# INTERNATIONAL STANDARD

# ISO 16734

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# Fire safety engineering — Requirements governing algebraic equations — Fire plumes

*Ingénierie de la sécurité incendie — Exigences régissant les équations algébriques — Panaches de feu*

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## Foreword

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International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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.

ISO 16734 was prepared by Technical Committee ISO/TC 92, *Fire safety*, Subcommittee SC 4, *Fire safety engineering*.

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# Introduction

This International Standard is intended to be used by fire-safety practitioners who employ fire-safety engineering calculation methods. Examples include fire-safety engineers; authorities having jurisdiction, such as territorial authority officials; fire service personnel; code enforcers; and code developers. It is expected that users of this International Standard are appropriately qualified and competent in the field of fire-safety engineering. It is particularly important that users understand the parameters within which particular methodologies can be used.

Algebraic equations conforming to the requirements of this standard are used with other engineering calculation methods during fire safety design. Such 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 tentative fire safety design is subject to specified design fire scenarios. Engineering calculation methods are used to determine if these performance criteria will be met by a particular design and if not, how the design shall be modified.

The subjects of engineering calculations include the fire-safe 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 equations discussed in this standard are very useful for quantifying the consequences of design fire scenarios. Such equations are particularly valuable for allowing the practitioner to determine very quickly how a tentative fire safety design should be modified to meet performance criteria agreed-upon, without having to spend time on detailed numerical calculations until the stage of final design documentation. Examples of areas where algebraic equations have been applicable include determination of heat transfer, both convective and radiant, 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. With respect to fire plumes, algebraic equations are often used to estimate flame dimensions so that the safe separation distance between a potential fire and a vulnerable target can be calculated. Algebraic plume equations are also useful for estimating rates of flame spread, both horizontal and vertical, within a built environment containing combustible materials.

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The algebraic equations discussed in this standard are essential for checking the results of comprehensive numerical models that calculate fire growth and its consequences.

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# Fire safety engineering — Requirements governing algebraic equations — Fire plumes

## 1 Scope

**1.1** The requirements in this International Standard govern the application of explicit algebraic equation sets to the calculation of specific characteristics of fire plumes.

**1.2** This International Standard is an implementation of the general requirements provided in ISO/TR 13387-3 for the case of fire dynamics calculations involving sets of explicit algebraic equations.

**1.3** This International Standard is arranged in the form of a template, where specific information relevant to algebraic fire plume equations 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;

e) domain of applicability of the calculation method.

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**1.4** Examples of sets of algebraic equations meeting all the requirements of this International Standard are be provided in separate annexes to this International Standard for each different type of fire plume. Currently, there is one informative annex containing algebraic equations for quasi-steady state, axisymmetric fire plumes.

## 2 Normative references

The following referenced documents are indispensable for the application 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/TR 13387-3, *Fire safety engineering — Part 3: Assessment and verification of mathematical fire models*

ISO 13943, *Fire safety — Vocabulary*

## 3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 13943 apply.

NOTE See Annex A for the terms and definitions specific to that annex.

## 4 Requirements governing description of physical phenomena

**4.1** The fire plume resulting from a source fire is a complex, thermo-physical phenomenon that can be highly transient or nearly steady state. It contains regions closer to the source fire where there is usually flaming combustion (unless the source is a smouldering fire) and regions further from the source where there is no combustion taking place, but only a turbulent upward flow dominated by buoyancy forces. The fire plume can be significantly affected by many environmental parameters, e.g., the nature and arrangement of the burning materials that act as a fire source, whether there is flaming or smouldering combustion, the type of boundary confinement, degree of air restriction or vitiation, wind flows or compartment air motion, etc. For a liquid hydrocarbon source fire burning in the open under calm (windless) conditions, the problem of describing the fire plume by algebraic equations is simplified since most of these environmental parameters have a negligible influence.

**4.2** General types of source fires, flow-boundary (including symmetry) conditions and other scenario elements to which the analysis is applicable shall be described with the aid of diagrams.

**4.3** Fire plume characteristics to be calculated and their useful ranges shall be clearly identified, including those characteristics inferred by association with calculated quantities (e.g., the association of smoke concentration with excess gas temperature based on the analogy between energy and mass conservation) and those associated with radiant heat transfer to targets remote from the plume, if applicable.

**4.4** Regions of the fire plume (whether or not flaming/combusting, degree of fire source influence, etc.) to which specific equations apply shall be clearly identified.

**4.5** Because different equations describe different plume characteristics (see A.4.3) or apply to different regions (see A.4.4), it shall be shown that if there is more than one method to calculate a given quantity, the result is independent of the method used.

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## 5 Requirements governing documentation

**5.1** General requirements governing documentation can be found in ISO/TR 13387-3.

**5.2** The procedure followed in performing calculations shall be described through a set of algebraic equations.

**5.3** Each equation shall be presented in a separate subclause containing a phrase that describes the output of the equation, as well as explanatory notes and limitations unique to the equation being presented.

**5.4** Each variable in the equation set shall be clearly defined, along with appropriate SI units, although equation versions with dimensionless coefficients are preferred.

**5.5** The scientific basis for the equation set shall be provided through reference to recognised handbooks, the peer-reviewed scientific literature or through derivations, as appropriate.

**5.6** Examples shall demonstrate how the equation set is evaluated using values for all input parameters consistent with the requirements in Clause 4.

## 6 Requirements governing limitations

**6.1** Quantitative limits on direct application of the algebraic equation 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 equation set within a more general calculation method shall be provided, which shall include checks of consistency with the other relations used in the calculation method and the numerical procedures employed. For example, the use of a given equation set for plumes in a zone model can yield different results from another equation set for ceiling jet flows in the zone model, where the plume and ceiling jet zones connect, leading to errors.

## 7 Requirements governing input parameters

**7.1** Input parameters for the set of algebraic equations shall be identified clearly, such as heat release rate or geometric dimensions.

**7.2** Sources of data for input parameters shall be identified or provided explicitly within the International Standard.

**7.3** The valid ranges for input parameters shall be listed as specified in ISO/TR 13387-3.

## 8 Requirements governing domain of applicability

**8.1** One or more collections of measurement data shall be identified to establish the domain of applicability of the equation set. These data shall have level of quality (e.g., repeatability, reproducibility) assessed through a documented/standardized procedure (see ISO 5725).

**8.2** The domain of applicability of the algebraic equations shall be determined through comparison with the measurement data of 8.1, following the principles of assessment, verification and validation of calculation methods.

**8.3** Potential sources of error that limit the set of algebraic equations to the specific scenarios given in Clause 4 shall be identified, for example, the assumption of a point fire source.

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# Annex A
(informative)

# Equations for quasi-steady state, axisymmetric fire plumes

## A.1 Terms and definitions used in Annex A

The terms and definitions given in ISO 13943 and the following apply:

**A.1.1**
**axisymmetric**
mean motion and properties, such as mean temperature rise, are symmetric with respect to a vertical centreline

**A.1.2**
**built environment**
any building, structure or transportation vehicle

EXAMPLE Structures other than buildings include tunnels, bridges, offshore platforms and mines.

**A.1.3**
**characteristic plume radius**
radius at which the time-average plume temperature rise above the ambient value is one-half the centreline value

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**A.1.4**
**combustion efficiency factor**
ratio of the heat of combustion, measured under specific fire test conditions, to the net heat of combustion

**A.1.5**
**convective fraction of heat release rate**
ratio of the convective heat release rate to the heat release rate

**A.1.6**
**convective heat release rate**
component of the heat release rate carried upward by the fire plume motion

NOTE Above the mean flame height, this component is considered invariant with height.

**A.1.7**
**entrained mass flow rate**
air drawn in from the surroundings into the fire plume

NOTE The mass flow rate in the plume at a given level can be considered equal to the mass rate of air entrained below that level into the plume (the fire source contributes an insignificant mass to the plume flow, typically less than 1 % of the total at the mean flame height (see Reference [15]).

**A.1.8**
**fire plume**
upward turbulent fluid motion generated by a source of buoyancy that exists by virtue of combustion and often includes a lower flaming region

**A.1.9**
**flame**
luminous region of fire plume associated with combustion

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**A.1.10**
**fuel mass burning rate**
mass generation rate of fuel vapours

**A.1.11**
**heat release rate**
rate at which heat is actually being released by a source of combustion (such as the fire source)

**A.1.12**
**jet flame**
flame that is dominated by momentum, rather than buoyancy, forces

**A.1.13**
**mean flame height**
time-average height of flames above the base of a fire, defined as the elevation where the probability of finding flames is 50 %

**A.1.14**
**mean temperature rise**
time-average gas temperature increase above the ambient value on the plume centreline

**A.1.15**
**mean vertical gas velocity**
time-average velocity of vertical gas motion on the plume centreline

**A.1.16**
**net heat of combustion**
amount of heat generated per unit mass lost by a material under conditions of complete combustion and water in the vapour phase

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**A.1.17**
**quasi-steady state**
assumption that the full effects of heat release rate changes at the fire source are felt everywhere in the flow field immediately

**A.1.18**
**radiant energy release factor**
ratio of the combustion heat released in a fire as thermal radiation to the net heat of combustion

**A.1.19**
**spatial-average plume temperature rise at a given height**
mean temperature rise in the plume associated with the plume mass flow rate and the plume convective heat release rate

**A.1.20**
**stoichiometric air-fuel mass ratio**
ratio of air to fuel mass that corresponds to complete chemical reaction, i.e., with no fuel or oxygen remaining

**A.1.21**
**virtual origin**
point source from which the fire plume above the flames appears to originate

NOTE The location of the virtual origin is likely to be above the surface of the burning fuel for the case of flammable liquid pool fires having a diameter of about 10 m or less and below the burning fuel surface for pool diameters larger than 10 m to 20 m [see Equation (A.9)].