TECHNICAL SPECIFICATION

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First edition

Fire safety engineering — Selection of design fire scenarios and design fires —

Part 2: Design fires

Ingénierie de la sécurité incendie — Sélection de scénarios d'incendie et de feux de calcul —

Partie 2: Feux de calcul

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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.*

This first edition, in conjunction with ISO/TS 16733-1:2015 cancels and replaces ISO/TS 16733:2006.

A list of all parts in the ISO 16733 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.

Introduction

This document provides guidance for the specification of design fires for use in fire safety engineering analysis. A design fire is linked to a specific scenario that is tailored to the fire-safety design objective. There can be several fire safety objectives being addressed, including safety of life (for occupants and rescue personnel), conservation of property, protection of the environment and preservation of heritage. A different set of design fire scenarios and design fires can be required to assess the adequacy of a proposed design for each objective.

The procedure for the selection of the design fire scenarios is described in ISO 16733-1. The design fire can be thought of as an engineering representation of a fire or a "load" that is used to determine the consequences of a given fire scenario. The set of assumed fire characteristics are referred to as "the design fire". In this document, various formulae are presented to calculate different phenomena. Formulae other than those presented here can also be applicable for a given application.

It is important that the design fire be appropriate to the objectives of the fire-safety engineering analysis. It should challenge the fire safety systems in a specific built environment and result in a final design solution that satisfies performance criteria associated with all the relevant design objectives.

Users of this document should be appropriately qualified and competent in the field of fire safety engineering. It is important that users understand the parameters within which specific methodologies may be used.

ISO 23932-1 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, heritage and the environment. ISO 23932-1 provides the process (necessary steps) and essential elements for designing a robust, performance-based fire safety programme.

ISO 23932-1 is supported by a set of ISO fire safety engineering standards available on the methods and data needed for the steps in a fire safety engineering design summarized in ISO 23932-1:2018, Clause 4 and shown in Figure 1. This system of standards provides an awareness of the interrelationships between fire evaluations when using the set of ISO fire safety engineering standards.

Each document includes language in the introductory material of the document to tie it to the steps in the fire safety engineering design process outlined in ISO 23932-1. Selection of design fire scenarios and design fires form part of conformance with ISO 23932-1, and all the requirements of ISO 23932-1 apply to any application of this document.

Fire safety engineering — Selection of design fire scenarios and design fires —

Part 2:
Design fires

1 Scope

This document provides guidance for the specification of design fires for use in fire safety engineering analysis of building and structures in the built environment. The design fire is intended to be used in an engineering analysis to determine consequences in fire safety engineering analyses.

2 Normative references

The following documents, in whole or in part, are normatively referenced in 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 13943, *Fire safety — Vocabulary*

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:

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

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

3.1
combustion efficiency
ratio of the amount of heat release in incomplete combustion to the theoretical heat of complete combustion

Note 1 to entry: Combustion efficiency can be calculated only for cases where complete combustion can be defined.

Note 2 to entry: Combustion efficiency is dimensionless and is usually expressed as a percentage.

3.2
design fire
quantitative description of assumed fire characteristics within a *design fire scenario* (3.3)

Note 1 to entry: Typically, an idealized description of the variation with time of important fire variables, such as heat release rate and toxic species yields, along with other important input data for modelling such as the fire load density.

3.3
design fire scenario
specific *fire scenario* (3.9) on which a deterministic fire safety engineering analysis is conducted

Note 1 to entry: As the number of possible fire scenarios can be very large, it is necessary to select the most important scenarios (the design fire scenarios) for analysis. The selection of design fire scenarios is tailored to the fire-safety design objectives, and accounts for the likelihood and consequences of potential scenarios.

3.4
effective heat of combustion
heat released from a burning test specimen in a given time interval divided by the mass lost from the test specimen in the same time period

Note 1 to entry: This is the same as the net heat of combustion if all the test specimen is converted to volatile combustion products and if all the combustion products are fully oxidized.

Note 2 to entry: The typical units are kilojoules per gram ($kJ \cdot g^{-1}$).

3.5
extinction coefficient
natural logarithm of the ratio of incident light intensity to transmitted light intensity, per unit light path length

Note 1 to entry: Typical units are reciprocal metres (m^{-1}).

3.6
fire growth
stage of fire development during which the *heat release rate* (3.15) and the temperature of the fire are increasing

3.7
fire load
quantity of heat which can be released by the complete combustion of all the combustible materials in a volume, including the facings of all bounding surfaces

Note 1 to entry: Fire load may be based on *effective heat of combustion* (3.4), gross *heat of combustion* (3.14), or net heat of combustion as required by the specifier.

Note 2 to entry: The word “load” can be used to denote force or power or energy. In this context, it is being used to denote energy.

Note 3 to entry: The typical units are kilojoules (kJ) or megajoules (MJ).

3.8
fire load density
fire load (3.7) per unit area

Note 1 to entry: The typical units are kilojoules per square metre ($kJ \cdot m^{-2}$).

3.9
fire scenario
qualitative description of the course of a fire with time, identifying key events that characterize the fire and differentiate it from other possible fires

Note 1 to entry: The fire scenario description typically includes the ignition and fire growth processes, the *fully developed fire* (3.13) stage, the fire decay stage, and the environment and systems that will impact on the course of the fire. Unlike deterministic fire analysis, where fire scenarios are individually selected and used as *design fire scenarios* (3.3), in fire risk assessment, fire scenarios are used as *representative fire scenarios* (3.10) within *fire scenario clusters*.

[SOURCE: ISO 13943:2008, 4.129, modified]

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3.10
representative fire scenario
specific *fire scenario* (3.9) selected from a *fire scenario cluster* (3.11) such that the consequence of the representative fire scenario can be used as a reasonable estimate of the average consequence of scenarios in the fire scenario cluster

3.11
fire scenario cluster
subset of *fire scenarios* (3.9), usually defined as part of a complete partitioning of the universe of possible fire scenarios

Note 1 to entry: The subset is usually defined so that the calculation of fire risk as the sum over all fire scenario clusters of fire scenario cluster frequency multiplied by *representative fire scenario* (3.10) consequence does not impose an undue calculation burden.

3.12
flashover
transition to a state of total surface involvement in a fire of combustible materials within an enclosure

3.13
fully developed fire
state of total involvement of combustible materials in a fire

3.14
heat of combustion
thermal energy produced by combustion of unit mass of a given substance

Note 1 to entry: The typical units are kilojoules per gram ($kJ \cdot g^{-1}$).

3.15
heat release rate
rate of thermal energy production generated by combustion

Note 1 to entry: The typical units are watts (W).

3.16
target
a person, object or environment intended to be protected from the effects of fire and its effluents (smoke, corrosive gas, etc.) and/or fire suppression effluents

4 Symbols

A	area of ventilation opening, m^2
A_T	total interior area of the enclosure excluding opening area, m^2
A_f	horizontal burning area of the fuel, m^2
A_{fl}	floor area, m^2
A_o	area of opening, m^2
c	distance of target from the centre of the flame, m
f	flapping length
$q_{f,d}$	fire load energy density, MJ/m^2
F_{size}	non-dimensionless form of fire

h_o	height of an opening, m
h_T	average effective heat transfer coefficient, kW/m^2/K
h'	heat flux
h'_{net}	net heat flux
H	height of ventilation opening, m
L	heat of gasification of the fuel, kJ/kg
$\dot{m}_f$	rate of mass loss of fuel, kg/s
$\dot{m}_{out}$	rate of entry of air outflow from the enclosure, kg/s
$\dot{m}_s$	mass loss rate for smouldering combustion, g/min
$\dot{m}''$	mass loss rate per unit area, kg/s/m^2
$\dot{m}_p$	mass flow of gases entrained into the fire plume, kg/s
$\dot{m}_{F,u}$	mass loss rate of fuel under well ventilated free burn conditions, kg/s
m_{growth}	mass of fuel burned during the growth phase, kg
m_{total}	total mass of fuel burned, kg
$\dot{Q}$	heat release rate, kW
Q_c	convective part of the heat release rate, W
$\dot{Q}_{fo}$	minimum heat release rate to cause flashover, kW
$\dot{Q}_{max}$	maximum heat release rate, kW
$\dot{Q}_v$	ventilation-controlled heat release rate, kW
$\dot{Q}''$	heat release rate per unit area, kW/m^2
$\dot{q}_{ext}$	total external heat flux from the smoke and compartment surfaces (kW)
$q_{f,d}$	design value of the fire load density related to the surface area of the floor, A_f
$\dot{q}''$	heat flux, kW/m^2
r	stoichiometric air requirement for complete combustion of fuel, expressed as the mass ratio of air to fuel
s	constant fire spread rate
t	time, s
t_b	constant burning time, s
t_g	time required to reach the reference heat release rate $\dot{Q}_o$, s
t_{grow}	time at which the heat release rate reaches a maximum value, s
t_{total}	total burning time

T_f reduced average near-field temperature

$\S_r$ radiative fraction of the total energy

Y_{O2} mass fraction of oxygen in the plume flow, kg/kg

$Y_{o,l}$ mass fraction of oxygen in the gases feeding the flame

$Y_{o,\infty}$ mass fraction of oxygen under ambient free-burning conditions

z height along the flame axis (m)

z' vertical position of the virtual heat source

α fire growth coefficient, kW/s^2

α_c convective heat transfer coefficient

χ combustion efficiency

ΔH_{eff} effective heat of combustion, kJ/kg

ΔH_c chemical heat of combustion, kJ/kg

ΔH_{O2} heat of combustion based on oxygen consumption, MJ/kg (~13,1 for hydrocarbons)

ε_f emissivity of the fire

τ_{grow} duration of the growing fire stage, s

τ_{steady} duration of the steady burning stage, s

τ_{decay} duration of the decay burning stage, s

σ Stefan Boltzmann constant

θ_m surface temperature of the member (°C) [see Formula (21)]

λ thermal conductivity

5 The role of design fires in fire safety design

Design fire specifications play a critical role in fire safety engineering. It is important that the procedures described in ISO 23932-1 be followed. This means that the fire safety objectives and performance criteria are stated and the relevant design scenarios are identified using ISO 16733-1 for fire scenarios and ISO/TS 29761 for behavioural scenarios.

Figure 1, taken from ISO 23932-1, illustrates the fire safety design process. The specification of design fires follows the scenario selection step and provides input data for the selected engineering methods. Following identification of the design fire scenarios in accordance with ISO 16733-1, the assumed characteristics of the fire on which the scenario quantification will be based shall be described. The assumed fire characteristics and the associated fire development over time are generally referred to as the "design fire".

This document is applicable to design fires that are quantifiable in engineering terms and therefore intended to form part of a deterministic or combined deterministic/probabilistic analysis. A deterministic approach calculating the consequence of individual fire scenarios may also form part of an overriding probabilistic analysis. For example, Monte Carlo simulation can be used to quantify uncertainty using statistical techniques in both inputs and outputs.

This document is also intended to accommodate a range of different analysis methods, including use of computational fluid dynamics models (CFD), zone models, or simple hand calculations. Each approach can require the use of different parts of this document. Some calculations may be handled within the analysis model, such as determining the ventilation limit or determining effect of suppression systems, while simpler analysis methods can require these elements to be estimated separately. Where computer models are used for the analysis, it is important for the engineer to understand the model limitations and which fire or other phenomena are included and not included. The model or tool selected for use should be appropriate for the overall analysis as described in ISO 23932-1:2018 Clause 11.

The nature of the fire scenario can require the application of selected clauses of this document rather than all parts. For example, where the fire scenario predominantly concerns:

— a growing or developing fire, refer to Clause 8.

— a smouldering fire, refer to Clause 9.

— a fully developed fire affecting structure, refer to Clause 10.

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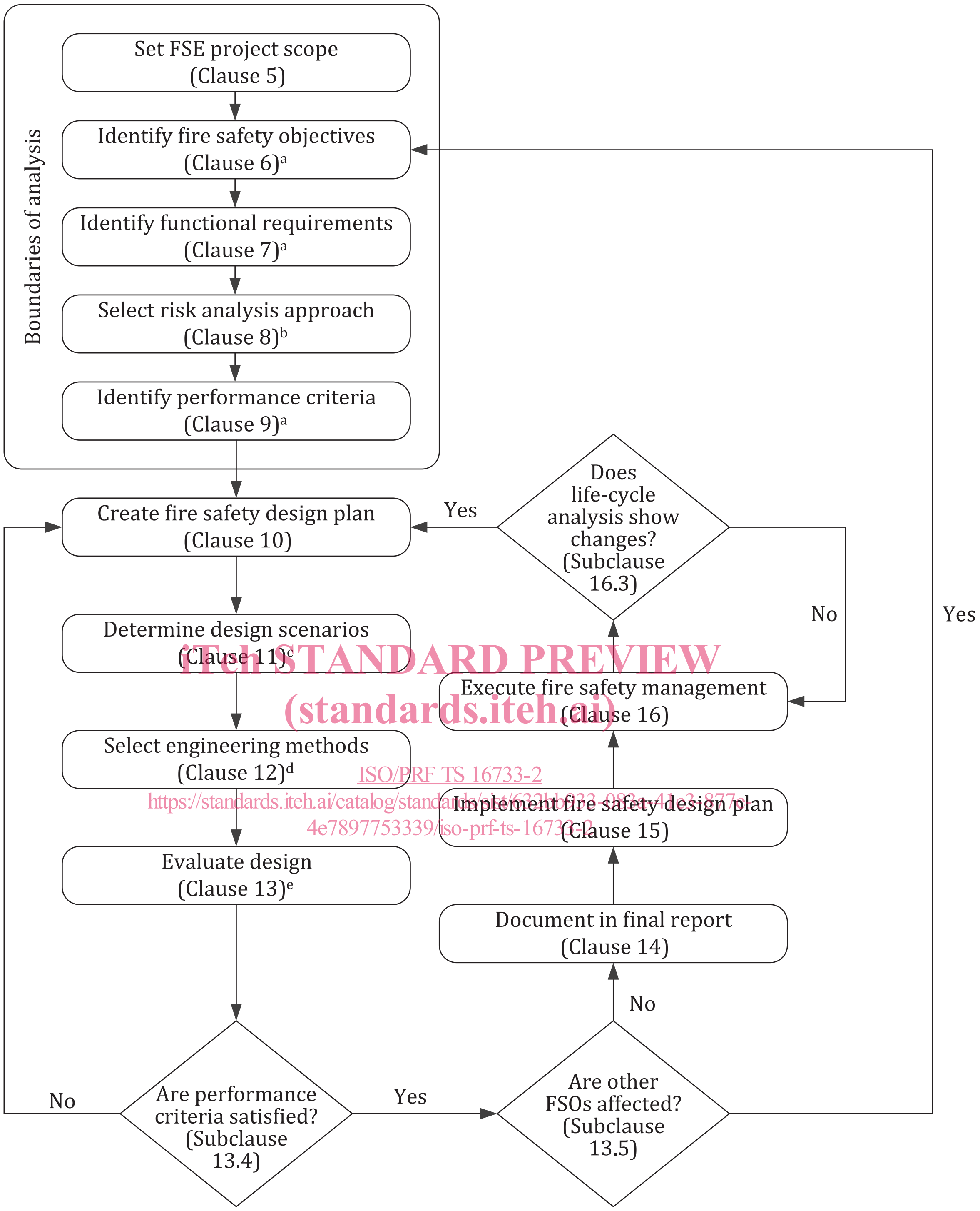

Key

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, ISO/TR 16730-3, ISO/TR 16730-4, ISO/TR 16730-5 (Examples), ISO 16734, ISO 16735, ISO 16736, ISO 16737, ISO/TR 16738, ISO 24678-6.

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

Figure 1 — Flow chart illustrating the fire safety design process and selection of design fire scenarios (Source: ISO 23932-1)

Clause 11 covers several specific correlations for external fire exposures.

Clause 12 discusses the use of fire tests for developing design fires when engineering calculation methods are not available or not applicable.

Where analysis involving probabilistic aspects of design fires are envisaged, readers should also refer to Clause 13 in addition to the relevant subclauses of Clauses 8-12.

The design fire can include descriptions of the heat release rate, gas temperature or heat fluxes as well as the yields of smoke and other combustion products. The most important parameter of the design fire is the heat release rate and different approaches are available to develop a design fire curve for the time-varying heat release rate from a fire. In general, the main approaches are:

1) To calculate the fire growth and heat release from first principles based on an understanding of the product materials and geometry, chemistry and underlying combustion processes.

   This is generally difficult and can currently be considered insufficiently reliable for general use in fire safety engineering. It is not discussed further in this document.

2) To construct composite heat release rate curves from the individual components.

   This is more applicable when information is known regarding the specific contents and their arrangement within the built environment. This requires consideration and estimation of fire spread from the ignition source to other nearby items and the relevant timeline for this to occur.

3) To assume a generalized heat release rate curve (e.g. t^2 fire).

   This may include a representative fire growth rate for different well-defined occupancies. This could be based on experimental data. It does not require fire spread from individual items to be assessed and is therefore very simple to apply. This approach may be prescribed in some codes of practice (see Annex A).

Initially, the engineer should determine the design heat release rate curve, without intervention, as would apply if the fire were allowed to develop in well-ventilated, open-air conditions. Interventions result in a potential change in the course of the fire. They could include:

— manual fire-fighting actions by occupants or by trained fire-fighters;

— automatic or manually operated fire suppression systems;

— restricted ventilation or changes in ventilation during the course of the fire (e.g. glass breaking);

— burning enhancement due to thermal feedback from the hot gases and enclosure surfaces to the fuel surface.

The selected approach will depend on what is known about the fire scenario and the items involved. The method of analysis may also determine the approach being dependent of what input information is available.

A complete description of the design fire from ignition to decay is estimated using the specified initial conditions and a series of simple calculations to estimate parameters such as the sprinkler activation time, transition to flashover and duration of any fully developed burning.

Alternatively, the design fire can be a combination of quantified initial conditions and subsequent fire development determined iteratively or by calculation using more detailed models that account for phenomena such as transient effects of changing ventilation on smoke production or thermal feedback effects from a hot layer to the fuel surface.

As with the design fire scenario, it is important that the design fire be appropriate to the relevant fire-safety objectives. For example, if safety of life is an objective, and the built environment includes a smoke control system, a design fire should be selected that challenges the smoke control system. If the severity of the design fire is underestimated, then the application of engineering methods to predict the effects of the fire can produce results that do not accurately reflect the true impact of fires and can underestimate the hazard. Conversely, if the severity is overestimated, unnecessary expense can result. It is important to appreciate that in real life, due to uncertainties associated with the fuel, ventilation and other factors, the actual severity of the fire varies according to statistical distribution.

6 Considerations based on methods of analysis

It is common for fire models to include some of the dynamic changes and stage transitions expected over the duration of the fire. For example, when a fire model constrains the heat release rate within a compartment to match the available oxygen supply. Other dynamic effects may not be included such as fracture and fallout of glazing within the compartment walls. The engineer is required to assess which elements of the design fire are required for a specific analysis allowing for those predicted by the fire model as well as those required as input to the model.

Whereas most advanced models require the heat release rate of the fire as input to a calculation of the enclosure temperature or other fire properties, there is a class of models that is simpler in nature and requires less sophisticated input data. For example, the parametric fire curves for post-flashover fires discussed in subclause 10.3 do not require estimates of the heat release rate of the fire as input. Instead, the gas temperature is predicted directly, employing simpler information, such as the geometry of the enclosure and its ventilation openings, the thermal properties of room lining materials and the fuel load.

For a given design fire scenario, the parameters determined in Clause 8 can be employed to predict the temperature/heat flux evolution versus time and the associated effluents using various calculation methods ranging in their complexity from simple to advanced.

7 Elements of a design fire

7.1 General

Fire can grow from ignition through to a fully developed stage and finally decay and eventual extinction. The design fire is described by the values of variables, such as the heat release rate and yield of combustion species, over the life of the fire.

A full specification of a design fire (see Figure 2) can include the following phases:

— incipient stage (A): characterized by a variety of sources, which can be smouldering, flaming or radiant.

— growth stage (B): covering the fire propagation period up to flashover or full fuel involvement.

— fully developed stage (C): characterized by a substantially steady burning rate determined from either the ventilation supply or the fuel surface area. During this stage, the heat output within an This paragraph has been automatically styled, please verify it is the correct styleenclosure is generally the lesser of the ventilation-controlled heat output and the fuel-surface-area-controlled (under free burn conditions) heat output. If the fuel bed-controlled rate exceeds the ventilation-controlled rate, then the difference can potentially contribute to burning external to the enclosure.

— decay stage (D): covering the period of declining fire intensity until extinction.