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REPORT

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Fire safety engineering —

Part 7:
Detection, activation and suppression

Ingénierie de la sécurité contre l'incendie —

Partie 7: Détection, activation et suppression

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Contents

International Organization for Standardization
Case postale 56 • CH-1211 Genève 20 • Switzerland
Internet iso@iso.ch

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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 main task of ISO technical committees is to prepare International Standards, but in exceptional circumstances a technical committee may propose the publication of a Technical Report of one of the following types:

- type 1, when the required support cannot be obtained for the publication of an International Standard, despite repeated efforts;
- type 2, when the subject is still under technical development or where for any other reason there is the future but not immediate possibility of an agreement on an International Standard;
- type 3, when a technical committee has collected data of a different kind from that which is normally published as an International Standard (“state of the art“, for example).

Technical Reports of types 1 and 2 are subject to review within three years of publication, to decide whether they can be transformed into International Standards. Technical Reports of type 3 do not necessarily have to be reviewed until the data they provide are considered to be no longer valid or useful.

ISO/TR 13387-7, which is a Technical Report of type 2, was prepared by Technical Committee ISO/TC 92*, Fire safety*, Subcommittee SC 4, *Fire safety engineering*.

It is one of eight parts which outlines important aspects which need to be considered in making a fundamental approach to the provision of fire safety in buildings. The approach ignores any constraints which might apply as a consequence of regulations or codes; following the approach will not, therefore, necessarily mean compliance with national regulations.

ISO/TR 13387 consists of the following parts, under the general title *Fire safety engineering*:

- *Part 1: Application of fire performance concepts to design objectives*
- *Part 2: Design fire scenarios and design fires*
- *Part 3: Assessment and verification of mathematical fire models*
- *Part 4: Initiation and development of fire and generation of fire effluents*
- *Part 5: Movement of fire effluents*
- *Part 6: Structural response and fire spread beyond the enclosure of origin*
- *Part 7: Detection, activation and suppression*
- *Part 8: Life safety — Occupant behaviour, location and condition*

Annexes A to C of this part of ISO 13387 are for information only.

Introduction

There are many important active measures that can be implemented to warn occupants and building management about the existence of a fire, to change or modify the normal progress of a fire so that safety and loss reduction criteria can be satisfied. These active protection measures, which constitute subsystem 4 in the fire safety engineering design process, are described and discussed in detail in this document.

Subsystem 4 provides guidance on the use of engineering methods for evaluation of the time to detect smoke or flames by a wide range of commercial devices, including the time required for heat sensitive elements in suppression or other control devices to respond to the gas-flow generated by an incipient or growing fire. To accomplish this, subsystem 4 draws on subsystems 1 to 3 for characterizing the size of the fire as well as the temperature, species concentration and gas velocity fields generated by the design fire, as described further in clause 5. Subsystem 4 also draws on a description of sensor locations and characteristics from building design parameters as well as information available from ISO/TC 21 (*Equipment for fire protection and fire fighting*) standards on fire detection and alarm systems.

Once detection has occurred, the subsystem also provides guidance on how to evaluate the time required to activate the desired response to a fire, such as an alarm, a smoke damper or a specified flow of extinguishing agent from typical distribution devices. To accomplish this, subsystem 4 draws on information from the vendors and manufacturers of detection and suppression systems. The hydraulic design of suppression agent piping systems is considered to be part of the activation process of bringing agent to the stage of interacting with the fire.

The effect of various suppression strategies on the fire heat release rate is evaluated in subsystem 4 by reference to installation guidelines, information obtained from ISO/TC 21 standards on fixed fire extinguishing systems and the use of engineering judgement in the application of these guidelines and standards to design-fire scenarios. Once a suppression strategy (usually in terms of a required agent flow rate) is assumed, there is considerable feedback required between subsystem 4 and subsystem 2 to determine the resultant fire environment, as described in clause 5. Typically, the success of a strategy is judged from expected maximum gas or material temperatures, radiant heat to target locations, effluent/species concentrations and/or the total amount of suppression agent required compared to design objectives.

The main discussion of how engineering methods are used to evaluate or calculate the important subsystem 4 outputs is carried out in clause 6, which is subdivided into subclauses on detection time, activation time and effect of suppression strategies. Each of these subclauses contains a discussion of fire safety engineering design, the important physical and chemical processes to be considered, evaluation methods for specific classes of devices as well as an explicit list of required input parameters needed to perform an engineering analysis and the outputs from such an analysis.

Clause 7 is a discussion of the engineering methods available to evaluate detection, activation and suppression design options. The engineering method selected to solve the design problem should be assessed and verified using the principles documented in ISO/TR 13387-3, *Assessment and verification of mathematical fire models*. Special care should be taken when using input data published in the literature since this information and/or data may be related to specific test conditions and/or specific commercial products; the application of information and/or data under different conditions may result in significant errors.

Further information and background material together with specific literature references that support the discussion in the preceding clauses with details of the fundamental approach to fire safety engineering is available from the sources listed in the bibliography.

Fire safety engineering —

Part 7:
Detection, activation and suppression

1 Scope

This part of ISO 13387 is intended to provide guidance to designers, regulators and fire-safety professionals on the fundamental engineering methods that should be included in design guides and reference manuals for the prediction of:

a) times to detect fire events, based on the design-fire environment and properties and/or location of automatic detection devices;

b) times to activate automatic alarm systems and automatic systems designed to control fire growth or to control the effects of fire, based on system design parameters;

c) the effectiveness of activated automatic suppression systems in limiting the potential consequences of a fire, based on key system characteristics.

NOTE The effect of human intervention on detection, activation or suppression is considered beyond the scope of this document.

This part of ISO 13387 is not itself a design guide or reference manual but can be used as a resource by national organizations in the preparation of such documents. This report also provides a framework for critically reviewing the suitability of engineering methods, whether hand calculations or predictive computer models or correlations based on empirical data, to predict detection, activation and the effect of fire suppression systems. Note that the term “engineering method” used in this document refers to any of the preceding techniques.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this part of ISO/TR 13387. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this part of ISO/TR 13387 are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

ISO 3009:1976, *Fire-resistance tests — Glazed elements*.

ISO 6182-1:—1), *Fire protection — Automatic sprinkler systems — Part 1: Requirements and test methods for sprinklers*.

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1) To be published. (Replaces ISO 6182-1:1993).

ISO/TR 13387-1, *Fire safety engineering — Part 1: Application of fire performance concepts to design objectives.*

ISO/TR 13387-2, *Fire safety engineering — Part 2: Design fire scenarios and design fires.*

ISO/TR 13387-3, *Fire safety engineering — Part 3: Assessment and verification of mathematical fire models.*

ISO/TR 13387-4, *Fire safety engineering — Part 4: Initiation and development of fire and generation of fire effluents.*

ISO/TR 13387-5, *Fire safety engineering — Part 5: Movement of fire effluents.*

ISO/TR 13387-6, *Fire safety engineering — Part 6: Structural response and fire spread beyond the enclosure of origin.*

ISO/TR 13387-8, *Fire safety engineering — Part 8: Life safety — Occupant behaviour, location and condition.*

ISO 13943, *Fire safety — Vocabulary*.

3 Terms and definitions

For the purposes of this part of ISO/TR 13387, the definitions given in ISO 13943, ISO/TR 13387-1 and the following apply.

3.1
activation time
time interval from response by a sensing device until the suppression system, smoke control system, alarm system or other fire safety system is fully operational

3.2
ADD
measured volumetric flow rate of water per unit area from ESFR sprinklers that is delivered near the base of a fire plume for a specific fire heat release rate

3.3
agent outlet
point in fixed extinguishing system at which a sprinkler, suppression or control device is located

3.4
control-mode sprinkler
sprinkler (for example, conventional or spray type) that limits fire propagation through wetting/soaking of uninvolved fuel

3.5
conventional sprinkler
sprinkler type which projects 40 % to 60 % of the total water flow initially downward

3.6
design density
sprinkler application rate in the absence of a fire

3.7
detection time
time interval from ignition of a fire until its detection by an automatic or manual system

3.8
engineering judgement
process exercised by a professional who is qualified, because of training, experience and recognized skills, to complement, supplement, accept or reject elements of a quantitative analysis

3.9

fire extinguishment

process by which agents eliminate all flaming combustion

3.10

HRR

heat release rate

3.11

method

abbreviation for one of the recommended engineering methods used to predict detection and activation times and the effect of fire suppression or fire control systems, whether by hand calculation, predictive computer models or empirical correlations

3.12

prewetting

process by which water from sprinkler sprays gradually, soaks or wets fuel surrounding the fuel region actively involved in fire, leading to a reduction in fire propagation

3.13

RDD

volumetric flow rate of water per unit area, applied uniformly to the top surface of a fuel array, needed to cause fire HRR to decay rapidly to a sufficiently low level

3.14

smoke management

the use of compartmentation and buoyancy effects, in addition to flow control, dilution and pressurization, to re-direct smoke

3.15

spray sprinkler

sprinkler type which projects 80 % to 100 % of the total water flow initially downward

3.16

sprinkler activation area

total horizontal area over which sprinklers are designed to operate

3.17

sprinkler application rate

volumetric water flow rate applied per unit surface area from operating sprinklers (also called “sprinkler density” or “discharge density” for horizontal surfaces or, more generally, “surface density”)

3.18

suppression-mode sprinkler

sprinkler (for example, ESFR type) that delivers water directly to burning fuel surfaces, thereby reducing the fire HRR

3.19

suppression system

a system designed for active stabilization, reduction or elimination of fire propagation and heat/smoke release

3.20

water mist protection system

array of devices designed for fire extinguishment through the use of multiple water sprays

4 Symbols and abbreviated terms

4.1 Symbols

C	Conductivity factor, expressed in $(\mathrm{m/s})^{1/2}$
d_{gn}	Geometric number-mean diameter of particles, expressed in mm
K	Light extinction coefficient in smoke/effluent species, expressed in m^{-1}
N	Number concentration of particles, expressed in m^{-3}
T_{e}	Temperature of detector sensing element, expressed in K
T_{ea}	Nominal operating temperature of detector, expressed in K
T_{g}	Actual gas temperature in test section of tunnel or near detector during fire, expressed in K
T_{u}	Ambient air temperature during testing, expressed in K
t_{R}	Response time of detector, expressed in s
u	Actual gas velocity in test section of tunnel or near the detector during fire, expressed in m/s
σ_{g}	Geometric standard deviation of particle diameter, expressed in mm

4.2 Abbreviated terms

ADD	Actual delivered density, expressed in mm/s
CFD	Computational fluid dynamics
ESFR	Early suppression fast response (suppression-mode sprinkler type)
HRR	Heat release rate, expressed in kW
IR	Infra-red
RDD	Required delivered density, expressed in mm/s
RTI	Response time index, expressed in $(\mathrm{m \cdot s})^{1/2}$
UV	Ultra-violet

5 Subsystem 4 of the total design system

5.1 General discussion

This clause describes the procedure by which this document is to be used together with other parts of ISO 13387.

5.2 Explanation and illustrations

To aid in the use of this document in a comprehensive fire safety design process, the information herein can be considered to be part of a detection, activation and suppression subsystem 4 within the total fire safety design system (see Figure 1). The first layer of the design system contains a set of global information, which contains data either transferred among various subsystems or employed to make engineering decisions. These data include three types of global information, which are described more fully in ISO/TR 13387-1:

a) prescribed and/or estimated parameters, consisting of
    1) building parameters (includes location and/or specifications for all fire-related systems);
    2) occupant parameters;
    3) fire loads;
    4) fire scenarios;
    5) environmental parameters;
b) intervention effects, consisting of
    1) alarm activation;
    2) heat and smoke control activation;
    3) suppression activation;
    4) fire brigade intervention;
c) simulation dynamics profiles versus time, consisting of
    1) size of fire and/or smoke;
    2) thermal profile;
    3) pressure and/or velocity profile;
    4) effluent/species profile;
    5) occupant condition;
    6) occupant location;
    7) building condition;
    8) contents condition.

The next layer of the design system consists of a set of evaluations, which in the case of subsystem 4, includes three types of analysis results providing

a) detection time;
b) activation time;
c) performance of suppression systems.

Each of these three types of evaluations is discussed in detail in the three parts of clause 6.

The final layer of the design system consists of processes that include

a) convective heat detection;
b) effluent/species detection;
c) radiant energy detection;
d) agent flow in suppression systems;
e) interactions between suppression systems and fires;
f) interactions between smoke control and suppression systems.

These six different processes, plus other related processes, are part of calculation procedures that generate the three types of evaluations required by subsystem 4 for use by the other subsystems in the total fire safety design system.

5.3 Information flow

To perform one of the three types of evaluations (detection, activation or suppression), a fire safety engineering practitioner must make use of global information data as input parameters for the detailed process calculations. These calculations allow the time for response of alarm, smoke and/or heat control and active suppression devices to be output for use by life safety (and in the future, property, culture and environmental protection) subsystems. In addition to outputting response times, the process calculations in this subsystem also evaluate the success of strategies for active suppression of fire by providing empirical information on required flow rates of suppression agents to reduce or eliminate flaming combustion. With information on the potential success of suppression strategies, the fire growth, smoke movement and life safety subsystems can more readily evaluate the net effect on the fire environment and on people. Finally, the process layer of design subsystem 4 can determine the detailed characteristics of suppression agent delivery, thus allowing alternative, predictive field model calculations to be performed in the fire growth and/or smoke movement subsystems.

ISO TC 92/SC 4 FIRE SAFETY ENGINEERING BUS SYSTEM

Subsystem 4 (SS4) — Detection, activation and suppression

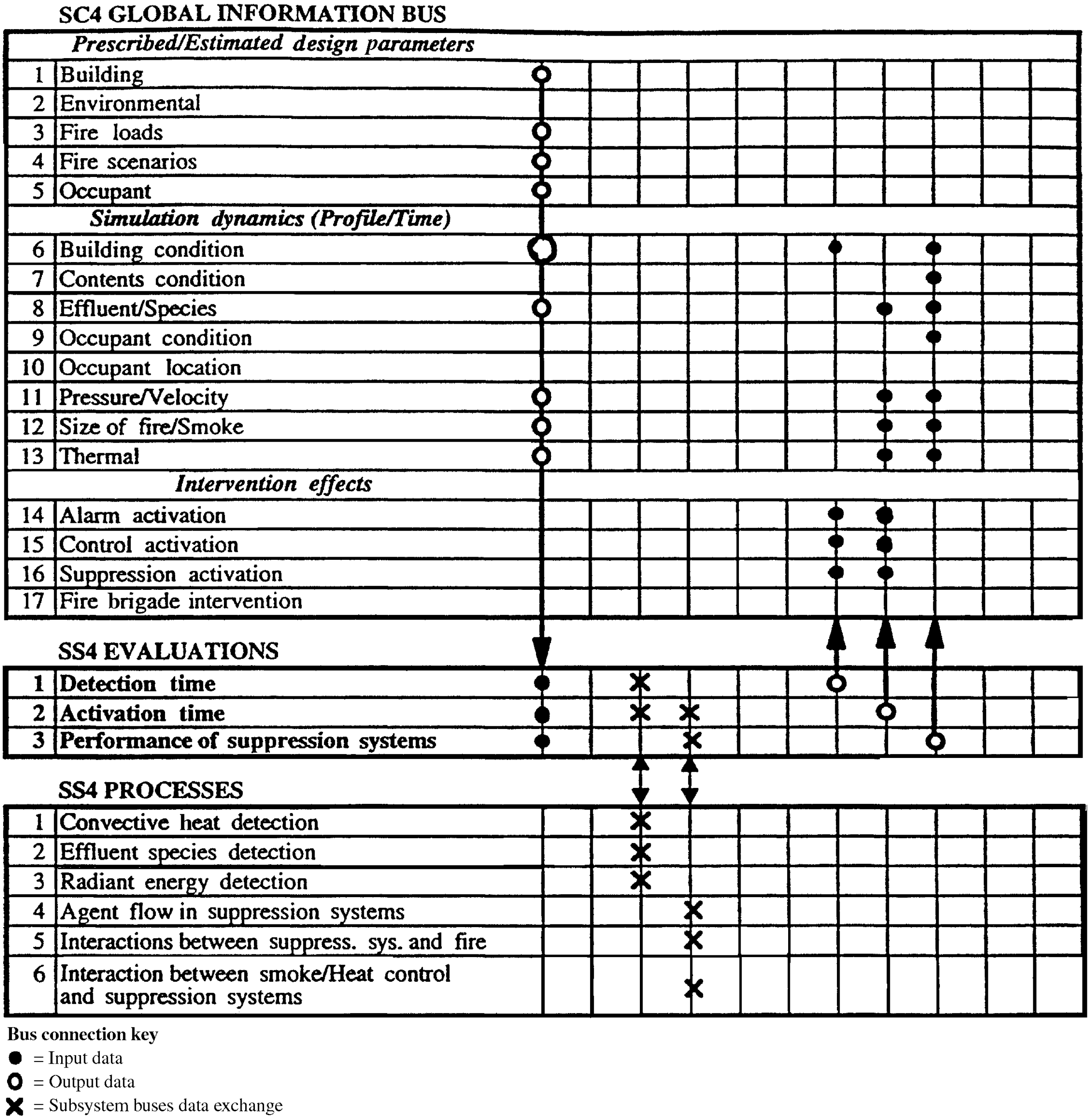

Figure 1 — Illustration of the global information, evaluation and process buses for SS4.

6 Subsystem 4 evaluations

This clause discusses in detail the primary engineering evaluations related to fire detection times (see 6.1), activation times (see 6.2) of alarms and heat and/or smoke control measures and the effectiveness of suppression and other systems (see 6.3) for actively reducing fire consequences. The evaluation of operating characteristics of fire suppression and control systems (for example, flow capacities, nozzle performance, exhaust capacities and other parameters typically obtained from vendors) is discussed as part of the evaluation of activation times in 6.2 since system operating characteristics actually determine the time required for these systems to begin to interact with the design fire. In 6.3, the system operating characteristics (for example, agent flow rates from nozzles) required for successful fire suppression are evaluated. These requirements must be met by system performance during activation, as calculated in 6.2.

Associated with each key subsystem output, recommended engineering methods for predicting unit physical and chemical processes are discussed and all input information required by such methods is identified. Guidance on locating unit process input data is also provided, along with available literature references. Areas for which a lack of knowledge and/or input data are known to exist are addressed.

6.1 Detection time

6.1.1 Role in fire safety engineering design

Because the response time of detectors plays such an important role in fire safety, the selection of the proper detector type and detector location for application to each type of occupancy must be consistent with clearly established design objectives. Descriptions of the three major detector types, thermal, effluent/species (which includes obscuration and/or optical beam detectors) and radiant emission, along with references to recommended design documents, are discussed in the following clauses. This information should be used to match particular design objectives (for example, resistance to non-fire related alarms, shortest possible detection time or compatibility with the building and/or contents environment) to the detector selection and location process. In very general terms (see references [10], [11] and [19] in the bibliography for additional information), thermal point or line detectors are best suited to situations where cost and reliability are overriding factors, for example, to trigger water flow in automatic sprinkler systems or where there are large numbers of locations to be monitored or where there is a high particle count (for example, fine dust or droplets, fumes, insects, etc.) that can cause other detector types to alarm without a fire. Effluent/species detectors are generally best suited when high sensitivity is needed to give the shortest possible detection time, for example, when life safety or sensitive contents is the overriding concern.

Point detectors, whether thermal or effluent and/or species, often depend on fire-induced convective flows to transport heat or smoke up to ceiling level in a plume and then radially outward in a ceiling-jet. This natural buoyant motion, especially in the earliest stages of fire growth, may often:

a) bypass detectors improperly located outside of the plume or ceiling-jet flows (see reference [45] for information on ceiling-jet thickness);

b) require significant transport times;

c) be disrupted by HVAC vent system flows; and

d) be disrupted by ambient stratification of the air in the building, as discussed in 6.1.2.4 of subsystem 2 and in reference [19], pp. 4-15.

All of these phenomena can lead to significant detection delays. Radiant emission detectors and tubing networks of sampling effluent/species detectors are often best suited for situations where such delays would result in detection times that are inconsistent with design objectives (for example, very early detection of small fires).

Detection systems that are not properly designed because of incorrect detector type or location can result in large numbers of alarms to non-fire signals, or “false alarms” being produced, especially when hundreds or thousands of smoke detectors at a single location (for example, a hospital) can produce several false alarms per day. In some instances false alarms can outnumber “real” alarms by ratios in excess of 20:1. Large numbers of false alarms can lead to situations in which the alarm is ignored by many or all of the occupants or in which all detectors are disabled. Careful location of detectors coupled with the correct choice of detector type and/or the use of detectors (see 6.1.6) which incorporate multi-criteria detection, for example, can result in significantly fewer false alarms. With correct design, false alarm to fire ratios can be reduced to 3:1 or fewer. The importance of the ongoing maintenance of fire detection and alarm systems as a means of minimizing false alarms should also not be overlooked.

The task of determining the response of detectors to a design fire that properly tests whether design objectives have been achieved is complicated by the fact that most occupancies (except some single-family residential units) contain detectors that are interconnected with a central control system. This central system can have a range of capabilities from activation of an alarm when any detector in the network responds all the way to sophisticated programmable or learned decisions as to the proper alarm level based on analysis of the history of previous ambient conditions. With such sophisticated systems, which can be just one component of a much larger building automation system, the calculation of “detection time” depends not only on information discussed in 6.1 but also on activation times associated with the complete control system. Just as non-fire signals can be minimized by careful location and selection of individual detectors, false alarms produced by a centralized detection system can be minimized by selection of the proper logic and/or computer algorithms, by a higher level of integrity for detection functions than for other building functions and by careful design to eliminate electrical interference, system faults and even malicious action by occupants or employees. Detection subsystems within a building automation system must have directly measurable performance and reliability that is suitable for an emergency system.

There are several reviews of engineering methods for evaluating the response of fire detectors in a variety of design situations. For example, reference [25] contains a comprehensive literature review, reference [10] contains excellent background information while references [11] and [36] describe specific predictive techniques and engineering methods. The selection and installation of detectors should be consistent with national standards, such as the codes in reference [2].

6.1.2 Thermal (point or line-type) detectors

6.1.2.1 Processes considered in evaluating system designs

The response of a thermal detector can be modelled by calculating the heat transfer taking place by convection between the gas and the detector, by conduction through the detector body to the mounting structure and by radiation to/from the surroundings. During the initial stage of fire growth, while temperatures and flame heights are relatively low, the effect of radiant heat transfer may be less important than convection. When the sensitive element is thermally isolated sufficiently from the remainder of the detector or when fire growth is rapid, conductive heat loss may also be less important than convection. However, as maximum flame thickness increases and flames surround the detector element, radiant heat transfer may no longer be negligible. Finally, conduction may not be negligible compared to convection for slowly growing fires. See reference [2] for engineering guidance on the evaluation of thermal detector performance and response time.

6.1.2.1.1 Methods to evaluate response of fixed temperature detectors to heat transfer

A fixed temperature detector is a device which responds when its sensitive element is heated to a temperature exceeding a predetermined level, called the activation temperature or device temperature rating. For point type detectors, by treating the sensitive element as a mass distinct from the rest of the detector, it is shown in reference [30] that element temperature depends on:

a) thermal properties of the element (mass, specific heat, surface area);

b) convective heat transfer coefficient with the fire environment;

c) conductive heat losses through connections to the rest of the detector or device.

As shown in reference [30] and annex B, a parameter called “response time index” (RTI), can be measured that characterizes both the thermal properties of the element and the heat transfer coefficient for the local fire environment. Similarly, a “conductivity factor” (C) can be measured that characterizes the heat loss from the sensitive element in conjunction with the RTI (see annex B). The RTI is really just a measure of the thermal time constant of the sensitive element for a given flow velocity. Both these parameters, which take values specific to the detector of concern, allow the detector response time to be determined from a knowledge of mean gas velocity and temperature near the detector. See reference [19] for information on the engineering evaluation of fixed temperature detector performance and response time.

Point type thermal detectors are normally tested, classified and installed consistent with national standards and regulatory guidelines. Activation temperatures are chosen so as to be compatible with the normal ambient temperature of the installation. Standard sensitivity tests on point type thermal detectors using a constant gas velocity and prescribed gas temperatures yield detector response time, which with the equations in annex B, can be used to estimate detector RTI (C factors tend to be insignificant for detectors). Alternatively, recommended spacing for detectors in national standards can be converted to equivalent values of RTI for engineering evaluation. For example, annex B of reference [2] contains tables where RTI values are listed explicitly along with recommended spacing.

One common point type, fixed temperature detector is the sensitive element (for example, glass bulb or fusible link) in an automatic sprinkler, which responds when the element is heated to its activation temperature, or temperature rating. The operation time of such sprinkler elements can be determined in the same manner as for a fixed temperature heat detector (see ISO 6182-1 for recommended sensitivity and temperature rating ranges and references [12] and [48] for engineering design methods). However, once the first sprinkler operates, prediction of the operation of subsequent sprinklers for purposes of engineering design becomes very difficult due to significant changes in gas temperature and velocity caused by:

a) energy absorption by sprinkler droplets due to sensible heating and evaporation;

b) momentum addition to the flow field due to the thrust force of the spray;

c) water vapour addition to the flow due to evaporation (a minor effect).

All of these effects can, in principle, be resolved by field modelling, as noted in 7.3.2.

Fixed temperature detectors may also be of the line type. Line detectors can sense a fire within a highly obstructed enclosure where it may not be practical to find suitable, discrete locations for point detectors. Such enclosures may occur within complex mechanical or electronic equipment. Line detectors can be activated by the melting of plastic insulation separating conductive wires (requiring replacement of the line segment after activation), by changes in the resistivity of a rugged, thermistor type of cable, by changes in the air pressure of a pneumatic conduit or by changes in the cladding reflectivity of fibre-optic cable. Intelligent monitors of such detectors can determine the location of the fire along the line element.

6.1.2.1.2 Methods to evaluate response of rate of rise detectors to heat transfer

A rate-of-rise detector is a device which responds when the temperature rises at a rate exceeding a predetermined amount. The approach is to assume a single response time index (RTI) and a conductivity factor (C) for the sensitive element (see annex B), then the temperature variation history of the sensitive element can be calculated in the same manner as described in 6.1.2.1.1. The response time can then be determined as the time at which the rate of rise of the calculated temperature exceeds that needed for operation.

A similar approach may also be taken with line-type detectors, using representative values for RTI and conductivity factor (C) and average values for the gas temperature and velocity.

See annex B of reference [2] and reference [19] for information on the engineering evaluation of the performance and response time of rate-of-rise thermal detectors.

6.1.2.2 Required input information and/or data

The required input information and/or data are as follows.

a) Size of fire and/or smoke:

The flame position, or the distance and the direction relative to the detector must be known to assess the effect of radiant heat transfer. For the purposes of this evaluation, design fire data appropriate for the occupancy should be used.

b) Thermal profile (includes HVAC effects):

The instantaneous rate of convective heat transfer from the gas to the sensitive element is proportional to the temperature difference between the gas and the element. Thus, the local gas temperature as a function of time must be provided for solving the heat transfer equation to obtain the temperature of the heat sensitive element.

c) Pressure and/or velocity profile (includes HVAC Effect):

Similar to the local gas temperature, the local velocity as a function of time must be provided to assess the rate of convective heat transfer from the gas to the sensitive element, because the heat transfer coefficient generally varies proportionally with the square-root of the local velocity.

d) Building parameters:

All inputs necessary to specify detector performance should be included in this group of parameters, including:

1) Detector spacing or location (vertical distance and radial distance) relative to the fire source is required, if the temperature and the velocity are calculated from the flow field induced by a fire source under a ceiling. The vertical distance of the sensitive element from the ceiling is also required to assess the effect of gas temperature and velocity more precisely. In the case of a line-type detector, the relative location of the sensing line is required to be integrated to obtain the overall response of the detector.

2) Device temperature rating — activation temperatures of detection devices should be in accordance with the nominal temperature ratings prescribed by ISO 6182-1:—, Table 2, column 1.

3) RTI (response time index)/C (conductivity factor) or other detector sensitivity parameters — values of RTI and C (defined in 6.1.2.1.1) can be determined from standardized wind tunnel tests conducted under prescribed gas temperature and gas velocity conditions. Ranges of RTI and C are commonly available for the sensitive elements used to activate sprinkler-type devices. However, for many thermal detectors, the time to respond to a maximum fire HRR, with a given installed spacing, may be used to classify the sensitivity level.

6.1.2.3 Outputs from subsystem engineering analysis

The output of the analysis is the time required for detection or whether detection will occur at all. This, plus design objectives, environmental factors and false alarm considerations, will help determine if thermal detectors are suitable for the application being analyzed.

6.1.3 Effluent/species(point or sampling) detectors

6.1.3.1 Processes considered in evaluating system designs

Effluent/species include the particles, aerosols and the gas species produced by chemical processes such as pyrolysis and oxidation of combustible materials. These combustion products are carried away from the fire source by the buoyancy-driven flow field and/or pre-existing heating, ventilating and air conditioning (HVAC) flows to another part of the building.

See reference [31] for a further discussion of the properties of the effluent/species from fires.

6.1.3.1.1 Methods to evaluate response of ionization detectors to mass transfer of effluent and/or species.

An ionization smoke detector has a small radioactive source inside the detection chamber and the air inside the chamber is continuously ionized, permitting a current flow between two charged electrodes. When smoke particles enter the chamber, they attach themselves to the ions and reduce the ion's mobility, resulting in the reduction of ionization current. The ionization detector responds when the ratio of the ionization current to an initial value becomes lower than a predetermined level or when a central monitoring system determines that the ionization current has dropped below a threshold dependent on ambient conditions (see 6.2.2 on activation of external devices).

The sensitivity of the ionization detector is strongly dependent on the size distribution of the smoke aerosol, because the chance of a smoke particle meeting with an ion differs with the size of the particle. In general, the number concentration rather than the mass concentration of smoke aerosol is important in the response of the ionization detector. Such response characteristics make the ionization detector most sensitive to the high concentration of small particles produced by flaming cellulosic (for example, wood, papers) fires, and least sensitive to the low concentration of large particles produced by smouldering fires, as described in references [31] and [32].

See references [19] and [25] for information on the engineering evaluation of the performance and response time of ionization detector systems.

6.1.3.1.2 Methods to evaluate response of sampling detectors to effluent and/or species

An effluent sampling detector consists of a pipe network connected from the detection unit and distributed to the area to be protected. An air pump draws air from the protected area through the piping to the detection unit and the effluent/species contained in the air are analyzed at the detection unit. The detector, often a highly sensitive unit, responds when the concentration of target species in the detection unit exceeds a user-established level. The concentration of the effluent/species at the detection unit is not generally equal to the concentration sampled at the local sampling ports, because the effluent/species sampled at a sampling port is mixed with the air sampled at different sampling ports before it arrives at the detection unit. Also, the residence time of air from the sampling port to the detection unit should be considered to evaluate the response time of the effluent sampling detector.

See reference [19] for information on the engineering evaluation of the performance and response time of sampling detector systems.

6.1.3.1.3 Methods to evaluate response of light scattering (photoelectric) detectors to mass transfer of effluent and/or species

A photoelectric detector contains a light source and a photosensitive device in the detection chamber. The light source is arranged not to directly illuminate the photosensitive device. When smoke particles enter the detection chamber, the light is scattered onto the photosensitive device by the smoke particles. Photoelectric detectors may be completely self-contained, producing only an alarm signal or an actual alarm when the amount of scattered light received by the photosensitive device exceeds a predetermined level. Networked and/or zoned photoelectric detectors may respond only when a central monitoring system determines that the electrical signal from scattered light has exceeded a threshold dependent on ambient, non-fire conditions or when circuitry determines that other types of conditions are satisfied (see 6.2.2 on activation of devices).

The intensity of the scattered light by a single particle (in the direction of the photosensitive element), or the response function of the photoelectric detector, is directly affected by the intensity and the wavelength of the light source, the scattering angle, and the size of the smoke particle. The dependence on particle size results in the photoelectric detector being most sensitive to large particles produced by smouldering fires, and least sensitive to small particles produced by flaming fires (just the opposite of the ionization detector).

The overall response time of point type smoke detectors may be calculated from:

a) the time to reach a given smoke density at the location of the detector;

b) the possible time lag due to the delay in smoke entering into the detector; and

c) the possible time lag due to the response of the sensor to smoke inside the detector.

The calculation of the detector sensitivity or sensor response can be replaced by data from tests in which the critical smoke density to trigger the detector has been determined. The value of this critical smoke density depends on the type of fuel and the type of fire (smouldering or flaming), as well as on the wavelength of the light used to make the measurement and the units in which smoke density is expressed, all of which vary in different standard tests. Given information on the critical smoke density for a particular detector and a particular fuel and type of fire, estimates or calculations of the fire smoke density at the detector provides the detection time. However, if smoke density is not known, then a rough estimate of detection time can be obtained by assuming detector response at a “small” gas temperature rise above ambient at the detector (see references [25], pp. 30-32, and [19] for a more complete discussion of this thermal model of a smoke detector and reference [2] for graphs based on this rough approximation).

See references [19] and [25] for information on the engineering evaluation of the performance and response time of light scattering detector systems.

6.1.3.2 Required input information and/or data

The required input information and/or data are as follows.

a) Fire loads (fuel type involved):

   This information is required for making a good estimate of mass concentration of effluent/species and the size distribution of smoke aerosol, because the production rate of effluent/species and the size distribution of particles that are produced generally differs with the fuel type and the combustion mode.

b) Fire scenarios (smouldering or flaming).

c) Pressure and/or velocity profile (includes HVAC effects).

   The local velocity may not directly affect the smoke or effluent/species detector's response. However, if combustion-induced velocities are very small, as observed during the smouldering stage, there can be significant delays in detection time due to flow transit times to the detector, the effect of ambient temperature stratification in confining smoke to levels well below the ceiling and delays in smoke entry into the detection chamber, all of which should be taken into account.

d) Effluent/species profile (includes HVAC effects)

   The local mass concentration of smoke (or target gas species) is a basic parameter required for estimating the response of a smoke (or other combustion product) detector. Other useful information concerning the smoke aerosol is the extinction coefficient K, the number concentration N, the geometric mean number diameter d_{gn} and the geometric standard deviation s_{g}.

e) Building parameters;

   All inputs necessary to specify detector performance should be included in this group of parameters, including:

   1) detector spacing or location (vertical distance and radial distance) relative to the fire source is required;

   2) detector sensitivity or response, ideally as a function of particle size, should be given. If not available, then the value of a coefficient which relates the detector's response to a measurable or predictable property (for example, gas temperature or particle concentration) is required;

   3) detector time lag due to smoke entry, or “characteristic length”. Following references [33] and [34], the time lag of the detector due to smoke entry can be represented by the ratio of a characteristic length to the ceiling-jet or other flow velocity just outside the detector. Hence, the characteristic length can be interpreted as the distance the smoke would travel at the local flow velocity before the smoke density inside the detector approaches that outside (typical values are in the range of 2 m to 5 m). In most cases, this lag time is negligible, but for smouldering fires, it may have to be considered.

6.1.3.3 Outputs from subsystem engineering analysis

The output of the analysis is the time required for detection or whether detection will occur at all. This, plus design objectives, environmental factors and false alarm considerations, will help determine if effluent/species detectors are suitable for the application being analyzed.

6.1.4 Light obscuration (optical beam) detectors

6.1.4.1 Processes considered in evaluating system designs

Methods to evaluate response of light obscuration (optical beam) detectors:

An optical beam detector is a line-type effluent/species detector which operates on a light obscuration principle. It consists of a light source and a photosensitive unit facing each other across the area to be protected. Smoke particles between the light source and the photosensitive unit attenuate the transmitted light reaching the photosensitive element. The optical beam detector responds when the transmitted light falls below a predetermined level or when a central monitoring system determines that the electrical signal from the optical beam has dropped below a threshold dependent on ambient conditions (see 6.2.2 on activation of external devices).

See references [19] and [25] for information on the engineering evaluation of the performance and response time of light obscuration detector systems. Information on the response of optical beam detectors to levels of smoke density is provided by national test methods.

The required input information and/or data are:

a) effluent/species profile (includes smoke particle sizes);

b) building parameters (beam geometry).

For an optical beam detector, information on the beam geometry (beam length and height from the floor, beam angle relative to the horizontal plane, and vertical distance from the ceiling) is required. The minimum optical density to trigger the detector should be available from the manufacturer.

6.1.4.2 Outputs from subsystem engineering analysis

The output of the analysis is the time required for detection or whether detection will occur at all. This, plus design objectives, environmental factors and false alarm considerations, will help determine the suitability of light obscuration detectors for the application being analyzed.

6.1.5 Radiant emission point detectors

6.1.5.1 Processes considered in evaluating system designs

Methods to evaluate response of UV/Visible/IR sensor detectors to radiant emission from fires:

Selection of the proper radiant emission detector depends on a proper balance between sensitivity and reduction of non-fire (false-alarm) response frequency for those situations where incipient flaming must be detected at some distance from the fire source or over a wide area but with a very short detection time. If detectors are located properly, there should be an unobstructed view of the flame zone or its reflection. To reduce false alarm frequency, a UV/Visible sensor can be selected to eliminate sensitivity to IR radiation from any ambient heat sources. On the other hand, a combination UV/Visible/IR sensor may be required if maximum sensitivity is the top priority. Modern radiant emission detectors utilise digital logic to analyse a number of different radiant emission bands for a characteristic fire output signature. The radiant emission detector responds when the emission signal is greater than a predetermined level or when a central monitoring system determines that the signal is greater than a threshold dependent on ambient conditions (see 6.2.2 on activation of external devices).

See references [2] and [19] for information on the engineering evaluation of the performance and response time of radiant emission detectors for both flames and glowing char.

6.1.5.2 Required input information and/or data

a) Fire scenarios (smouldering or flaming);

b) fire loads (fuel type involved);

c) size of fire and/or smoke;

d) building parameters.

6.1.5.3 Outputs from subsystem engineering analysis

The output of the analysis is the time required for detection or whether detection will occur at all. This, plus design objectives, environmental factors and false alarm considerations, will help determine the suitability of received radiation for fire detection.

6.1.6 Multi-sensor or multi-criteria detectors

A newly developed category of detectors involves the use of more than one type of sensor in a single point detector in order to increase overall sensitivity while reducing the incidence of false alarms. For example, a detector can combine a sensor that responds to smoke particulates with a sensor that responds to one or more other effluent and/or species. Such detectors can make use of sophisticated cross-correlation techniques to insure that there is an output only for a fire event and not for a normal environmental change.

6.2 Activation time

6.2.1 Role in fire safety engineering design

The intent of this subclause is to give guidance on the basic principles for assessing activation times for automatic fire alarm systems, automatic smoke and/or heat control systems and automatic fire suppression systems.

The activation time is the time interval from response by a sensing device until the suppression system, smoke control system or the alarm system is fully operational. From this definition it follows that the activation time consists of both a possible delay time after detection and the actual time it takes to activate the devices (i.e. time to open fire vents, time before air is displaced).

As part of the activation process of fire suppression, the agent delivery system is calculated, or a pre-engineered system is selected, to give the required agent flow (for example, sprinkler application rate) through the delivery device or nozzle. For this calculation, the flow capacity versus pressure relationship of each nozzle would be needed to determine if the required flow from the nozzle can be attained with the assumed agent supply capabilities. Any delays due to agent transit times in a piping system would be included in such a calculation.

6.2.2 Activation of external devices by detection systems

The activation time of a detection system includes any time delays between the response of individual detectors and the final output of the complete system in terms of triggering alarms as well as other types of safety devices. For detectors which produce a continuous electrical signal that is monitored at some frequency by a central control point with fixed or programmable or other logic, detection results from the “activation time” of the central control logic (for example, in defining the threshold separating a fire event from ambient, non-fire conditions) and not from a specific response of individual detectors. Note that there may be a significant time delay for acquiring the electrical signal from any one detector if there are large numbers of detectors in the system. For self-contained, stand-alone detectors as well as complex systems of multiple detectors, activation time can include possible and deliberate built-in fixed or variable delays and even a manual over-ride to further change the delay time.

6.2.2.1 Processes considered in evaluating system designs

Activation of a centralized detection system may include the process of keeping a historical record of ambient, non-fire conditions that are appropriately averaged to determine the threshold for triggering system output. Whether this process is performed using analogue circuitry with fixed logic or digital circuitry with programmed logic, the reliability of the system is an important consideration.

6.2.2.1.1 Methods to evaluate the response of multiple detector systems with fixed logic

The activation time for a two detector-dependent, or coincidence detection, alarm system can be calculated as the time difference between detection time for the first and the second detector. Generally, the second detector must be in a different “zone” from the first detector in order to generate an output signal that is less susceptible to false alarms.

6.2.2.1.2 Methods to evaluate the response of multiple detector systems with programmed logic

Generally, building automation networks must process information from a large number of different detectors. It is important to determine from the equipment vendor or operator what delay time may be expected between the time of response of an arbitrary fire detector and computer activation of alarms and telecommunications messages under worst-case conditions. System and/or network reliability is an important factor to consider in the engineering design process, as discussed near the end of 6.1.1.

6.2.2.2 Required input information and/or data

To calculate the activation time of system operation the following information is required for building parameters — all parameters necessary to characterize system performance are included here, such as:

1) delay times from vendor specifications;

2) fixed built in system logic as part of the design;

3) input parameters required by application software on building automation networks.

6.2.2.3 Outputs from subsystem engineering analysis

The output of the analysis is the time required for a detection system, once triggered by a response from the initial sensor, to activate external devices, or whether such devices are activated at all.

6.2.3 Selection and activation of visual or audible alarms

6.2.3.1 Processes considered in evaluating designs

Engineering design information on the selection of alarms for life safety or property protection can be found in references [2], [19] and [39]. The type of visual and/or audible alarm selected should be consistent with design objectives, as discussed below. Alarm delays may be due to signal transmission times from central station services or to fixed and/or selectable delay times built into the alarm system, rather than due to delays in the detection system itself, as calculated in 6.2.2.

6.2.3.1.1 Life safety

Automatic fire alarms installed for life protection must be clearly audible by the occupants in all parts of the building and the sound or voice message should be sufficiently distinctive for the occupants to be able to distinguish the warning from any other warning sounds which may also be used within the building. However, it is possible in noisy environments, or where the occupants have impaired hearing for fire alarm sounders to be ineffective. Under such circumstances, visual signals should be used to supplement the audible signals and should result in a significant reduction in reaction time of the trained occupants. It is essential that the type of alarm and content of voice messages take into account the use of the building, the likely nature of the occupants involved and the fire safety management systems in place. Further guidance on these issues is given in ISO/TR 13387-8, *Life Safety — Occupant behaviour location and condition.*

When specifying the location and sound level output of alarms, it is important to avoid high sound pressure levels in relatively small spaces (for example, 110 dB in a corridor), as this can result in the occupant becoming disoriented when trying to escape.

6.2.3.1.2 Property protection

The primary purpose of automatic fire alarm systems installed for property protection is to summon fire fighting assistance. The number, characteristics and location of alarm sounders within the building should be sufficient to summon local, trained staff fire fighters, such as a plant emergency organization or a works fire brigade. The alarm will normally be heard by staff who are trained to recognize and respond to the sound and any delays in taking the required action should be minimal. In addition the alarm may automatically be relayed to fire service personnel, either directly or via a supervised alarm centre or central station which should comply with national standards for such operations. The alarm will not necessarily give any information concerning the location and extent of the fire. This information may be made available in either text or diagrammatic and/or pictorial form at the fire alarm panel or on visual display units near the fire alarm panel or at suitable locations within the premises. Any such additional positional information can significantly reduce delays in manually suppressing the fire and also help improve fire service utilization and efficiency through prior knowledge of the situation.

6.2.4 Activation of fire suppression systems

Time for activation of fire suppression systems is the time from detection system response until fire suppressant actually is released into the occupancy.

6.2.4.1 Processes considered in evaluating system designs

Prediction of activation time for suppression agent release depends on supply pressures, system flow resistance characteristics between the supply reservoir and distribution nozzles and on properties of the suppression agent. Commercial and institutional software that takes these processes into account is readily available to help with the engineering of complex suppression systems that minimize activation time and meet design objectives.

Methods to evaluate activation time for design agent flow are:

a) water-filled sprinkler systems: water-filled and pressurized conventionally-activated sprinkler systems will be fully activated at the same time the sprinkler system detects fire. Thus, activation time can be neglected if the system has been designed to provide the water flow required to the most remote sprinkler device. Details of how to design such systems, including proper sizing of pipes and pumps, can be found in several texts (for example, references [12] and [13]);

b) dry pipe sprinkler and/or suppression device systems: activation time is equal to the time it takes to expel system air. The activation time should be set equal to the longest time for suppression agent to expel air through the agent outlet at the furthest point from the system control valve;

c) deluge (for example, water mist systems) and pre-action systems: activation time is equal to the time it takes for suppression agent to expel air in system pipework through the agent outlet at the furthest point from the system control valve;

d) gaseous flooding systems: activation time for flooding systems (for example inert gasses) is the time it takes to establish the specified concentration of suppression agents in the volume in question. This time can be calculated on the basis of bottle pressure and the design of the delivery system (pipes and nozzles). For detailed information on the engineering design of such systems to minimize activation times, see references [14], [15] and [17];

e) foam and wet chemical extinguishing systems: activation time is equal to the time it takes for suppression agent to expel free air in system pipework through the agent outlet at the furthest point from the system control valve plus the time taken to generate the required concentration of foam or wet chemical agent. The foam system must be properly designed to produce the flow of agent required with a minimum activation time. Details of this design process can be found in several texts (for example, references [16] and [21]);

f) dry powder: activation time is equal to the time it takes for suppression agent to expel air in the system pipework through the agent outlet at the furthest point from the agent container, which can be calculated based on the operating pressure of the agent container and on the system pipework design;

g) powder aerosols: activation time is negligible for those systems that are triggered by pyrotechnic or explosive devices.

6.2.4.2 Required input information and/or data

a) building parameters (includes detailed description of suppression system hardware, such as specifications of nozzle performance, pipe-flow characteristics and suppression agent properties, for example, density, viscosity, boiling point, vapour pressure);

b) required (design) agent flow rate from agent outlets or other distribution devices (for example, “design density” for sprinklers) from 6.3.

6.2.4.3 Outputs from subsystem engineering analysis

The output of the analysis is the time, from the onset of detection, for agent to flow from distribution nozzles at the rate required for suppression or to meet design objectives.

6.2.5 Activation of smoke control or smoke management systems

6.2.5.1 Processes considered in evaluating system designs

Smoke control systems implement the opening or closing of vent dampers and other flow-control devices within a building to allow control of smoke in a fire situation for life safety and manual fire fighting to protect contents in high value occupancies. Prediction of smoke control system performance requires information on system characteristics. See reference [38] for detailed information on the evaluation and design of systems involving the activation of pressurization, flow control and fresh air dilution and the use of compartmentation and buoyancy to manage smoke movement in a variety of building enclosures. Note that all these systems can be manually operated.

Methods to evaluate activation time for design flow capacity or resistance:

a) collapsible smoke vents, for example, thermoplastic roof lights, can be modelled as a heat detector with a temperature and RTI value. The activation time is thus negligible;

b) smoke vents: the activation time is the time from detection to reach design flow capacity;

c) powered smoke exhaust system: the activation time is time from detection until the system has reached design flow capacity;

d) smoke control door: activation time is time from detection to door being closed (see ISO 3009 for such doors);

e) smoke dampers: the activation time is the time from detection until the damper is closed to meet the design resistance.

Information on the evaluation of smoke vent performance and activation time can be found in references [1] and [18].

6.2.5.2 Required input information and/or data

The required input information and/or data are as follows:

a) building parameters (including detailed description of smoke control system hardware and its location);

b) information from HVAC or mechanical services engineer and/or vendor specifications on system characteristics (for example type of activation plus fixed activation times) and suitability to applications;

c) required (design) flow capacity or flow resistance from subsystem 2.

6.2.5.3 Outputs from subsystem engineering analysis

The output of the analysis is the time required, from the onset of detection, for smoke control or smoke management to achieve required levels of performance.

6.2.6 Activation of heat control systems

6.2.6.1 Processes considered in evaluating designs

Heat control systems implement the opening or closing of sections within a designed enclosure to allow control of temperatures for protection of property in a fire situation. Predictions of heat control performance require information on system characteristics. Note that these systems can be manually operated.

Methods to evaluate activation time for design flow capacity or fire resistance:

a) heat vents: activation time is the time required from detection to reach design flow capacity;

b) collapsible heat vents, for example, thermoplastic roof lights, can be modelled as a heat detector with a temperature and RTI value. The activation time is thus negligible;

c) heat control doors and dampers: activation time is time from detection until the system has been closed to meet design resistance.

Information on the evaluation of heat vent performance and activation time can be found in references [1] and [18].

6.2.6.2 Required input information and/or data

The required input information and/or data are as follows:

a) building parameters (including detailed description of heat control system hardware and its location);

b) vendor specifications of system characteristics (for example, type of activation plus fixed activation times) and suitability to applications;

c) required system performance (design heat flow capacity or heat flow capacity) from subsystem 2;

d) required fire resistance from subsystem 3.

6.2.6.3 Outputs from subsystem engineering analysis

The output of the analysis is the time required, from the onset of detection, for heat control systems to achieve required levels of performance.

6.2.7 Activation of safety control valves, agent flow alarms and interlocks

6.2.7.1 Processes considered in evaluating designs

The following are the processes to be considered when evaluating designs.

a) Safety control valves control the opening or closing of a fluid supply within or to a designed enclosure in a fire situation. Prediction of safety control valve operation is dependent on system characteristics. Note that these valves can be manually operated.

b) Agent flow alarms are devices that provide an external alarm based on activation of a suppression system. Such devices are required by national codes because there may be no independent detection devices other than those (for example, fusible links or glass bulbs) built into the suppression system.

c) Interlocks include devices that provide a means for escape by unlocking doors, etc., or that prevent the spread of smoke by turning off air conditioning, etc., or that prevent further ignition of potential fuel sources by removing power from devices, such as equipment, once fire is detected.

d) Methods to evaluate activation time: for all types of safety devices, the activation time is the time taken from detector response to the safety device being opened and/or closed and/or switched, as required

6.2.7.2 Required input information and/or data

The required input information and/or data are as follows:

a) building parameters (including detailed description of control valve hardware and location);

b) vendor specifications -vendor specification of system characteristics (for example type of activation plus fixed activation times), and suitability to applications.

6.2.7.3 Outputs from subsystem engineering analysis

The output of the analysis is the time required, from the onset of detection, for activation of the safety device.

6.3 Performance of suppression systems

6.3.1 Role in fire safety engineering design

The evaluation of suppression systems generally is based on relating the design occupancy to relevant fire loss statistics, empirical correlations of full-scale fire test data, engineering interpretations of generic (full-scale, intermediate-scale or bench-scale) test data or to results from a validated mathematical model. Generally, the design objective is for reliable suppression of a particular stage of fire growth by limiting heat or smoke (effluent/species) release rates or by limiting the total quantity of smoke or heat produced. With some suppression devices, this objective can be satisfied, in part, by specification of a required agent flow rate or total quantity of agent to be injected within a certain time, consistent with installation standards and relevant regulatory guidelines. With other suppression devices, the design objective is partially satisfied by specification of a required application rate of agent, with or without a fire, again consistent with installation standards and relevant regulatory guidelines. As implied above, a high level of suppression (and the prerequisite detection) reliability is usually included in the design objective, so the evaluation of any suppression system should address long term system reliability.

6.3.2 Water-spray systems

6.3.2.1 Processes considered in evaluating system designs

Fire suppression by water sprays involves physical processes that are discussed in annex A. These processes, many of which are also important during suppression by water-based foams, consist of the following:

a) heat absorption by water droplets in the spray;

b) gas phase inerting due to water vapour generated from the spray;

c) thrust force effects on fire gases due to spray momentum.

All these physical processes are at work to some degree when water sprays are activated for fire suppression, generally leading to a reduction in fire heat release rate or the extent of fuel involvement. Even when water spray suppression is not effective in reducing fire growth, there may be significant reductions in gas temperature levels and cooling of surfaces subjected to direct impingement of water spray droplets. An example is the case of structural steel, which may be protected by spray droplet impingement during the types of fires that are not intended to be suppressed by such sprays.

6.3.2.1.1 Methods to evaluate fire suppression by automatic sprinkler sprays

In general, automatic sprinkler fire protection systems control fire spread and the growth of heat release rate, as opposed to water mist protection systems (see 6.3.2.1.2), which are intended to eliminate flaming combustion. It is assumed that a fire service will be notified and will be on site to bring about final fire extinguishment by combining the sprinkler output with hose streams. The decision as to what type of sprinkler to use in any given building or facility should depend on an assessment of factors including:

a) occupancy and/or fuels (from building parameters and fire loads);

b) water availability (pressure, flow, capacity);

c) automatic connections and/or fire service support;

d) design and/or commissioning skills;

e) maintenance.

Although there are thousands of automatic sprinkler models commercially available, these can be grouped into just two distinct types: control-mode sprinklers and suppression-mode sprinklers.

6.3.2.1.1.1 Control-mode sprinklers

Control-mode sprinklers control fire growth by “prewetting” of the fuel surrounding the active fuel-burning region, so as to limit the fire to a particular area. For recommendations on what type of building occupancies require protection by automatic control-mode sprinklers, see reference [20].

For design purposes, it is often possible to assume that the heat release rate (HRR) and maximum quantity of fuel involved is limited by the operation of control-mode sprinklers to values not measurably greater than those existing at the time of activation of the sprinklers most remote from the fire. Thereafter, the HRR is assumed a constant value until burn-out of the fuel that was involved at sprinkler activation (as discussed, for example, in reference [1], clause 3-2.2.1). However, if tests with the assumed design fire flame height and height of installed ceiling sprinklers show that fire in the combustible material of interest will be suppressed, then a reduction in HRR can be assumed starting at the time of sprinkler activation (see reference [1]).

An example of such suppression testing may be found in reference [35], where large-scale experiments were performed to determine the HRR of eight unshielded office fuel packages with and without sprinklers operating. Results from these experiments were used to develop a time-dependent HRR reduction factor, which then was used to develop a complete HRR time history before and after sprinkler activation. The fire suppression algorithm developed in reference [35] is limited to the specific fuel arrays and sprinkler positions and/or characteristics that were actually tested, although the authors attempt to gain somewhat more general applicability by treating the HRR time history as an upper bound for a range of real office occupancies.

Limitation of HRR by control-mode sprinklers (as described above) assumes that the minimum design density is achieved within the specified sprinkler activation area required by the relevant national installation standard or regulatory guideline (see, for example, references [3] or [44]) for the particular occupancy type being protected. Note that the occupancy classification system in national installation standards, and hence this limiting HRR assumption, may not apply to situations involving processing or storage of materials having unusual composition or height, ceiling clearances (above contents) that are unusually large or sprinklers installed with sensitive elements below the ceiling-jet (see reference [45] for information on ceiling-jet thickness) that would be produced by a fire. High ceiling clearances and sprinklers installed too far below a ceiling can be especially dangerous since fire size and HRR at sprinkler activation may be so large that control of radiant fire spread by sprinklers is not possible.

6.3.2.1.1.2 Suppression-mode sprinklers

Suppression-mode sprinklers, such as the ESFR type (early suppression fast response), deliver water droplets directly to the burning fuel surfaces through any intervening flames. Typical installation standards and relevant regulatory guidelines (see, for example, reference [3]) for ESFR sprinklers are based on the assumed activation of no more than two concentric rings of ESFR devices (for example, a total of 12 activated devices, if ignition is centred under 4 agent outlets of a square grid) surrounding the design fire to achieve a low fire HRR for extinguishment by hose streams. These standards and engineering guidelines relate ESFR sprinkler performance directly to the fire challenge and the characteristics of the sprinkler spray, which involves the requirement that the required delivered density (RDD) of water be less than the actual delivered density (ADD).

RDD, determined experimentally in a special facility, is the volumetric flow rate of water, applied uniformly to the top surface of a defined fuel array, that is needed to cause the HRR of the burning fuel to decay rapidly to a sufficiently low level. Water application in the RDD apparatus is initiated at a time that simulates the activation of a real, ceiling-mounted ESFR sprinkler. The greater the HRR when water application is initiated, the greater will be the RDD. Hence, fast response, from sensing elements having low RTI and being properly placed within the ceiling-jet, is important for minimizing the HRR at sprinkler activation and the RDD.

ADD, determined in a special facility that simulates a range of fire HRR, is the measured water flux delivered near the base of the fire plume for specific ESFR sprinklers being evaluated. As the HRR of the simulated fire plume increases, the ADD will decrease due to droplets being deflected by the significant plume gas velocities (note that ADD can also be reduced if there is any significant interference with an ESFR spray envelope, for example, due to improper installation close to ceiling fixtures or structural elements). Hence, ADD is maximized by fast response, when HRR is still low, from sensing elements having low RTI and being properly placed within the ceiling-jet.

A knowledge of RDD and ADD allows a determination of whether suppression will be effective or not. For successful suppression, ADD (for the specific ESFR sprinkler system chosen) must exceed RDD (for the specific fuel array being considered) at the maximum HRR expected when ESFR sprinklers are activated. This performance-based design approach has been completed for challenging occupancies and fire scenarios listed in national installation standards (see, for example, reference [3]).

6.3.2.1.2 Methods to evaluate fire suppression by water mist sprays

In general, water mist fire protection systems are intended to eliminate flaming combustion (i.e., produce extinguishment) through the use of water droplets in the 50 µm to 1 000 µm diameter range. Mechanisms for this extinguishment process are discussed in reference [41]. Extinguishment may not always be the only protection objective, with control-mode operation possible in some circumstances. A significant feature of water mist sprays is that, for certain applications, reduced total water flow rates and quantities may be sufficient, and that for certain applications (for example, fires involving flammable liquid pools and sprays), water mist sprays may be more efficient than a typical sprinkler system. In general, the range and limits of application for these systems still have to be determined. Water mist systems are inherently more complex than sprinkler systems, usually requiring some type of zoned, deluge operation of multiple mist sprays to be successful.

Water mist sprays can most easily extinguish large fires within enclosed spaces where the thermal energy generated by the fire can lead to rapid vaporization of the water mist spray droplets into copious amounts of steam that then causes a sufficient thermal ballast effect to eliminate flaming combustion. Small fires that have not yet heated an enclosure or are in large open areas cannot be easily extinguished by water mist sprays unless the fire is literally within the droplet envelope (or boundary) of the spray. For further information on the physical processed involved in water mist fire suppression, see reference [40].

A general design method is not yet recognized for water mist protection systems. Because of this, water mist spray systems are designed and installed in accordance with their listing by those product certification organizations that are acceptable to the authority having jurisdiction or to relevant regulatory officials. See reference [9] for guidance on the design and installation of such listed systems.

6.3.2.2 Required input information and/or data

The required input information and/or data are as follows:

a) fire loads (includes type of occupancy);

b) fire scenarios;

c) size of fire and/or smoke;

d) building parameters — all inputs necessary to specify suppression system performance should be included in this group of parameters, such as:

    1) position of spray devices;

    2) characteristics of spray devices;

e) relevant regulatory guidelines for maximum/minimum water pressure, maximum/minimum device spacing and total water flow requirement (or sprinkler activation area versus sprinkler application rate) as a function of building occupancy classification; alternatively, empirical information from loss experience or full-scale testing on required sprinkler application rate and sprinkler activation area versus the type of fire, and fire heat release rate at activation, can be provided.

6.3.2.3 Outputs from subsystem engineering analysis

The outputs from subsystem engineering analysis are the following.

a) Required water flow rate from each agent outlet, the maximum/minimum agent outlet spacing and the total number of agent outlets that must be designed for activation to suppress successfully a design fire in a given occupancy.

b) Impact on heat and smoke release:

Sprinklers and water mist sprays, are not only used to limit fire propagation, thereby preventing thermal damage to a building and burns to occupants, but are also used to limit nonthermal damage and threat to life due to effluent and/or species. While it is recognized that sprinklers can prevent flashover and its associated large volumes of smoke, sprinkler systems that are properly designed to match the occupancy can also suppress fires to limit the total area subject to immediate or delayed (due to corrosive effects) smoke damage.

c) Impact on thermal and effluent/species profiles:

Sprinkler sprays have a very significant effect in reducing hot gas layer temperatures away from the fuel zone. Ceiling jets, hot layers and combustion gases far from the fire source can be cooled significantly, leading to reductions in fire damage and in the number of operating sprinklers too distant from the fire to be effective. This effect of sprinkler sprays, which is amenable to calculation by CFD modelling (see 7.3.2), is implicitly taken into account by sprinkler installation standards and regulatory guidelines. See subsystem 2, ISO/TR 13387-5, for a discussion of how to evaluate cooling and smoke movement by water sprays.

6.3.3 Other suppression systems

This subclause covers the evaluation of suppression systems that use agents other than water sprays. A discussion of aerosol agents is provided in annex C since suppression systems using this type of agent are still under development.

6.3.3.1 Processes considered in evaluating designs

6.3.3.1.1 Methods to evaluate fire suppression by inert gaseous flooding agents

Scientific measurements (refer to references [28] and [29]) have established that the three chemically inert agents, carbon dioxide (CO_2, to be released when the area is unoccupied), nitrogen (N_2), argon (Ar) and their mixtures, all extinguish flames by cooling the flame gases ("thermal ballast" effect due to dilution) below a critical temperature, which is the same for each of the above agents, but which depends on the particular fuel and combustion situation. This allows critical extinguishing concentrations for all inert gases to be calculated once the extinguishing concentration for one gas is known. For example, in theory, volumetric concentrations of 39,5 % N_2 and 50,5 % Ar are completely equivalent in terms of extinguishing effectiveness to the proven CO_2 concentration of 28,6 %. Note that the oxygen concentration at these equivalent extinguishment conditions is not the same for each agent, ranging from a high of 15 % with CO_2, to 12,7 % with N_2, to a low of 10,4 % with Ar.

Because of practical limitations on the size of distribution pipe and/or tubing, discharge of the large volumes of inert agent (required by the high concentrations noted above) into a building enclosure can take one to two minutes or even longer, depending on the design of the inert gas extinguishing system, with perhaps a further one minute to ensure complete mixing and total extinguishment. There is usually a period between activation of alarms after detection and the commencement of agent discharge to allow for evacuation of personnel in an occupied area. Agent discharge times cannot be shortened significantly due to noise and cold shock considerations that require pipe and agent outlet flows to be subsonic and due to the potential for pressure build-up in some enclosures, leading to structural damage to walls, etc. The size of pipe to maintain reasonable discharge times is also an issue for specialized equipment that is protected with inert gaseous flooding agents because of space limitations in and near such equipment.

The successful implementation of inert gaseous systems (see reference [15] for information on the engineering design of carbon dioxide systems) depends upon achieving and maintaining a design concentration for flame extinguishment, which requires:

a) proper design calculations (software is available);

b) appropriate approved hardware (containers, piping, valves, nozzles) and agent;

c) careful commissioning and installation consistent with regulatory guidelines;

d) control of doors, dampers, etc. to avoid leakage.

Inert gases will not extinguish fires where the following materials are actively involved in the combustion process:

a) chemicals containing their own oxygen supply, such as cellulose nitrate;

b) reactive metals such as sodium, potassium, magnesium, titanium, and zirconium; and

c) metal hydrides.

6.3.3.1.2 Methods to evaluate fire suppression by chemically active, gaseous flooding agents

Chemically active, gaseous suppression agents (for example, halocarbons or halogenated agents) extinguish fires partly by chemical interaction with the combustion process and partly by flame cooling (“thermal ballast” effect noted in 6.3.2.1). The concentration of agent required is in the range of 5 % to 15 % of room volume and agent discharge to reach this concentration takes 10 s to 20 s, with perhaps a further minute to ensure complete mixing and extinguishment. There is usually a time period between activation of alarms after detection and the commencement of agent discharge to allow for evacuation of personnel in an occupied area. See reference [43] for a comprehensive review of performance and references [14], [17] and [46] for information on the engineering design and performance of systems using halocarbon suppression agents.

Many of the halocarbons have a propensity to leak out of the protected area because their discharged gas density is much different from that of air. Fan pressurization leakage testing should therefore be part of the installation process for such agents.

Times for agent discharge and fire extinguishment must be minimized to prevent the generation of damaging and/or toxic breakdown products, such as acid gases, from the agent and/or fire interaction. In practice, this means that agent delivery must be accomplished while the fire is still very small, through well-designed detection and delivery subsystems.

6.3.3.1.3 Methods to evaluate fire suppression by low-expansion foam and other water-additive systems

6.3.3.1.3.1 Low expansion foam and aqueous film-forming foam (AFFF)

Fire-fighting foam is an aggregate of air-filled bubbles formed from aqueous solutions and is lower in density than flammable liquids. It is used principally to form a cohesive floating blanket that prevents or extinguishes fire by excluding air and cooling the burning fuel. It also prevents re-ignition by suppressing formation of flammable vapours. It has the property of adhering to surfaces, which provides a degree of exposure protection from adjacent fires. AFFF is a type of low expansion foam that produces a highly stable aqueous film that spreads rapidly over a liquid hydrocarbon surface (see reference [16]).

Foam may be used as a fire prevention, control or extinguishing agent for many flammable liquid hazards but is not suitable for flowing liquid fuel fires or for gas fires. See references [5], [16] and [21] for additional information on the engineering design of foam systems and reference [6] for information on systems required to meet both foam and water spray design criteria.

6.3.3.1.3.2 Wet chemical extinguishing systems

Wet chemical solutions in extinguishing systems are generally potassium carbonate based, potassium acetate based, or a combination thereof mixed with water to form an alkaline solution capable of being discharged through piping. The effect of such solutions applied to flammable liquid fires is to create a rapidly spreading vapour-suppressing foam on the fuel surface that extinguishes the flame by forming a barrier between the liquid fuel and oxygen and by cooling the flammable fuel.

See references [7] and [24] for information on the engineering design of water additive, or wet chemical systems.

6.3.3.1.4 Methods to evaluate fire suppression by medium- and high-expansion foam agents

High-expansion foam is an agent for control and extinguishment of solid-fuel and flammable liquid fires and is particularly suited as a flooding agent for use in confined spaces. Medium-expansion foam was developed to meet the need for a foam that was more wind resistant than high-expansion foam for outdoor applications. See [8], [16] and [21] for detailed information on the engineering design of medium and high expansion foam systems.

Medium- and high-expansion foams are mechanically generated by the passage of air or other gases through a net, screen or other porous medium that is wetted by an aqueous solution of surface active foaming agents. (Note that gases for foam generation should not be taken from the fire area as smoke can contaminate the foam, causing it to break down). Under proper conditions, fire-fighting foams of expansion ratios from 20:1 to 1 000:1 can be generated. These foams provide a unique agent for transporting water to inaccessible places; for total flooding of confined spaces; and for volumetric displacement of vapour, heat and smoke.

Medium- and high-expansion foam have the following effects on fires:

a) where generated in sufficient volume, foam can prevent movement of air to the fire;

b) water in the foam is converted to steam, inerting the flame and cooling the environment;

c) solution from the foams that is not converted to steam will tend to penetrate solid fuel materials because of their relatively low surface tension;

d) where accumulated in depth, foam can provide an insulating barrier for protection of exposed materials or structures not involved in a fire and can thus prevent fire spread;

e) solid fuel fires are controlled when the foam completely covers the fire and burning material. If the foam is sufficiently wet and is maintained long enough, the fire can be extinguished;

f) flammable liquid fires involving high flash point liquids can be extinguished when the surface is cooled below the flash point. Liquid fuel fires involving low flash point liquids can be extinguished when a foam blanket of sufficient depth is established over the liquid surface.

6.3.3.1.5 Methods to evaluate fire suppression by dry-chemical agents

Information on the engineering design of dry-chemical systems can be found in reference [22]. See annex B for background information on new types of aerosol agents that may be used in specialized applications.

6.3.3.2 Required input information and/or data

a) Fire loads (includes type of occupancy);

b) fire scenarios;

c) size of fire and/or smoke;

d) building parameters — all inputs necessary to specify suppression system performance should be included in this group of parameters, such as:

    1) position of agent distribution devices;

    2) characteristics of agent distribution devices;

    3) suppression characteristics of agent, such as extinguishment concentration;

e) relevant regulatory guidelines on suppression system design.

6.3.3.3 Outputs from subsystem engineering analysis

a) Required agent flow rate from each nozzle, the maximum/minimum nozzle spacing and the total number of nozzles that must be designed for activation to successfully suppress a design fire in a given occupancy.

b) Impact on heat and effluent/species release:

    Clean, gaseous agents are not only used to limit fire propagation, thereby preventing threat to life due to burns and thermal damage to a building and its contents, but are also used to limit nonthermal damage and the more common threat to life due to effluent and/or species. Systems combining such agents with fast response detectors can extinguish fires while they are still small. This may be a requirement for occupancies containing equipment and/or product that can well be much more sensitive to fire products than people, such as clean rooms in the semiconductor, biotechnology and pharmaceutical industries, where rapid detection and suppression can prevent catastrophic damage from smoke.

c) Impact on thermal and smoke profiles — evaluated in ISO/TR 13387-5.

6.3.4 Interactions of smoke and/or heat control and suppression systems

6.3.4.1 Interactions of sprinklers with smoke control systems

Interactions between sprinklers and smoke control systems are difficult to predict because ventilation is introduced as an additional variable into the exceedingly complex fire suppression problem. A survey of the present state of the art of making such predictions is given in reference [48]. In general, there are three types of interactions between sprinklers and natural or powered ventilation systems designed to exhaust or vent smoke during a fire and are given as follows.

a) Influence of smoke exhaust on sprinkler operations or opening patterns — When buoyancy is used to exhaust hot fire products, this is normally done in conjunction with draft or smoke curtains that divide the ceiling into zones serviced by automatic or manual opening roof vents. Care must be taken in locating sprinklers with respect to these curtains, which may extend about one meter below the ceiling or more. This is especially important for suppression-mode (ESFR) sprinklers since the draft curtains can easily distort the spray envelope of one of the few ESFR sprinklers that normally would be operating. Draft and/or smoke curtains can also influence which control mode or suppression-mode (ESFR) sprinklers will open, especially if the initial fire is directly under a curtain or the intersection of two curtains (see reference [26] for test results). A possible outcome is the operation of an excess number of sprinklers as the fire continues to grow, thereby reducing flow pressures below acceptable levels or increasing the amount of water damage. Similar effects may result when sprinklers are located near power vent openings (see 6.1.2.6 of subsystem 2). These types of interactions are far more critical for the case of suppression-mode (ESFR) sprinklers because there are so few sprinkler operations expected when the system is operating properly that any distortion in the opening sequence can have major consequences.

b) Influence of smoke exhaust or smoke vents on the effectiveness of sprinklers — When smoke vents operate automatically, there is the possibility of fresh air being introduced into the enclosure during the critical period when sprinklers are in the process of controlling or suppressing fire growth. Experiments have shown (see reference [23]) that smoke venting during this sprinkler control process may lead to an increase in the number of sprinklers activated and hence an increase in the total water flow requirement. This degradation in sprinkler effectiveness may be overcome, for those cases where smoke venting is necessary/required, by using, for example, manual instead of automatic activation of vents or automatic vents with a delayed activation compared to that of the sprinklers. Alternatively, smoke venting to improve visibility for manual fire fighting can be initiated automatically well before sprinklers, thereby decreasing the total number of sprinklers activated if manual fire fighting is successful (see references [55] and [56]).

c) Influence of sprinklers on the effectiveness of smoke control systems — At some distance from the fire, the sprinkler spray will interact with a slowly moving ceiling jet (layer) that, with time, is submerged within a thickening, hot gas layer. In many cases, the spray will cool this hot gas layer and reduce its buoyancy. A system using natural ventilation depends on the buoyancy of the hot gases to expel smoke, so the system would be under-designed if sprinkler cooling were underestimated. On the other hand, a powered smoke extraction system, which removes a nearly fixed volume of smoke irrespective of temperature, may also be under-designed if sprinkler cooling is overestimated since fire gases would then occupy a larger volume than expected. For a relatively cool gas layer or at a high water discharge rate, smoke may be pulled down from the hot layer, causing a loss of visibility at lower levels. Data on heat loss from fire effluent gases to sprinkler sprays, suitable for design application, are not yet available (see, for example, reference [27]).

6.3.4.2 Interactions of flooding agents with smoke control systems

Suppression systems that depend on volumetric flooding effects, such as water mist sprays and various gaseous agents (for example, carbon dioxide), often cannot be used in conjunction with smoke exhaust or control systems unless tests or calculations are performed to confirm that the suppression system is still effective. Generally, additional agent flow must be provided to counteract the influence of agent depletion by the smoke exhaust system.

For example, if clean gaseous agents are used, as is often the case, to protect the interior spaces of production equipment from incipient fire or gas and/or dust explosions, then any fume ventilation-control built into such equipment must be take into account in evaluating the suppression system performance. Similarly, it is noted in reference [38] (introduction-suppression systems), that for rooms and/or enclosures protected by gaseous agents, the activation of the suppression system should take precedence over activation of any smoke control and/or management system.

7 Engineering methods

7.1 General applications to subsystem 4

Different practical engineering methods exist to solve engineering problems. The purpose of this subclause is to give guidance on how to select proper methods or how to become confident that proper engineering methods have been applied by addressing the advantages and limitations of each method. The following types of methods have been identified:

7.2 Estimation formulae

Estimation formulae are typically derived through analysis of highly simplified real physical situations or through correlations of empirical data (or combinations of both) and may involve the use of pre-calculated look-up tables or graphs and/or nomographs. Such formulae can be used to indicate approximately (see, for example, references [11], [25] and [36]):

a) the time when a smoke detector will activate for a given design fire scenario;

b) the fire size when a heat detector or the **first** sprinkler will activate.

Such techniques will only produce acceptable results when used within applicable parameter ranges and when used by individuals having an understanding of the relevant physical processes.

7.3 Computer models

More accurate results can be obtained from the solution of sets of differential equations describing, to some level of approximation, the complex and interacting mechanisms involved in the detection or suppression processes being modelled. Computer models or computer simulations are simply computer software solutions to these approximate mathematical formulations of the real physical and chemical phenomena.

7.3.1 Zone models

Computer zone models involve the solution of a simplified set of differential equations within a small number of flow “zones” that have been identified from experimental studies (for example, the plume, the hot ceiling layer, the outflow from an enclosure opening, etc.). Because the hot ceiling layer in typical two-zone models is generally assumed to be homogeneous, the average hot layer flow properties that are calculated do not reflect accurately conditions near ceiling level detectors and suppression devices. One method for correcting this model defect is to introduce a ceiling-jet (see reference [47]) “zone” to predict the time at which a fire will be detected or sprinklers will be triggered, based on appropriate threshold and detector response parameters (see 6.1). Use of a zone model specialized for such predictions is described in annex B of reference [2].

Currently, zone models are not readily available to handle the general interaction of fires with suppression systems since empirical data correlations are still being developed. One strategy that has been used with several models is to assume arbitrarily a restricted interaction between sprinkler water sprays and the fire. In one case, only changes in the fire burning rate are considered by using the specialized suppression algorithm in reference [35]. In other cases, only effects of the spray on the flow field or only effects of the flow field on the spray are considered (see, for example, references [55] and [56]).

7.3.2 CFD field models

Field models use computational fluid dynamics (CFD) to subdivide the compartment or room into a large number of sub-volumes and to apply mass, momentum and energy conservation to each sub-volume. The technique is very demanding on both computer memory and processor speed and requires considerable skill to establish boundary and initial conditions properly.

Field models have been used successfully to calculate the movement of smoke in enclosures. This type of calculation is capable of simulating smoke movement under the influence of pre-existing temperature profiles characteristic of many complex enclosure situations. Although smoke concentration near detector locations is being modelled, the actual detector response is not being modelled. Currently, correlations of detector response with smoke characteristics are used in the calculation but there is a lack of detailed experimental validation of these CFD calculations when applied to the design of detection systems.

As discussed in reference [42], field models employing CFD and particle tracking can also be used to evaluate the interaction of sprinkler sprays with fires, leading to a prediction of the ADD (the water application rate actually reaching the burning fuel) as well as the cooling effect on the fire-induced flow. This technique requires as an input to the calculation details about sprinkler spray conditions (initial droplet size distributions, velocity vector distribution near the sprinkler) that are not easily obtained. As a result of this and the large amount of computing power required, such calculations have not been performed routinely and have not been validated except in a very few isolated cases (see reference [42]).

7.4 Experimental methods

General aspects of experimental methods, the design of experiments and ignition sources for experiments are discussed fully in subsystem 1, ISO/TR 13387-4. Due to the lack of other engineering methods to evaluate the performance of fire suppression designs, experimental methods are essential for this important area of fire protection. Consequently, special considerations applicable to the experimental evaluation of fire suppression performance will be listed as follows.

a) It is critical that experiments to confirm or validate the performance of a suppression system be conducted at full- or real-scale since the size of the experiment or test will affect gas motion and ventilation, flame radiative heat transfer and the residence time for flow field chemical reactions, all of which help determine whether a suppression system will be successful. Such full-scale tests have been used to develop sprinkler installation standards (for example, see reference [3]). Of course, preliminary experimentation at reduced or intermediate scales coupled with analytical methods is highly desirable to obtain the most information and the greatest likelihood of success from full-scale tests. Intermediate-scale testing is also useful for interpolation between (not extrapolation beyond) existing full-scale test conditions, especially when effects of changes in material composition for the same configuration are being evaluated.

b) When attempting to study fire suppression in very large building areas, such as storage occupancies, it is critical that confirmation/validation tests be conducted in a facility that is sufficiently large so as to allow:

   1) the activation of all the suppression devices (for example, sprinkler nozzles) that would be activated in the actual protection situation; and

   2) air ventilation that simulates the actual protection situation so that effluent/species do not prematurely dilute the air surrounding fire propagation zones.

   The latter requirement is particularly important because fire propagation is extremely sensitive to the flame cooling (thermal ballast effect) caused by dilution with, for example, the carbon dioxide in fire products, which will cause complete extinguishment when the oxygen concentration is only reduced to 15 % (see 6.3.3.1.1).

c) When selecting an ignition source or fire initiation scenario for experimental evaluation of suppression performance, it is important to simulate the most challenging source that might occur in the actual protection situation. The goal of the experiment is to determine if well established fire propagation can be stopped or limited by the suppression system before a significant fraction of the fuel load is consumed (see the discussion of design fire scenarios in ISO/TR 13387-2).

Experimental methods involving the use of full-scale tests are used for areas other than fire suppression. Standards for detector placement and spacing have been derived from this type of testing (for example, see reference [2]) in the past and such testing will be needed in the future to validate and confirm new analytical or computer models of detector response.

7.5 Reliability analysis

This part of ISO 13387 on detection, activation and suppression is solely concerned with “active” systems, such as automatic fire detectors, automatic sprinkler systems and automatic compartmentation systems. Reliability must be considered to be a crucial parameter in the evaluation of such systems for life or property protection in the context of an overall fire safety engineering sensitivity analysis. Information on reliability is also needed for any probabilistic analysis of risk (see ISO/TR 13387-1).

Much investigative and predictive work on the lifetime of components, failure rates and system reliability has been undertaken in the nuclear power industry. Data are available detailing reliability of components, mean time between failures, system reliability and system availability (combination of reliability and time to repair) but much of this is only applicable to systems which are built to high specifications and are to be used in demanding situations such as nuclear power, military or aerospace applications.

Most detection, activation and suppression systems are installed to handle very rare events, such as fire, and typically spend extended periods in quiescent rather than activated states. It is difficult to test such systems thoroughly without causing significant disruption to the occupants of the premises, although these systems may incorporate self-monitoring circuitry that allows some degree of functionality testing to be ongoing.

References [49], [50], [52] and [54] contain limited information on the reliability of detection systems while references [51] and [53] address the reliability of automatic sprinkler systems. See reference [57] for information on specific reliability methodologies applicable to fire safety engineering.

Annex A
(informative)

Physical mechanisms of suppression by water sprays

The fire suppression effect of water is due to the simultaneous effects of liquid-phase heat absorption (cooling), gas-phase inerting (thermal ballast) and droplet spray momentum processes. Generally, liquid phase cooling, especially at the fuel surface, is predominant. The suppression effect can be improved by sprinkler response at an early stage of the fire, which will be achieved by a small value of the response time index, RTI, a small conductive factor, C, and a small ceiling clearance above the fire source.

Heat absorption by liquid droplets can result in fire suppression through the following mechanisms:

a) cooling of flame by extinguishing water distributed and vaporized inside the flame;

b) prewetting of the non-burning fuels around the source of the fire, whereby the thermal decomposition of fuel will be delayed and decreased;

c) disturbance of the burning reaction sequence by cooling of the burning surface and elimination of chemical radicals, assuming that water can reach the burning fuel surfaces.

Once water vapour is produced [see a) above], the following gas-phase inerting mechanisms can lead to reduced flame heat transfer or even extinguishment:

a) decrease in the flame temperature toward or below the critical flame temperature for extinguishment, with an associated decrease in oxygen concentration (refer to references [28] and [29]) due to the diluent effect of water vapour;

b) blockage of air supply in flue spaces due to the large volume of water vapour generated;

c) blockage and reduction of flame radiant heat transfer by water vapour due to radiant absorption and reduced soot particle production.

If water is applied to the fire in the form of a spray, there may be the following effects of spray momentum (thrust force) interacting with the fire gases:

a) reduction of the air supply into the flame premixing zone by obstruction of the rising plume; the buoyancy of the diffusion flame produces a subatmospheric pressure in the flame premixing zone, to draw in surrounding fresh air flows;

b) decrease in the oxygen concentration associated with dilution of air supply into the flame premixing zone by addition of smoke cooled and forced down by the water discharge.

Prewetting [item b) under liquid cooling, above] of the fuels around the source of fire is achieved if the water sprays of the activated sprinklers can enclose the fire propagation zone and can wet the non-burning fuels. This process is too complex to be predicted in detail because it depends on the total area over which sprinklers are activated as well as the degree to which water runs off or soaks the fuel array. If sprinkler activation over a given non-burning area is known and if the radiant exposure from a spreading fire is known, then the minimum sprinkler application rate (water flux) needed to absorb this radiant exposure can be calculated. In practice, a safety factor (of 2 or more) is needed due to water runoff from vertical surfaces.

Annex B
(informative)

Calculation of response time for fixed temperature detectors

The following discussion is applicable to the sensitive elements of thermally activated suppression/control devices and thermally activated detectors for which RTI and C factors are known or can easily be determined (see ISO 6182-1, including 6.6.2.2 for C factor).

Treating the sensitive element as a lumped mass thermally isolated from the rest of the detector, reference [30] shows that the instantaneous rate of the rise of the element temperature can be obtained using a simple convective heat transfer equation expressed in terms of the response time index (RTI) and the conductivity factor (C), both parameters which take values specific to the detector of concern. The temporal history of the temperature, T_e, of the sensitive detector element can then be obtained by integrating the following heat transfer equation with respect to time:

$$\frac{\mathrm{d}T_\mathrm{e}}{\mathrm{d}t} = \frac{\sqrt{u}}{\mathrm{RTI}}\left[\left(T_\mathrm{g} - T_\mathrm{u}\right) - \left(\frac{1+C}{\sqrt{u}}\right)\left(T_\mathrm{e} - T_\mathrm{u}\right)\right] \qquad \text{(B.1)}$$

The other needed inputs are the initial temperature of the sensitive element (usually, ambient air temperature during testing) and the temporal profiles of the environmental gas temperature and velocity near the sensitive element. The response time can be determined as the time at which the calculated temperature reaches the operating temperature.

For the purposes of evaluating the response time of detectors in a given installation, an RTI value and a C-factor, established under known conditions, should be stated by the detector vendor or manufacturer. After integration of equation. (B.1), these parameters are related by:

$$\mathrm{RTI} = \frac{-t_\mathrm{R} \times \sqrt{u} \times \left(1 + \frac{C}{\sqrt{u}}\right)}{\ln\left\{1 - \left[(T_\mathrm{ea} - T_\mathrm{u}) \times \left(1 + \frac{C}{\sqrt{u}}\right) \times \left(\frac{1}{T_\mathrm{g} - T_\mathrm{u}}\right)\right]\right\}} \qquad \text{(B.2)}$$

where:

RTI	is the response time index $(\mathrm{m \cdot s})^{1/2}$
t_R	is the response time of detector (s)
u	is the actual gas velocity in test section of tunnel (m/s)
T_ea	is the nominal operating temperature of sensitive detector element (K)
T_g	is the actual gas temperature in test section (K)
T_u	is the ambient air temperature during testing (K)
C	is the conductivity factor $(\mathrm{m/s})^{1/2}$
T_e	is the temperature of sensitive detector element (K)

Annex C

(informative)

Extinguishment by chemical and powder aerosols

Because many of the possible replacements (i.e., having acceptable toxicity, ozone depletion and global warming potentials, fire extinguishing effectiveness and materials compatibility) for the traditional halon flooding agents are either liquids which have a boiling point that is near ordinary room temperature or are solids, it is likely in the future that many of these chemicals may be accepted as fire extinguishing agents in the form of sub-micron powder aerosols or fine droplet, fog-type aerosols. Such aerosol would be likely to vaporize in a sufficiently short time, especially near or inside a flame, to produce an extinguishing concentration of the agent before the occurrence of significant fire growth. At the present time, there are no listed droplet chemical aerosol systems and certainly no design criteria for such systems. However, several vendors have already developed fairly advanced powder aerosol systems, some of which are activated by simple, pyrotechnic devices that rapidly disperse the powder. There is still great uncertainty as to the toxicity and corrosive nature of these powders so their widespread use must await additional research.

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