)

ρ_a density of normal ambient air (1,2 kg/m^3)

τ atmospheric transmissivity (–)

A.2 Description of the physical phenomena addressed by the algebraic formula set

A.2.1 General

The formulae described in this annex provide radiation heat fluxes from a pool fire to a target and can be applicable to various locations and orientations. The set of formulae is particularly convenient for horizontal and vertical target orientations. The formulae presented here have been validated on sooty liquid hydrocarbon fires.

A.2.2 General description of the calculation method

Estimating the radiation heat flux received by a target from a pool fire involves the three following steps:

— determination of the characteristics of the pool fire (burning surface, mass burning rate, duration of the fire, time to steady-state conditions, etc.);

— determination of the thermal radiation characteristics of the pool fire (flame height, flame tilt, emissive power of the flames, etc.);

— calculation of the radiation heat flux received by a target (configuration factor of a flame to a target, atmospheric transmissivity along radiation path).

It is very important that a single method be used for all the three steps of this process. The methods presented in this annex constitute whole methods and its parts cannot be changed. The validation of the whole model needs to be considered, not its components individually.

A.2.3 Scenario elements to which the set of formulae is applicable

The set of formulae is applicable to thermal radiation from quasi-steady-state pool fire flames that are approximately circular or square in plan area in an unobstructed environment, unless otherwise stated.

A.2.4 Self-consistency of the set of formulae

The set of formulae provided in this annex has been derived and reviewed to ensure that the calculation results from different formulae in the set are consistent (i.e. do not produce conflicts).

A.2.5 Standards and other documents where the set of formulae is used

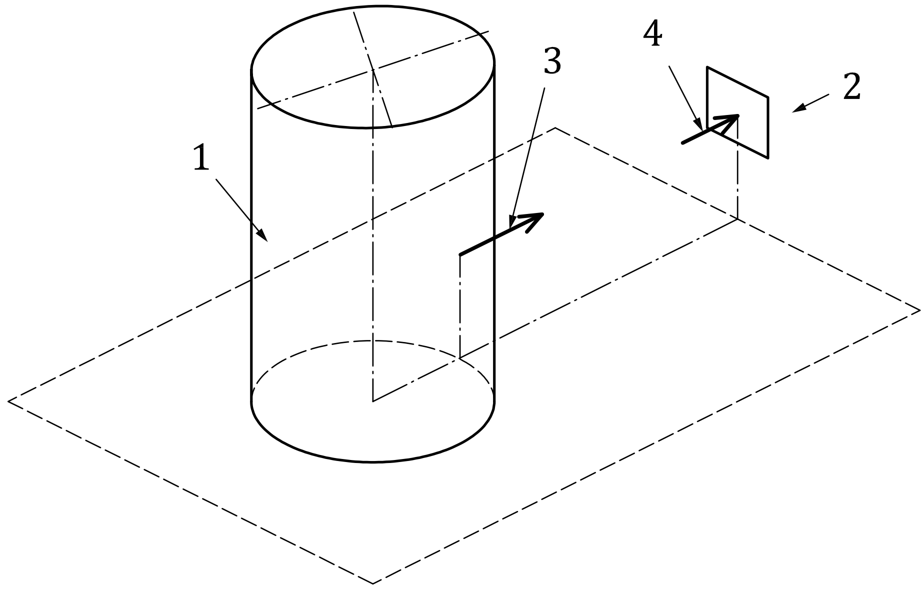
None specified.

A.3 Documentation of the set of formulae

A.3.1 General

As shown in Figure A.1, radiation is emitted by a flame and received by a target. The heat flux received by a target from a pool fire can be calculated with the following algebraic formula:

$$\dot{q}'' = \tau E F_{12} \quad \text{(A.1)}$$



Key

1 flame (surface 1)
2 target (surface 2)
3 emissions (to all directions)
4 heat flux to a target

Figure A.1 — Radiation from a flame to a target

Figure A.2 depicts the successive steps to estimate the radiation heat flux received by a target from a pool fire. From the specified burning object characteristics, the heat release rate and the diameter of the pool, when not given, are estimated. The emissive power from the flame surface is assumed to be a function of the diameter of the pool. The flame geometry is calculated by using the heat release rate and fire source diameter. Finally, the configuration factor of a flame to a target is calculated. The effect of blockage by a participation medium such as soot, water vapour and dipole gases is considered, where necessary, as atmospheric transmissivity.

The target is considered as an infinitesimally small plane element, which is assumed to be located at the minimum distance between the fire and the real target. Because configuration factors are also considered in the calculations of the physical phenomena, the point is associated with an element surface. In the rest of this document, the target will be seen as a unit surface of a target. In this annex, a solid cylindrical flame model is adopted. As presented in Figure A.2, the method is composed of different interdependent sub-models, mean flame height, emissive power and so on.