INTERNATIONAL STANDARD

ISO 16732-1

First edition
2012-02-15

Fire safety engineering — Fire risk assessment —

Part 1: General

Ingénierie de la sécurité incendie — Évaluation du risque d'incendie — Partie 1: Généralités

Reference number
ISO 16732-1:2012(E)

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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.

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

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

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 16732-1 was prepared by Technical Committee ISO/TC 92, *Fire safety*, Subcommittee SC 4, *Fire safety engineering*.

This first edition of ISO 16732-1 cancels and replaces ISO/TS 16732:2005, which has been technically revised.

ISO 16732 consists of the following parts, under the general title *Fire safety engineering — Fire risk assessment*:

— *Part 1: General*

The following parts are under preparation:

— *Part 2: Example of an office building*

— *Part 3: Example of an industrial facility* [Technical Report]

Introduction

This part of ISO 16732 is for use by fire safety practitioners who employ risk assessment based methods. Any fire safety practitioner can have reason to employ such methods. All fire safety decisions involve uncertainty. Probabilities are the mathematical representation of uncertainty, and risk assessment is the form of fire safety analysis that most extensively uses probabilities and so most extensively addresses all types of uncertainty.

Examples of types of such fire safety practitioners include fire safety engineers; authorities having jurisdiction, such as territorial authority officials; fire service personnel; code enforcers; code developers; insurers; fire safety managers; and risk managers. Users of this part of ISO 16732 are to be appropriately qualified and competent in the fields of fire safety engineering and risk assessment. It is particularly important that the user understand the limitations of application of any methodology that is used.

Risk assessment is preceded by two steps: establishment of a context, including the fire safety objectives to be met, the subjects of the fire risk assessment to be performed, and related facts or assumptions; and identification of the various hazards to be assessed. A “hazard” is something with the potential to cause harm.

The subjects of fire risk assessment include the design and control of any part of the built environment, such as buildings or other structures. Fire risk assessment of a design consists of analysis of the risks, e.g. frequency and severity of harm, that are predicted to result if the design is implemented, combined with an evaluation of the acceptability of those risks.

Fire risk assessment can be used to support any decisions about fire prevention or fire protection of new or existing built environments, such as buildings, where probabilistic aspects, such as fire ignition or the reliability of fire precautions, are important. Fire risk assessment can also be used to establish safety equivalent to a code, to assess the balance between the cost and the risk reduction benefit of a proposal, or to examine acceptable risk specifically for severe events. Fire risk assessment can also be used to provide general guidance or to support choices in the selection of scenarios and other elements of a deterministic analysis.

Fire risk assessment can be used as part of compliance with ISO 23932, and all the requirements of ISO 23932 apply to any application of this part of ISO 16732. ISO 23932 identifies different applications of fire risk assessment. One application is for the limited purpose of identifying a manageable number of design fire scenarios for a deterministic analysis. This use of fire risk assessment is cited in ISO 23932:2009, 9.2.2.2 and 9.2.2.3. Additional guidance for this application is contained in ISO/TS 16733.

The other application, cited in ISO 23932:2009, 10.1.1.2, is as a calculation method to assess whether a proposed or existing design plan meets fire safety objectives when the performance criteria for the fire safety objectives are expressed in a probabilistic form. That application is the one for which ISO 16732 is principally designed. In that application the concept of design fire scenario, as described in ISO 23932, is better addressed through the dual concepts of fire scenario cluster and representative fire scenario used in this part of ISO 16732. The user should regard representative fire scenarios as the types of design fire scenarios used in fire risk assessment. The term “representative” and the linkage with fire scenario clusters are necessary to establish that calculations based on the selected scenarios will produce an acceptably accurate estimate of the required performance criteria, expressed as measures of fire risk, in accordance with ISO 23932.

Fire safety engineering — Fire risk assessment —

Part 1: General

1 Scope

This part of ISO 16732 provides the conceptual basis for fire risk assessment by stating the principles underlying the quantification and interpretation of fire-related risk. These fire risk principles apply to all fire-related phenomena and all end-use configurations, which means these principles can be applied to all types of fire scenarios. The principles and concepts in this part of ISO 16732 can be applied to any fire safety objectives, including the five typical objectives listed as examples in Clause 1 of ISO 23932:2009:

— safety of life,

— conservation of property,

— continuity of business and safety operations,

— protection of the environment,

— preservation of heritage.

This part of ISO 16732 is designed as a guide for future standards that provide formal procedures for the implementation of the risk assessment principles for specific applications, e.g. situations in which only certain types of fire scenarios are possible. Those future standards will complete the process of full standardization begun by this part of ISO 16732, which not only specifies the steps to be followed in fire risk assessment but also provides guidance for use in determining whether the specific approach used for quantification falls within an acceptable range.

Principles underlying the quantification of risk are presented in this part of ISO 16732 in terms of the steps to be taken in conducting a fire risk assessment. These quantification steps are initially placed in the context of the overall management of fire risk and then explained within the context of fire safety engineering, as discussed in ISO/TR 13387. The use of scenarios and the characterization of probability (or the closely related measure of frequency) and consequence are then described as steps in fire risk estimation, leading to the quantification of combined fire risk. Guidance is also provided on the use of the information generated, i.e. on the interpretation of fire risk. Finally, there is guidance on methods of uncertainty analysis, in which the uncertainty associated with the fire risk estimates is estimated and the implications of that uncertainty are interpreted and assessed.

This part of ISO 16732 is not structured to conform with any national regulation or other requirement regarding the use of fire risk assessment or the type of analysis that is to be performed under the name of fire risk assessment.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 13943:2008, *Fire safety — Vocabulary*

3 Terms and definitions

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

3.1
acceptance criterion
⟨fire risk assessment calculations⟩ qualitative and quantitative criterion which forms an acceptable basis for assessing the safety of a built environment design, defined on particular fire risk measurement scales

Note 1 to entry: Adapted from ISO 13943:2008.

3.2
consequence
outcome or outcomes of an event, expressed positively or negatively, quantitatively or qualitatively

3.3
design load
⟨fire risk assessment calculations⟩ fire scenario with sufficient severity to provide an appropriate basis for assessing whether a design will produce unacceptably large consequences

3.4
engineering judgement
process exercised by a professional who is qualified by way of education, experience and recognized skills to complement, supplement, accept or reject elements of a quantitative analysis

3.5
event tree
depiction of temporal, causal sequences of events, built around a single initiating condition

[SOURCE: ISO 13943:2008, 4.85]

3.6
fault tree
depiction of the logical dependencies of events on one another, built around a critical resulting event, which usually has an unacceptable level of consequence and may be described as a failure

[SOURCE: ISO 13943:2008, 4.95]

3.7
fire risk
⟨scenario⟩ combination of the probability of a fire and a quantified measure of its consequence

Note 1 to entry: Adapted from ISO 13943:2008.

3.8
fire risk
⟨design⟩ combination of the frequencies and consequences of scenarios associated with the design

Note 1 to entry: In definition 3.8, risk is typically expressed as risk per unit time, which is the reason that frequency is used instead of probability in the definition. Frequencies are normally calculated for fire scenario clusters (see 3.16), and consequences are normally calculated for representative fire scenarios (see 3.15).

3.9
fire risk, acceptable
⟨fire risk evaluation calculation⟩ risk that satisfies defined acceptance criteria

3.10
fire risk assessment
⟨built environment fire risk calculation⟩ well-defined procedure for estimation of fire risk for a built environment and evaluation of estimated fire risk in terms of well-defined acceptance criteria

3.11
fire-risk curve
graphical representation of fire risk

Note 1 to entry: It is normally a log/log plot of cumulative probability versus cumulative consequence; when consequences are measured as fatalities, fire-risk curve is also called an fN-curve, where f refers to frequency and N refers to number of deaths.

[SOURCE: ISO 13943:2008, 4.125]

3.12
fire risk evaluation
comparison of estimated risk, based on fire risk analysis, to acceptable risk, based on defined acceptance criteria

3.13
fire risk matrix
matrix display in which (1) rows or columns are defined by ranges of fire scenario cluster frequencies, (2) columns or rows are defined by ranges of fire scenario design loads, and (3) cell entries are specified acceptable consequences for the scenario clusters contained in the cell's row and column

Note 1 to entry: A fire risk matrix implicitly assumes that the design itself has no influence on the size or intensity of the fire challenging the building, but rather treats the fire scenario as an externally imposed load.

3.14
fire scenario
qualitative description of the course of a fire with time, identifying key events that characterize the fire and differentiate it from other possible fires

Note 1 to entry: Adapted from ISO 13943:2008.

Note 2 to entry: The fire scenario description typically includes the ignition and fire growth processes, the fully developed fire stage, the fire decay stage, and the environment and systems that will impact on the course of the fire. Unlike deterministic fire analysis, where fire scenarios are individually selected and used as design fire scenarios, in fire risk assessment, fire scenarios are used as representative fire scenarios within fire scenario clusters.

3.15
fire scenario, representative
specific fire scenario selected from a fire scenario cluster such that the consequence of the representative fire scenario can be used as a reasonable estimate of the average consequence of scenarios in the fire scenario cluster

Note 1 to entry: For additional information, see ISO/TR 13387-1:1999, 8.2.1 a) to f).

3.16
fire scenario cluster
subset of fire scenarios, usually defined as part of a complete partitioning of the universe of possible fire scenarios

Note 1 to entry: For additional information, see ISO/TR 13387-1:1999, 8.2.1 a) to f).

Note 2 to entry: The subset is usually defined so that the calculation of fire risk as the sum over all fire scenario clusters of fire scenario cluster frequency multiplied by representative fire scenario consequence does not impose an undue calculation burden.

3.17
limit state
⟨fire risk assessment calculation⟩ threshold or limiting value on a consequence scale that marks the line between acceptably large consequence and unacceptably large consequence

3.18
reliability
probability that a unit will perform a required function for given conditions and for a given period of time

3.19
individual risk
measure of fire risk limited to consequences experienced by an individual and based on the individual's pattern of life

Note 1 to entry: There is nothing in the definition that implies or requires acceptance.

[SOURCE: ISO 13943:2008, 4.195]

3.20
societal risk
measure of fire risk combining consequences experienced by every affected individual

Note 1 to entry: There is nothing in the definition that implies or requires acceptance.

[SOURCE: ISO 13943:2008, 4.297]

3.21
risk acceptance
decision to accept an estimated level of risk, based on either compliance with acceptance criteria or an explicit decision to modify those criteria

3.22
risk aversion
given two choices for which the product of frequency and consequence are identical, preference for the choice with the lower consequence

3.23
risk communication
exchange or sharing of information about risk between decision-maker and other individuals, groups or organizations who may affect, be affected by, or perceive themselves to be affected by the risk

3.24
risk management
processes, procedures, and supporting culture for ongoing achievement of desired risk criteria

Note 1 to entry: Risk management is a combination of risk assessment, risk treatment, risk acceptance, and risk communication.

3.25
risk treatment
risk modification measure, normally used to refer to changes other than changes to design, and the process used to select and implement the measures

Note 1 to entry: Risk modification measures that are not changes to design include changes to fire safety management procedures.

3.26
sensitivity
measure of degree to which a small perturbation of a system will create a large change in system status

3.27
uncertainty
quantification of systematic and random error in data, variables, parameters, or mathematical relationships or of failure to include a relevant element

3.28
propagation of uncertainty
mathematical analysis of uncertainty of calculated risk as a function of uncertainty in variables, parameters, data, and mathematical relationships used in the calculation

3.29
variability
quantification of probability distribution function for variable, parameter, or condition

4 Applicability of fire risk assessment

4.1 Circumstances where fire risk assessment provides advantages relative to deterministic fire safety engineering analysis

Scenarios with low frequency but high consequence present a challenge. It may be impossible to achieve the fire safety objectives at acceptable cost for such scenarios, but it may be unacceptable to ignore such scenarios entirely. Weighting the consequences of such scenarios by their frequency, as is done in fire risk assessment, incorporates such scenarios into the calculation without making them the only scenarios driving the calculation. Any of the following scenario characteristics can produce low-frequency, high-consequence scenarios:

If there is great diversity in the fire scenarios of concern or if consequences are very sensitive to small changes in input parameters, it may not be possible to produce a short list of design fire scenarios that collectively address and represent all fire scenarios. In such circumstances, fire risk assessment can provide a more flexible framework for analysis using a large number of representative fire scenarios, as well as providing quantitative evidence that the scenarios selected are representative of all scenarios.

Reliability is inherently probabilistic. Fire risk assessment has considerable advantages in analysing any problem where the results are highly sensitive to reliability or where reliability varies substantially from one design specification to another.

5 Overview of fire risk management

Risk management includes risk assessment but also typically includes risk treatment, risk acceptance, and risk communication. Risk acceptance marks the conclusion of risk assessment. If risk is not accepted, another risk assessment is necessary, and risk treatment is an option after each risk assessment. Risk communication is conducted after risk acceptance (see Figure 1). Fire risk assessment can also be used to assess alternative designs prior to selecting a specific design or making changes to that design to achieve compliance with the acceptance criteria.

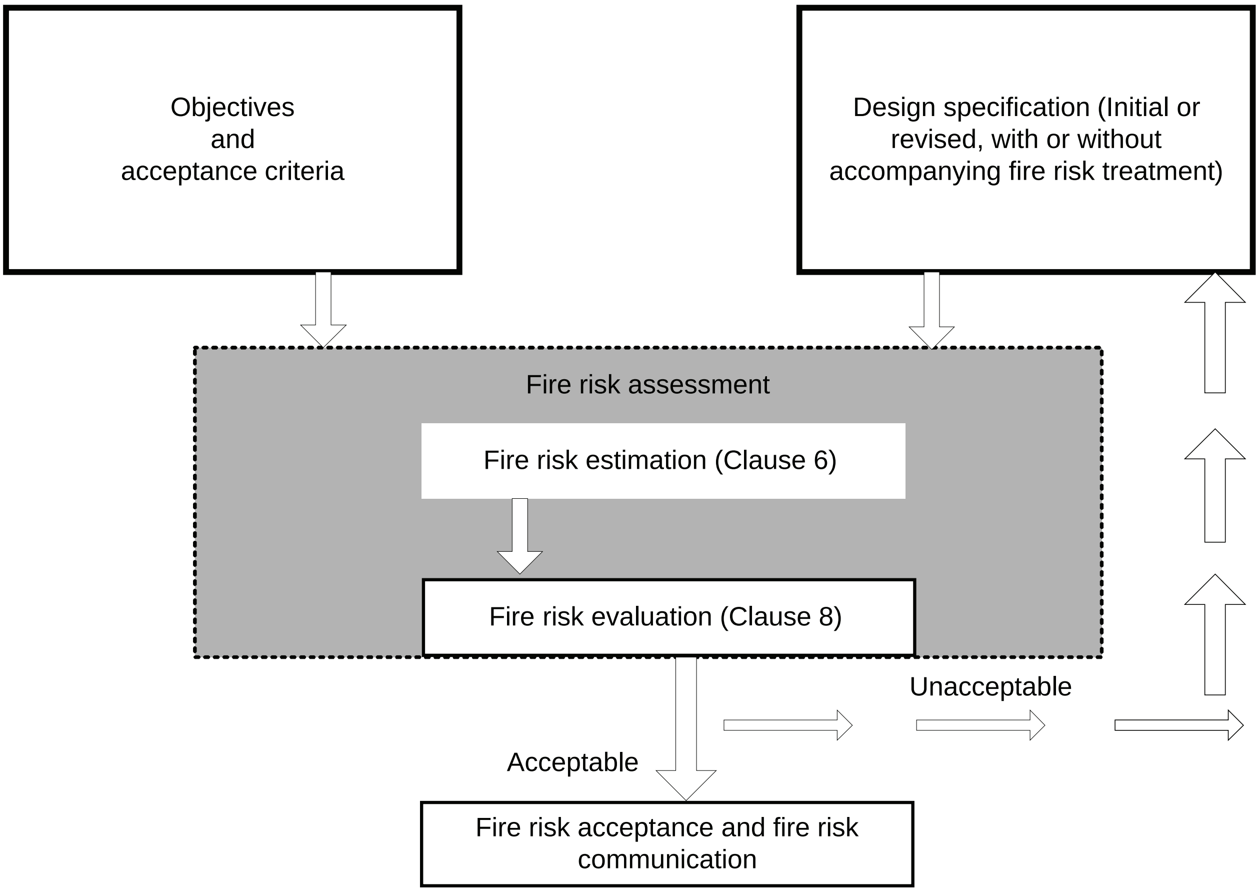

Figure 1 — Fire risk management flow chart

Fire risk assessment begins with objectives and a proposed design specification for the structure or other part of the built environment to be assessed. The risk associated with the design specification is estimated and then evaluated. Risk evaluation consists of comparison of the estimated risk for the design to the acceptance criteria. This comparison and the ensuing steps and actions are described in ISO 23932:2009, 11.2.

6 Steps in fire risk estimation

6.1 Overview of fire risk estimation

Figure 2 illustrates the sequence of steps involved in fire risk estimation as it is conducted when the scenario structure is explicit and when frequencies and consequences are explicitly calculated in quantitative form. Later sections describe the use of risk curves, risk matrices and other techniques for which the flow chart is not fully applicable in detail.

Fire risk estimation begins with the establishment of a context. The context provides a number of quantitative assumptions, which are required with the objectives and the design specifications, to perform the estimation calculations. For example, many quantitative assumptions will be implied by the selection of the property use for the design. If the building is to be used as an office building, this has implications in terms of the types of rooms and areas, the typical sizes of those rooms by type, the number of occupants by type of day, and the mix of characteristics of those occupants.

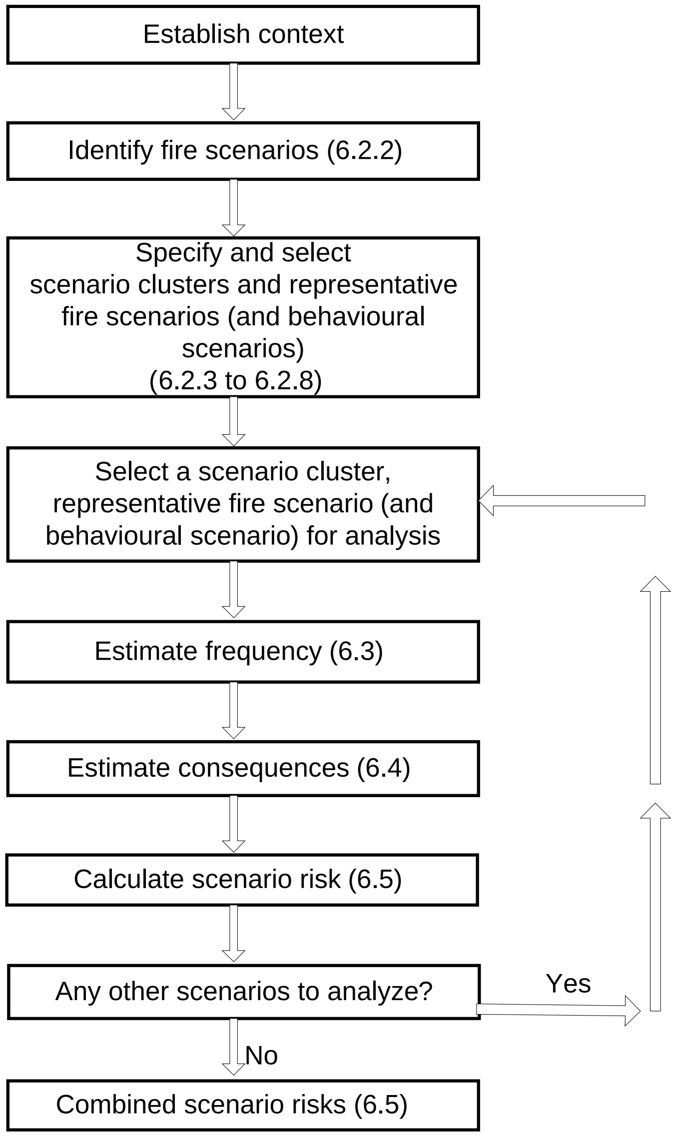

Figure 2 — Fire risk estimation flow chart

The next step is identification of hazards, which are then used as the basis for specification and selection of the scenario clusters and associated representative fire scenarios that will form the basis for the estimation. One scenario cluster and representative scenario pair is then selected for analysis, and the frequency of that scenario cluster and consequence for that scenario are estimated. This procedure is repeated until all the selected scenarios and scenario clusters have been analysed. The combined fire risk for the design is then calculated as the fire risk for all scenarios combined.

An abbreviated fire risk calculation can be used to select a small number of scenarios for a deterministic evaluation (see ISO/TS 16733:2006, 6.2.4). If this is the application, then the final step is not combining the scenario fire risks but selecting the scenarios with the highest scenario fire risks (or perceived fire risks, if for example risk aversion is explicitly considered). That alternative final step is not shown in Figure 2 because it is not a step in fire risk estimation.

6.2 Use of scenarios in fire risk assessment

6.2.1 Overview of specification and selection of scenarios

The number of distinguishable fire scenarios is too large to permit analysis of each one. Therefore, any fire risk assessment must develop a scenario structure of manageable size but must also make the case that the estimate of fire risk based on these scenarios is a reasonable estimate of the total fire risk. The principal techniques to achieve these goals are identification of hazards, combining of scenarios into clusters and exclusion of scenarios with negligible risk.

6.2.2 Identification of fire scenarios

The systematic identification of fire hazards and fire scenarios should be carried out in accordance with ISO/TS 16733:2006, 6.2, steps 1 to 5.

6.2.3 Combining scenarios into scenario clusters

The characterization of scenarios performed in 6.2.2 should now be refined into a concise, parametric description of the universe of possible scenarios. For example, one could identify five types of rooms or areas (e.g. normally occupied rooms, normally unoccupied rooms, means of egress, concealed spaces, exterior locations) or three ranges for the rate of increase in fire severity (e.g. linear growth, corresponding to smouldering, and two ranges for the alpha parameter in a t-squared fire representation, corresponding to flaming and fast flaming). By selecting a type or range from each parameter, the user defines a specific scenario cluster, which combines more fully specified scenarios (e.g. each of the specific points of origin in each of the rooms that fit a particular room type). Each scenario cluster is represented by a single representative fire scenario whose consequence will be used to characterize the average consequence for all scenarios in the cluster.

6.2.4 Caution on exclusion of scenarios believed to have negligible risk

Because there are a very large number of possible fire scenarios, the process of combining scenarios into a collectively comprehensive set of scenario clusters will be simplified if some scenarios can be excluded at the outset based on negligible risk. This step should be justified explicitly and quantitatively and should be taken only when there is strong evidence that the facts support a judgement of negligible risk. It is particularly dangerous to use this step to exclude low-frequency, high-consequence scenarios. Scenarios that have low frequency individually may not be low frequency if considered as a group. Scenarios that have low estimated frequency may have sufficient uncertainty for their frequencies that they cannot be confidently treated as low frequency.

A conservative selection procedure includes more rare-event scenario clusters. Note the distinction here between a conservative selection procedure as contrasted with conservative estimates of frequency and consequences. A conservative selection procedure can improve the accuracy of the risk estimates, while conservative estimates introduce unknown biases and do not improve accuracy.

6.2.5 Demonstrating that the scenario structure is complete

Provide a mapping of the universe of potential scenarios into scenario clusters either selected for analysis or specifically excluded, as specified in 6.2.3 and 6.2.4. This will establish that all scenarios have been considered and that their treatments were explicitly chosen, which means the scenario structure is complete.

If two or more candidate designs are to be compared to each other rather than to externally defined acceptability criteria, then scenario clusters can be excluded even if they involve significant risk, if the two designs can be expected to have similar or identical risk in those scenarios, where “similar” means that the expected difference in risk for the scenarios proposed for exclusion is substantially less than the expected difference in risk for the scenarios proposed for explicit analysis. Set these expectations on the basis of engineering judgement. Because consensus engineering judgement can reflect a shared misperception of the true risk, these kinds of exclusions should be few in number.

In any scenario structure, it is difficult to strike an appropriate balance between high-frequency, low-consequence scenarios and low-frequency, high-consequence scenarios. Yet, both are important.

6.2.6 Fire risk assessment without explicit scenario structures

Some fire risk assessment methods do not use an explicit scenario structure, e.g. analysis using risk curves or risk matrices. Even if an explicit scenario structure is not used, it is necessary to provide evidence that the underlying or implicit scenario structure is appropriate and sufficient. Examine the procedure for implicit assumptions regarding the specification, inclusion or exclusion, and relative likelihood of underlying scenarios.

Then use engineering judgement to identify and document sources of bias in those assumptions, and propose changes to the analysis to compensate for those biases in the interpretation.

6.2.7 Behavioural scenarios

For purposes of analysis, it is normally necessary to specify not only fire scenarios but also behavioural scenarios, in which the number, characteristics and behaviours of occupants related to fire, including egress, are specified. Additional guidance on behavioural variables is provided in ISO/TR 16738 and in ISO/TS 16733:2006, 6.2.6.

6.2.8 Fire risk assessment for selecting design fire scenarios for deterministic analysis

When the selection of design fire scenarios for deterministic analysis is the purpose, the guidance in ISO/TS 16733 addresses all steps in the analysis.

6.3 Estimation of frequency and probability

As shown in Figure 2, a frequency must be estimated for each fire scenario cluster included in the final scenario structure in compliance with 6.2.1 to 6.2.7. Subclause 6.3.1 describes alternative general methods of frequency estimation, and 6.3.2 and 6.3.3 provide specific guidance for estimation of frequencies of ignition and probabilities of system status, respectively. Additional guidance is provided in ISO/TS 16733:2006, 6.3.2.

6.3.1 Methods of estimation of probabilities and frequencies

The probabilities and frequencies discussed here are initiating event frequencies and status probabilities, including reliability measures. Some risk analysis methods, such as state-transition models, require additional probabilities. For detailed, broadly applicable guidance on estimation of needed probabilities, see Reference [6].

Probability and frequency values can be obtained from any or all of three approaches: (1) direct estimation from data; (2) inference from a model that relates the probabilities and frequencies of interest to other probabilities and frequencies, such as relating the frequency of fire ignition to frequencies of equipment component failure, relevant human error, proximity of readily ignited materials, and the like; and (3) engineering judgement.

Note that while frequencies and probabilities are themselves expressions of uncertainty, there is also uncertainty attached to the estimates of these frequencies and probabilities. This uncertainty is part of the uncertainty to be examined in the uncertainty analysis phase.

In estimating probabilities and frequencies, there are certain common errors or biases, and the following steps are designed to reduce or avoid these errors and biases:

— Be aware that individuals often under-estimate low frequencies and probabilities and over-estimate high frequencies and probabilities. Seek to compensate for this common tendency when eliciting judgement estimates. Do not seek to compensate by deliberately over-estimating the high consequences associated with low frequencies or deliberately under-estimating the low consequences associated with high frequencies.

— Do not assume that conditions and events are statistically independent. Look for common-cause events, correlated high-risk occupant characteristics, and other situations where the combined probability will be higher than the product of the component probabilities. For example, practices that make ignition more likely are typically associated with practices that reduce the performance or reliability of active and passive fire protection systems and features, resulting in non-operational detectors and sprinklers, penetrations in walls, doors blocked open, or other degradations of fire safety systems and features.

— Use fire incident data in estimating ignition frequencies. It is not unusual for engineering judgement to over-estimate the relative likelihood of scenarios involving the special hazards and conditions of a property while under-estimating or ignoring common scenarios such as heating-equipment or electrical-system fires.

— When selecting databases, place at least as much emphasis on data representativeness as on data quality. It is not unusual for engineers to rely on databases with the highest quality and thoroughness of fire investigation in each incident. Such databases lead to misleading results in probability and frequency estimation, because they include only a small fraction of the fires that occur and are biased toward fires with high death tolls, thereby missing the smaller fires where most deaths actually occur and many of the largest fires in terms of property damage.

— Redundancy of fire safety systems and features is neither necessary nor sufficient for high overall reliability. Estimates of reliability should not use redundancy as a dependable indicator of high reliability.

— Do not use a frequency estimate of zero for fires that have never occurred or have never been documented in the databases used for analysis. Instead, use a larger scenario cluster for which a meaningful frequency can be calculated or consider the use of extreme value statistical methods to estimate a non-zero frequency for an event that is known not to have yet occurred.

6.3.1.1 Probability and frequency estimation directly from data

Probabilities and frequencies estimated from data are typically estimated as ratios, each of which is calculated from a numerator of an estimated number of relevant events and a denominator giving the extent of exposure or opportunities for events to occur. Denominator measures for frequencies include time units (e.g. events per year), people (e.g. fires per thousand persons located in a property), valued property (e.g. fires divided by total value of all buildings and contents), spatial entities (e.g. fires per thousand buildings of a type), or other entity (e.g. fires per thousand companies operating buildings of this type). Denominator measures for probabilities include numbers of events (e.g. number of times a fire large enough to activate an operational sprinkler occurs in an area protected by a sprinkler).

Databases for numerators or denominators may be sample-based (permitting a statistically sound basis for estimating the size of the total group, or universe, from which the sample was drawn) or census-type (providing an essentially complete tally of the total group of interest).

Estimates based on data implicitly assume that the future will be the same as the past. Estimates based on models or engineering judgement do not require that assumption.

6.3.1.2 Probability and frequency estimation using models

A major advantage of using a model is that, unlike the other two methods of estimation, a model typically provides not only the estimates needed to analyse a design, but also an understanding of the relationship between changes in the design and changes in the resulting frequencies and probabilities, which will be needed if the fire risk assessment of the initial design does not produce an acceptable estimate of associated risk.

Use of a model does not remove the need for experiential or subjective data but does change the type of data needed. Instead of requiring data to support direct estimation of frequencies or probabilities from data, typically through ratio calculations, a model-based estimate requires data to support estimates of the variables used by the model. For these model variables, data may be more or less difficult to obtain. It may be necessary to trade off the advantages of the model, in terms of sophistication and fundamental grounding, against the uncertainty associated with the data inputs required by the model, as compared with the uncertainty associated with data if used directly.

The simplest type of model for probability estimation is Bayesian analysis, which calculates needed probabilities from other probabilities that may be more easily measured. Bayesian analysis is a mathematical technique for reverse-analysing conditional probabilities, so that a body of evidence (e.g. a set of observations) can be combined with known probability distributions giving the probability of the evidence given an assumed probability distribution for a parameter of interest to yield a best estimate of the probability distribution for the parameter most consistent with the evidence.

Bayes' Law, the basis for Bayesian analysis, is a generalization of the statement that the conditional probability of y given x is equal to the joint probability of x and y, divided by the conditional probability of x given y. In Bayesian analysis, non-observational information, such as the best estimates of experts, can be converted to an equivalent number of observations and used in combination with observational data, in order to produce probability and frequency estimates that are not simply sampling frequencies.

For an introduction to Bayesian analysis, see Reference [7].

Monte Carlo sampling is not an alternative source of probability and frequency estimates but is a numerical method for executing the fire risk calculation from a defined set of probability distributions. The latter are used as a basis for selecting a sample of specific scenarios, with implicitly equivalent probability weightings, so that the average consequence for such a sample is a best estimate of the probability-weighted consequence for the entire universe of scenarios. For detailed guidance on Monte Carlo sampling and variance reduction, see References [8] and [9].

6.3.1.3 Probability and frequency estimation using engineering judgement

Engineering judgement can be made more systematic and consistent from one engineer to another through the use of Delphi methods or other explicit procedures for reducing bias and improving the quality of estimates. For a description of the Delphi method, see Reference [10]. For a comparison of the Delphi method to other procedures, see Reference [11].

Engineering judgement can be done for point values or for ranges. The latter will be subject to less disagreement between estimators and will be sufficient for use in a risk matrix or other qualitative fire risk assessment procedure. For guidance on elicitation of engineering judgement-based estimates, see Reference [12].

6.3.2 Initiating event frequencies

Loss experience used as data for calculation of the numerators of frequencies may be specific to the building being studied, all buildings of a type sharing a common location or owner, or any larger aggregation of properties up to national or international databases. Each of these choices has advantages and disadvantages, in terms of demonstrated relevance, level of detail available, data accessibility, and magnitude of the database to support precise estimates.

Frequencies can be estimated through calculation from estimated frequencies of some but not all of the characteristics of a full scenario. For example, the frequency of a fire due to sparks from a piece of equipment beginning in a factory’s production area could be estimated from probabilities that factory fires, when they occur, will be due to sparks combined with frequencies of fires beginning in a factory’s production area. In such calculations, it is essential that assumptions of statistical independence not be made without substantiation. Independence needs to be demonstrated, not just assumed.

The most serious example of violation of independence in initiating events is in common cause event fires, such as an earthquake that simultaneously contributes to multiple fire ignitions and breaks the sprinkler piping. Each fire and the damage to sprinkler piping are rare events, but the frequency of the combination event is not equal to the low value given by treating the unconditional probability of each characteristic, given that fire occurs, as a valid estimate of the conditional probability that a fire will have that characteristic, given that it has the other characteristics. Such a calculation will inappropriately compound the unlikelihood of the multi-characteristic event, because the earthquake is a common cause. If an earthquake occurs, which is itself unlikely, then all the other characteristics become likely.

6.3.3 Status probabilities and reliability

Every fire safety feature or system will have alternative possible statuses when ignition occurs, e.g. detector connected or not connected to power source, sprinkler valve open or closed, and door open or closed. Any status condition that can affect the frequency or consequence of a scenario must be addressed, which requires estimation of a probability for that status.

Other conditions also have status probabilities. The number, locations and conditions of occupants all have associated status probabilities important to the handling of behavioural scenarios. The amounts, locations and burning properties of frequently moved contents all have associated status probabilities important to the estimation of fire growth and the availability of paths for occupant movement.

Status probabilities refer to conditions at time of ignition. Reliability normally refers to probabilities of events after ignition, such as whether the detector or sprinkler did or did not activate and whether the structural element did or did not continue to bear its load without unacceptable deformation. Reliability probabilities are probabilities of success or failure, where “failure” refers to not performing a required function, in whole or in part and need not refer solely to a failure to activate. For the load-bearing elements of structures, “failure” is most often used to describe collapse. For active fire protection systems, “failure” can be used only when activation does not occur or can also be used when the result of activation is not acceptable or is not in accordance with design specifications.

These are examples of probabilities that are not ignition frequencies but are also required for fire risk estimation. Behavioural scenarios will also require frequencies and probabilities.

Reliability applies to the performance of any building or product design feature whose performance can influence the course of fire development, thereby contributing to the specification of the fire scenario that occurs and the risk consequences associated with that scenario. It is also possible that the design feature performance is better described by a range of partial successes or partial failures.

6.4 Estimation of consequence

In the fire risk estimation procedure shown in Figure 2, consequence must be estimated for each representative fire scenario included in the final scenario structure in compliance with 6.2.1 to 6.2.7. Subclauses 6.4.1 to 6.4.3 describe alternative methods of consequence estimation, using loss experience, models, or engineering judgement, respectively. Additional guidance is provided in ISO/TS 16733:2006, 6.3.3.

6.4.1 General consideration in consequence estimation

Consequence estimation normally involves the development of an integrated chain of calculation procedures. Based on fire scenario characteristics, one calculation estimates the rate of production of different fire effects, a second calculation estimates the rate of change in fire-based conditions throughout the affected spaces, and a third calculation estimates the impact of fire-based conditions on the fire safety objectives in any location. Standards from ISO/TC 92/SC 1 provide procedures for the first type of calculation, standards from ISO/TC 92/SC 4/WG 9 provide procedures for the second type of calculation, and standards from ISO/TC 92/SC 2 and SC 3 provide procedures for the third type of calculation.

In estimating consequences, there are certain common errors or biases to be wary of, including:

— When selecting a representative fire scenario, be careful not to assume that the fire scenarios in the scenario cluster are dominated by the lowest or highest severity scenarios. It is not unusual for estimates to be simplified, so that a scenario cluster with a wide variety of scenarios is regarded stereotypically in terms of its most or least severe scenarios. As an example of erring in the direction of too much severity, the average consequence of an arson fire is statistically only slightly greater than the average consequence of an unintentional fire. It is a mistake to assume that a typical arson fire involves multiple points of origin, the use of accelerants, or actions to deliberately impair the operation of fire safety systems or features. As an example of erring in the direction of too little severity, some stovetop or chimney fires spread to and destroy entire buildings even though most remain very small and are quickly and easily extinguished with only minor damage.

— It is difficult to estimate consequences through engineering judgement for scenarios involving partial effectiveness of any fire safety system, feature, or program. Full effectiveness and complete ineffectiveness, which is typically the same as absence of the system, feature, or programme, are simpler, easier to visualize, easier to model, and so easier to estimate through judgement. Partial effectiveness often includes a wide variety of different types and degrees of degradation of performance, and the user may not have enough experience to select a specific form of partial effectiveness for estimation purposes.

6.4.2 Consequence estimation from loss experience

When loss experience is used, it can be loss experience specific to the structure (or other part of the built environment) being studied (if it already exists and its design is intended to modify it, as in a building renovation, because clearly, anything new has no loss history), all structures of a common type sharing a common location or owner, or any larger aggregation of structures of a common type, up to national or international databases. Each of these choices has advantages and disadvantages, in terms of demonstrated relevance, level of detail available, data accessibility, and magnitude of database to support precise estimates.

Estimates based on loss experience implicitly assume that the future will be the same as the past. Estimates based on models or engineering judgement do not require that assumption.

6.4.3 Consequence estimation from models

See the first two paragraphs of 6.3.1.2 for general guidance on the use of models in risk-related estimation.

Do not assume that a more detailed model leads to more accurate final risk estimates. A more detailed model typically requires much more input data, and some types of data, such as field observation data, are subject to greater uncertainty when estimated in greater detail, because a limited number of real cases are spread more thinly over a larger set of needed estimates. Also, the detail available from a typical deterministic fire model is far greater than the detail available to support the estimation of associated frequencies and probabilities. These two sources of greater data uncertainty can lead to the same uncertainty in the combined estimates as would be achieved with a simpler model.

6.4.4 Consequence estimation from engineering judgement

See 6.3.1.3 for general guidance on more systematic methods to elicit and use engineering judgements for risk-related estimation.

6.5 Calculation of scenario fire risk and combined fire risk

6.5.1 Mathematical formulations of fire risk

Based on the form of the objectives and acceptance criteria, select an appropriate definition of fire risk. Any such definition will fit the general mathematical formulation of a combination of the frequencies and consequences of all scenarios associated with a design:

Risk $= \sum f$ (frequency, consequence of a given scenario), for all scenarios

NOTE Adapted from ISO/TR 13387.

The two most frequently used specific mathematical formulations are:

a) Risk $= \sum$ (frequency x consequence of a given scenario), for all scenarios

NOTE Adapted from ISO/TR 13387.

b) Risk $=$ Combined frequency of all scenarios where the consequences exceed the specified safety threshold

NOTE Adapted from ISO/TR 13387.

The first of the two formulations above defines scenario fire risk as the expected value, i.e. product of frequency and consequence, and defines the combined fire risk estimate as the sum of the scenario fire risks.

The second of the two formulations above defines scenario fire risk as the frequency of scenarios whose consequences are unacceptable, therefore as the frequency of the scenario times 1 if the consequences are unacceptable and 0 if the consequences are acceptable.

6.5.2 Event trees, fault trees, and alternative definitions of fire risk

Use event trees and fault trees as efficient formats for calculating fire risk according to any of the risk definitions shown in 6.5.1.

A fire scenario in an event tree is given by a time-sequence path from the initiating condition through a succession of intervening events to an end-event. Each fire scenario corresponds to a different branch of the event tree, and the branches collectively comprise or represent all fire scenarios. A fire scenario in a fault tree is given by that critical resulting event and one of the alternative, fully specified logical sequences by which that critical resulting event can occur. For an introduction to decision tree analysis, see Reference [13].

Event trees provide a basis for estimating scenario cluster frequencies using a tree structure with both logical and temporal sequencing. Additional guidance is contained in ISO/TS 16733:2006, 6.3.1. Fault trees normally use only logical sequencing, while event trees normally emphasize temporal sequencing. If consequence estimation is done using fire models that track developments over time, then there is a parallel construction to the event tree format and the consequence estimation format. This favours the use of event trees. When the second definition of risk from 6.5.1 is used (combined frequency of consequences exceeding a specified threshold) then consequence estimation can be less elaborate and either event trees or fault trees can be used to develop needed scenario cluster frequencies.

6.5.3 Risk defined by the design load or limit state

When a safety threshold is used, an associated measure useful for design purposes is the design load, in which one of the scales defining the fire scenarios is set at the value just sufficient to exceed the specified safety threshold. This is sometimes referred to as the limit state just sufficient to cause failure. Such a measure will focus attention on consequence and not so much on frequency. An acceptable design may result in unacceptably large consequences under a scenario more severe than the design load. In structural risk analysis, a “design load” is a mechanical load sufficiently large as to provide an appropriate basis of testing whether a design will fail. The severity of the design load is usually defined in terms of a single continuous scale of fire size or intensity.

A limit state equates a condition of the built environment with just barely acceptable consequence, and so the term is usually used in the context of a time-sequence state description of the fire scenario. Such a description defines the scenario in terms of states, and that provides a basis for identifying states that are and are not limit states. In the context of structural engineering, a “limit state” defines a state beyond which the structure no longer satisfies the design performance requirements.

6.5.4 Other aspects of risk calculation

If estimation by engineering judgement is used for both frequency and consequence, it is not necessary to estimate them separately. Instead, a risk measure implicitly combining the two can be estimated directly. An explicit procedure, with or without calculation, may be used to provide greater consistency of subjective estimation between users, either for estimation of frequency or consequence values or for direct estimation of a risk measure.

Measures of risk can be expressed as dimensionless, nonparametric statistics, such as ranking values. These are qualitative risk measures, as contrasted with quantitative risk measures for which the rules of ratio-scale numbers apply. Semi-quantitative risk measures use dimensionless, nonparametric statistics derived from categories that are themselves defined by numerical ranges of ratio-scale variables.

Both frequency and consequence can be characterized using categories, either categories based on ranges of underlying numerical values or categories directly defined. If both frequency and consequence are so characterized, the summary characterization of fire risk outcomes can be constructed as a risk matrix, using the category characterizations of frequency and consequence to define rows and columns. Each matrix cell represents a fire risk measure that need not be explicitly calculated. In such a case, rules must be specified to determine whether any matrix cell falls above or below a threshold of acceptable risk.

For design purposes, it can be useful to construct a risk matrix in a different manner. If scenarios can be characterized by a single scale of external hazard severity (e.g. earthquake intensity or energy in a lightning strike), then categories can be derived from that scale to provide the rows of a risk matrix for which the columns are categories corresponding to ranges of frequency of occurrence for a defined range of hazard severity. Matrix cell entries can be specified as consequence, which will be a function of hazard severity and the performance of the design. Acceptable risk can be defined as a threshold on consequence, cell by cell, without the need to construct a formal risk estimate. Note that this approach implicitly assumes that hazard frequency is independent of design. For fire hazards, this assumption requires close scrutiny and evaluation.

The results of fire risk estimation can also be presented in the form of a risk curve. Such a curve, plotted with frequency versus consequence axes, smoothly connects points representing individual estimates of the frequency and consequence associated with specifically analysed fire scenarios. Once a fire risk curve has been established for a specified design and with specified assumptions, changes in the design can be translated into a new risk curve through the risk estimation process. The relative proximity of alternative risk curves to the origin of the graph (i.e. the zero-frequency, zero-consequence position) is a measure of the relative risk of alternative designs.

7 Uncertainty, sensitivity, precision, and bias

Uncertainty refers to any potential differences between the computed risk measure and the underlying true risk that the computed measure is intended to represent. Precision refers to the statistical magnitude of such deviations, based implicitly on the standard deviation of a probability distribution of error around the computed risk measure. Bias refers to any lack of symmetry in the distribution of deviations.

Sensitivity analyses do not quantify uncertainty but are an initial step toward such quantification. Sensitivity analyses examine the propagation of uncertainty, by measuring the magnitude of change in the computed risk measure produced by a change in the value of one of the variables or parameters involved in the computation. If a sensitivity analysis can be combined with information on the likely magnitudes of errors in the component values, then a full calculation of random uncertainty is possible. Sensitivity analysis is useful in setting priorities for uncertainty analysis by focusing attention on variables and parameters having greatest impact on the results and so on variations most likely to change the conclusion of the analysis.

Uncertainty is not limited to statistical variation but also occurs as a result of gaps or errors in the knowledge underlying the procedure for computing the risk measure. If a particular phenomenon is missing from the calculation, such as pre-movement time from an evacuation time calculation or turbulence from a calculation of fire development and effects, then this will be a source of uncertainty, typically biased uncertainty, in the risk measure calculation.

Additional guidance on techniques of uncertainty analysis relevant to fire safety engineering models is contained in ISO 16730.

7.1 Elements of uncertainty analysis

Fire risk assessment can be affected by deficiencies of relevant data or of scientific understanding of some relevant fire phenomena. In many instances, uncertainty analysis can be used to express the magnitude and address the importance of such deficiencies.

In fire risk assessment, uncertainty analysis involves quantifiable uncertainty for the frequency and consequence estimates. Uncertainty can also be quantified for the risk evaluation criteria. More difficult to quantify are errors associated with missing phenomena or misapplication of data or calculation methods.

Quantification of uncertainty in frequency and consequence estimates begins with quantification of uncertainty in source data.

Quantification of uncertainty in laboratory measurements can normally rely upon known calibration data and precision values for the laboratory equipment. A better quantification is possible if multiple experiments are conducted for every measurement of interest. Then, a probability distribution of the experimental results can be used to represent that portion of the uncertainty.

Quantification of uncertainty in field data, such as statistics on reported fire experience, can be achieved by using the variation in values from year to year or from place to place. Each fire is not a data point for estimation of the number of fires per year, but each year's experience in each community can be a data point. If the data is converted to a probability or frequency, such as an ignition frequency or a reliability probability, then one uses the variability in field data to fit parameters on a probability distribution for the probability or frequency parameter.

Quantification of uncertainty in subjective estimates or subjectively derived parameters is possible if the estimates have been systematically solicited in a process with multiple participants. Then, the variability in individual estimates provides a basis for quantification of uncertainty.

None of these methods is useful to quantify the role of systematic bias in uncertainty. For example, if the fire experience data of one country is used to estimate ignition frequencies in another country, there are likely to be systematic differences. Subjective estimates of these differences can be elicited, and uncertainty quantified for them based on variation in those subjective estimates.

Once these uncertainty distributions have been developed for all identified parameters in the fire risk calculation, it is necessary to calculate the effect of these different forms of uncertainty on the final risk estimates. Because the initial risk calculation can involve calculations of frequency and consequence for a large number of fire scenarios, it is possible that many of the uncertainty variations of one scenario will correspond to other scenarios that are already due to be calculated. This fact can reduce the calculation burden. Alternatively, one can use Monte Carlo or other sampling methods to calculate the estimated uncertainty-based frequencies and probability distributions for the fire risk estimates.

In conducting the uncertainty analysis, it is important to examine the basic risk estimation procedure for any parameters, or assumptions that can be expressed as parameters, that are not normally regarded as variables. Any such parameters involve uncertainty. Even the speed of light and the gravitational force constant have uncertainty in their measurements, although the uncertainties are now so small as to be safely ignored. For a fire modelling example, if fire growth is represented by a t-squared curve, there is uncertainty involved not only in the parameter (alpha) that is the coefficient of time-squared fire growth but also in the value (two) of the exponent in the representation. It is not practical to conduct uncertainty analysis on every parameter, but it is important to consider every one and to systematically identify those uncertainties that have the potential to be sufficiently large to change not only the estimate of risk but also the decisions to be based on those estimates.

7.2 Validation and peer review

The purpose of uncertainty analysis is to provide validation of the fire risk estimation. As noted, many of the data estimates can involve the use of subjective engineering judgement, in the absence of observational bases. For this reason, peer review can be useful when quantitative methods of validation are not possible. The level of peer review deemed appropriate can range from peer review by another engineer from the company leading the project to peer review by an engineer from another company. The value of a review by someone from another company is greater if the estimated performance of the design is highly sensitive to precise probability estimates or to elements of design with which there is little or no field experience available. This can be the case if the design differs from a traditional prescriptive design with respect to multiple design elements, if the building design is complicated and innovative, if improved performance of one design element is used to justify reduced performance of multiple design elements, or if the maximum scenario consequence is more severe than with a traditional prescriptive design.

Separately from these peer reviews, regulatory authorities in some jurisdictions require a third party independent review for approval, as described in more detail in 12.3 of ISO 23932:2009.

8 Fire risk evaluation

After uncertainty analysis of estimated risk, the resulting estimates must be evaluated through comparison to defined acceptance criteria, as indicated in Figure 2. Risk evaluation compares the estimated risk against predetermined criteria that may be explicit, such as standards or target risk levels, or implicit, such as comparison to the estimated risk for an alternative design or a reference design compliant with existing prescriptive requirements. Additional guidance is contained in ISO/TS 16733:2006, 6.3.4, and 6.3.5.

8.1 Individual and societal risk

Acceptance criteria may be defined in terms of individual or societal risk. An example of a measure of individual risk is the annual frequency of a specified person suffering a specific type of harm such as loss of life as the result of a particular type of incident. An example of a corresponding measure of societal risk is the annual frequency that a specified minimum number of persons will suffer that type of harm as the result of that type of incident. Individual and societal risks are rarely the same. Individual risk focuses on who is harmed and also has no special concern with the total number of fatalities. Society is typically more averse to multiple deaths than a simple sum of the individual risks of the multiple victims would imply.

If the fire risk measure is frequency of an unwanted consequence, such as death, then individual risk would be an estimate, typically expressed as events per unit time, of the frequency of that unwanted consequence for a specific individual. The risk measure may be expressed as conditional on exposure to the hazard, such as being at a hazardous location. Individual risk is independent of the number of individuals affected. The individual referenced here can be a person but can also be a company, a site or building, or other single entity.

Combining consequences to all affected parties will also affect the overall frequency of an incident. It will equal the sum of the individual risks of all affected individuals but can be expressed as a rate relative to the number of affected or exposed individuals, in which case it will be in a form directly comparable to the component individual risk measures.

In societal risk, some consequences experienced by one individual may cancel consequences experienced by another individual. For example, business interruption losses experienced by one company can be exactly offset by increased business income for a competitor not affected by fire.

8.2 Risk acceptance criteria

Risk acceptance criteria are an expression of society's or a decision-maker's values, and as such, they are not yet ready and may never be appropriate for international normalization. However, it is possible to provide a format and structure for selecting criteria.

Risk aversion is one of several risk perception phenomena that can be considered during the risk evaluation phase of a fire risk assessment.

8.2.1 Baseline from defined recent experience

The normal first step in setting risk acceptance criteria from defined recent experience is the use of documented loss experience for a specified type of loss and a specified population to be used as a point of reference. For example, a point of reference for the estimated risk of a proposed new building is the risk experience of similar buildings constructed and used in the same ways during the past five to ten years.

8.2.2 Establishing criteria based on baseline

The normal second step in setting risk acceptance criteria is to set the criterion as some fraction of the baseline. If the baseline is set in terms of existing risks, for example, then the criterion for new risks could be set equal to the baseline, viewed as acceptable to society because society has allowed it to occur, or lower than the baseline, taking the view that newer techniques of risk reduction are more affordable if implemented in a new design than in an existing design.

If the criterion is set in terms of acceptable risk for each specific scenario, then the risk assessment must address the implications for combined risk from all scenarios. For example, a criterion set on an order of magnitude lower than the baseline for each scenario will mean a combined risk higher than the baseline if there are more than ten scenarios.

It is common practice to set a lower criterion for a new risk than for an existing risk. It is common practice to set a lower criterion for an involuntary risk than for a voluntary risk, but there can be disagreement as to the voluntary or involuntary nature of a risk. It is not unusual to set different criteria for risk due to natural causes and for other risks. It is not unusual to set a higher criterion for a risk whose effects are delayed. Other characteristics of a risk can also be the basis for differentiation of risk acceptance criteria.

8.2.3 Acceptable frequency and revised criteria for multiple-death events

If an annual acceptable risk level has been defined, then the implied acceptable annual frequency for a fire involving more than one death would be equal to the acceptable annual risk divided by the number of deaths involved in the event. However, society is normally more risk averse than this proportional formula would imply. An acceptable annual frequency reflecting risk aversion will be lower than the implied acceptable annual frequency.

This risk aversion can be reflected by setting the acceptable annual frequency for such an event as the acceptable annual risk divided by a power function (such as the square) or exponential function of the number of deaths involved in the event. More generally, it is possible to define an acceptance curve on a graph of annual frequency versus consequence.

8.2.4 Acceptance based on ALARP

A further refinement of risk acceptance criteria is the establishment of three risk-acceptance regions on a display of frequency versus consequence:

— acceptable risk (the left-most region);

— risk that is As Low As Reasonably Practicable (ALARP) (the middle region);

— unacceptable risk (the right-most region).

Through the use of logarithmic axes, the lines separating the regions can be defined as implied exponential curves.

When estimated risk falls in the ALARP region, it is not clear whether the risk is acceptable or not. This can lead to more discussion or a more detailed analysis of technical feasibility and cost. If the proposal is not technically feasible, then the proposal could be rejected. Also, a proposal to further reduce risk would be rejected if the costs were deemed to be disproportional, and a proposal to further reduce cost would be rejected if the increase in risk were deemed to be disproportional.

8.3 Safety factors and safety margins

Safety factors and safety margins are multiplicative and additive terms, respectively, which are applied to the measure of risk to permit interpretation of the risk information to compensate for the uncertainty in that measure.

If a safety factor is used, then the ratio of the acceptable risk to the estimated risk for the design should equal or exceed the safety factor. If a safety margin is used, then the value of the acceptable risk minus the estimated risk for the design should equal or exceed the safety margin.

Because of uncertainty considerations, there is a probability distribution for the risk of the design around the point estimate of the design’s risk. The safety factor or safety margin is equivalent to selecting a point on this probability distribution of uncertainty. For example, if the uncertainty distribution is normally distributed around the point estimate of the estimated risk and the safety margin is equivalent to 1,64 times the standard deviation of that uncertainty distribution, then there is a 95 % probability that a design satisfying that safety margin relative to the acceptable risk will in fact have a risk that is lower than the acceptable risk.

The uncertainty distribution around the estimated design risk should ideally be calculated from an analysis of the uncertainties associated with each variable involved in the risk calculation. Such calculations can be easier to interpret using safety factors rather than safety margins. More often, the uncertainty analysis is more qualitative and does not provide a sufficient basis for choosing between safety factors and safety margins.

For reasons of practicality, the choice between safety factor and safety margin can be based instead on the type of final risk measure.

If risk is estimated as a frequency (of unacceptable events), then a risk estimate will be described in terms of an order of magnitude (such as events per million exposure years). With very small numbers, a safety margin is inconvenient to use and can lead to a conclusion that the only acceptable risk is less than zero. A safety factor is more realistic and is equivalent to a safety margin applied to the logarithm of the risk estimate.

If risk is estimated as an expected value (such as deaths per year or monetary loss per year), then the risk values will tend to fall in a range where a safety margin is appropriate.

Because safety factors and safety margins are intended to be used to assess risk acceptability in the presence of uncertainty, the appropriateness and adequacy of the safety factors and safety margins will depend on the adequacy of the uncertainty analysis. A safety factor or safety margin that is well designed to address natural variability (such as variations in travel speed by different occupants escaping a building) cannot be assumed to be adequate to address missing variables (such as pre-movement time).

A partial safety factor is an uncertainty-based adjustment in a specification or characteristic of a fire scenario. The “safety concept approach” is a variation of the use of fire risk assessment to identify a short list of fire scenarios for deterministic analysis. First, fire risk assessment is used to identify a list of fire scenario clusters and to identify a representative fire scenario from each. Then, partial safety factors are applied to the defining characteristics of each representative fire scenario so that assessment based on the modified fire scenarios will incorporate the relevant uncertainties. It is then unnecessary to conduct additional uncertainty analysis on the final calculated scenario consequences or scenario risks.

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ICS 13.220.01

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