Vladimír Mózer, PhD.

University of Zilina, Faculty od Security Engineering, Department of Fire Engineering, Ul. 1. mája 32, 010 26 Žilina, Slovakia, vladimir.mozer@fbi.uniza.sk

FIRE SAFETY ENGINEERING: Principles and application

Abstract: This education material covers the topic of fire safety engineering from the perspective of its application and principles. It covers the role of fire safety engineering in the fire safety design framework and should provide student with introductory knowledge of its underlying principles, intended use and potential caveats. The material presents the concept of fire safety objectives, functional requirements and performance criteria, fire hazard identification and fire risk assessment, fire and behavioural design scenario construction. Since fire safety engineering is an advanced fire safety design approach, the prerequisite is the knowledge of general fire safety design and supporting engineering disciplines such as thermodynamics, fluid dynamics, human behaviour, etc.

Keywords: fire safety engineering, design scenario, fire hazard, fire risk assessment

1 INTRODUCTION

Fire safety engineering is a relatively young engineering discipline when compared to the more traditional disciplines such as mechanical and structural engineering. Despite its relatively young age it requires a high level of interdisciplinary knowledge, since it combines various engineering and scientific disciplines, for example:

- thermodynamics;
- structural mechanics;
- fluid mechanics;
- mechanical engineering;
- chemistry…

In addition to the above "hard" disciplines a significant portion of fire safety engineering relates to "soft" disciplines, such as:

- human and crowd dynamics;
- human behaviour;
- toxicology;
- risk perception…

Due to the interactions this also means that fire safety engineering requires a team of experts in the above disciplines, particularly for more complex project, in which an in depth analysis is required.

The fire safety design approaches may be divided in the following categories:

- **prescriptive approach** – involves the application of a series of *prescribed* measures, relating to fire resistance, widths and lengths of escape routes, compartment areas, etc. If the design complies with all the prescribed requirements it is considered safe and satisfactory from the fire safety perspective.
- **flexible-prescriptive approach** – is similar to the prescriptive approach, but gives the designer the option to take into account more building design specifics, e.g. ceiling heights, ventilation openings etc., and/or exchange one fire safety measure for another, e.g. reduce fire resistance if sprinkler protection is provided, or extend travel distances if a voice alarm system is provided.
- **performance-based approach** – also known as fire safety engineering, which takes into account very detailed building and occupant specifics, however, also requires the most effort and knowledge. The design involves the application of the underlying principles which are generalised to a various extent in prescriptive approaches.

There is no hard boundary between the fully prescriptive and flexible-prescriptive approaches and the degree of flexibility depends on the national approach. It could be said that the more prescriptive the fire safety design approach is the easier is to apply and to check, however, may be more difficult and less appropriate for more complex projects, requiring specific attention. So while prescriptive approach is a good solution for low- to medium-rise office, residential and retail buildings with simple layout it is not appropriate for large assembly places, designs involving atria, large-volume industrial buildings, etc. In the latter cases fire safety engineering is more appropriate.

Fire safety engineering (FSE) is therefore considered an advanced system for designing and assessing fire safety of buildings, technologies and systems. FSE involves application of advanced calculation methods, professional knowledge and engineering judgement.

ISO 23932-1:2018 Fire safety engineering – General principles – Part 1: General defines FSE as application of engineering methods based on scientific principles to the development or assessment of designs in the built environment through the analysis of specific fire scenarios or through the quantification of risk for a group of fire scenarios [1].

1.1 Fire safety engineering in the context of risk

The role of any fire safety design approach is to reduce fire risk to a tolerable level, i.e. to ascertain that the likelihood of adverse fire consequences is sufficiently low. From this perspective fire safety design and more pronounced fire safety engineering is a form of fire risk analysis. Two forms of risk expression are present:

- **Implicit risk expression** – the actual risk is "hidden" and expressed through either:
  - *a set of prescriptive rules* in prescriptive design, which when satisfied the risk is considered tolerable, or;
  - *the worst-reasonable case(s)* in **deterministic approach** in performance-based (FSE) design, which intends to challenge the design to such an extent (severity) that it is very unlikely that it will be exceeded.

  Still, implicit risk expression usually considers only a single or limited number rather severe design scenarios, hence great care should be taken when selecting them. This is due to the fact that a fire scenario that may be very challenging for evacuation may not pose any significant challenge to structural fire safety.
- **Explicit risk expression** – the actual risk is expressed through a numerical value or a combination of qualitative or semiquantitative descriptors of frequency and consequence. Explicit risk expression is used in **probabilistic approach** in performance-based (FSE) design, often called fire risk assessment.

Hence, we may consider FSE always a form of *fire risk analysis* with the goal of reaching tolerable risk levels.

1.2 Goals and objectives of FSE

The primary goal and objective of FSE is to provide an adequate level of fire safety in cases, where the use of prescriptive approaches is not appropriate due to the specifics or complexity of the project.

FSE involves not only methods and tools selection but also the selection of fire safety objectives. Hence there is a risk of inappropriate objective definition, which may lead to the implementation of inadequate or insufficient fire protection measures. With this risk a greater level of responsibility lies with the fire safety engineer who is not only responsible for the design work itself but also for sourcing, communicating and using all the necessary information throughout the process.

To set the goals and objectives of performance-based design properly the fire safety engineer must communicate with a wide range of affected parties (stakeholders). And since the goals and objectives are not universal, an agreement must be reached as to what is the tolerable level of fire risk.

The designer should also be aware, that FSE is not an approach intended to replace prescriptive design standards and guidance, where these are clearly applicable. It may be estimated that the ratio of prescriptive to performance-based designs is around 85-15 per cent of total building designs. This is also driven by higher efforts and therefore price of performance-based fire safety engineering.

1.3 FSE application around the world

The application of FSE is on the rise. The main drivers are modern architectural trends, multi-use occupancies, large open spaces and volumes inside the buildings, high-rise buildings etc. All of these create specific fire safety challenges and which may be difficult or even inappropriate to address through traditional prescriptive approach.

Therefore a number of countries around the world have adopted or created their own FSE design standards or guidance, acknowledging the fact that some boundaries and regulation must be set. These are a number of examples of FSE standards or standards incorporating the performance-based design approach to a certain extend (e.g. mandatory fire scenario specification):

- **ISO 23932-**1:2018 Fire safety engineering – General principles – Part 1: General – an international standard from the FSE standard suite comprising various FSE guidance documents.
- **BS 7974**:2019 Application of fire safety engineering principles to the design of buildings. Code of practice – a British FSE standard which is a cover document for a suite of Published Documents (PDs) covering all aspects of FSE design.
- **NFPA 101**:2018 Life Safety Code® – an American fire safety standard which covers the application of the performance-based approach through a series of mandatory fire scenarios to which is the fire safety engineer obliged to test their design.

2 ISO 23932 FIRE SAFETY ENGINEERING APPLICATION

This section will introduce the application of FSE principles as described in ISO 23932. There are also other approaches too, some of which are mentioned above, however, since ISO 23932 is an international standard it does not contain any country specific elements and is therefore most universally applicable.

Fire safety designs often rely on prescriptive specifications set in national, regional or local regulations. It is possible that various engineering approaches also be allowed by these regulations. In addition to prescriptive design, regulations can also allow the use of performance-based design, i.e. the reliance on engineering methods to determine whether a given design meets stated performance objectives. Fire safety can be evaluated through engineering approaches based on the quantification of the behaviour of fire and people, and based on the knowledge of the consequences of such behaviour on life, property, operations, environment and heritage.

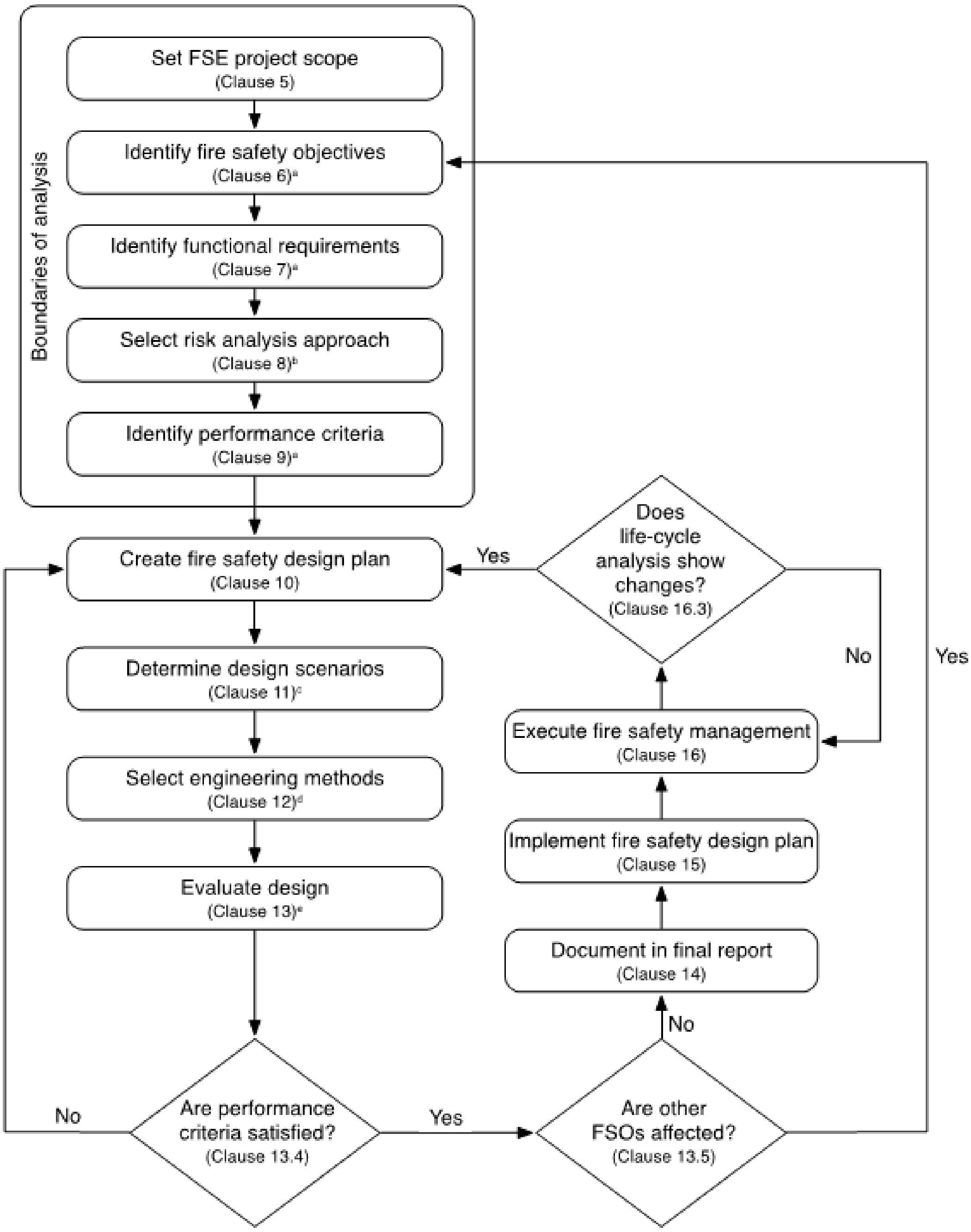
ISO 23932:2018 provides general principles and requirements for FSE, and is intended to be used by

professionals involved in:

- performance-based fire safety design (of both new and existing built environments),
- implementation for fire safety design plans, and
- fire safety management.

ISO 23932:2018 is not intended as a detailed technical design guide, but does provide the key elements necessary for addressing the different steps and their linkages in the fire safety design process. The document also provides key elements linked to the implementation of fire safety design plans and fire safety management. It is intended not only to be used on its own, but also in conjunction with a consistent set of FSE documents covering methods in performance-based fire safety design, implementation and management [1].

The workflow of FSE application during the design, implementation and management phases is shown in Figure 1.



Clause numbers refer to the clauses in ISO 23932:2018.

Figure 1 FSE process – Design, implementation and management [1]

2.1 Boundaries of the analysis – Goal of the project

As it is apparent from Figure 1 the initial set of steps is to address a number of questions, which set frame the fire safety engineering analysis and define its limits and performance limits against which the design will be evaluated. These questions include, but are not limited to:

1. What is the objective of the (construction) project? – new building, alteration, extension, change of technology…;

2. Is / why is engineering approach required? – prescriptive approach not sufficient, applicable, etc…;
3. What is the scope and extent of engineering approach? – deviation justification, level of safety proof, entire / part of building,…;
4. Who are affected / involved parties? investor, user, public, AHJ, insurer,…;
5. Is there enough information available for engineering approach? – building characteristic, use, occupants, internal and external factors…;

2.2 Fire safety engineering goal definition

The areas in which fire safety engineering goals are set are as follows:

- life safety;
- property protection;
- business and operations continuity;
- environment protection;
- heritage protection.

Each of the above areas, have their specific requirements and ways to fulfil them. When defining FSE performance-based design goal a hierarchy is usually applied in which first the high-level goals are established (e.g. relating to life safety) and these are subsequently expanded at more detailed levels. Fire safety engineering goals are defined in the following order:

1. **Fire safety objectives** – top level goals indicating what shall be achieved in the given area at large.
2. **Functional requirements** – functions and features that shall be provided by the building design in order to provide functionality meeting the defined objectives.
3. **Performance (acceptance) criteria** – are limit values against which is are the correct/intended function of building or its part evaluated.

To illustrate the above formal description a life-safety oriented set of FSE goals may be presented:

- **Fire safety objective –** The fire safety design shall be such that fire related injuries to occupants (away from the immediate areas of fire origin) are minimized.
- **Functional requirement –** Occupants are not exposed to untenable conditions due to elevated temperatures, radiation, toxic species, irritant species or reduced visibility while moving along the paths of egress.
- **Performance criteria –** Analysis method is the deterministic analysis. PC corresponding to conservative estimates are chosen for functional requirement, i.e. levels of exposure to elevated temperatures (< 353 K), radiation (< 2,5 kW/m^2), toxic species (CO < 2 000 ppm, CO2 < 5 %, O_2 > 15 %), irritant species FEC < 0,3 and reduced visibility (< 10 m).

2.3 Analysis approach selection

As a step between the identification of functional requirements and definition of performance criteria the fire safety engineer must select and appropriate analysis approach. This will have a direct impact on how the performance criteria will be defined (quantitative vs. qualitative, comparative vs. absolute). ISO 23932:2018 defines a number of analysis approaches which are identified in Figure 2.

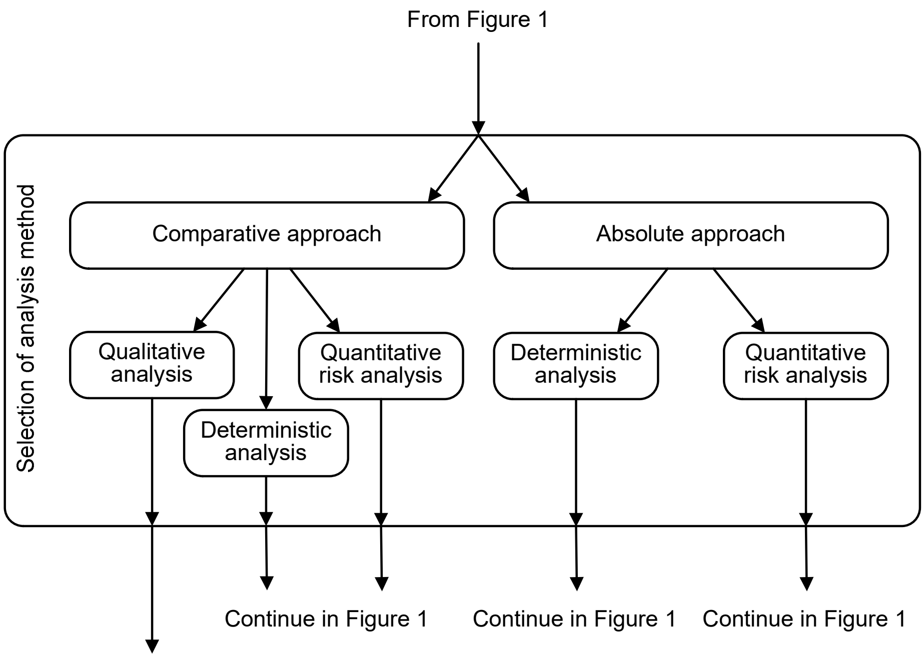


Figure 2 Different types of analyses in the FSE process [1]

2.3.1 Approach selection

The main distinction lies between the comparative and absolute approaches. The differences are as follows:

Comparative approach – design is acceptable if it is at least as good as the prescriptive solution.

Assumption: Fire risk is tolerable when the prescriptive requirements are fulfilled.

Requirement: Necessary to have two designs – reference design (prescriptive) and assessed (engineered).

Absolute approach – design is acceptable if all approved performance criteria are met.

Assumption: Fire risk is tolerable when the defined performance criteria are met.

Requirement: Necessary to have a clearly identified tolerable risk level and expressed through performance criteria.

2.3.2 Analysis types

There are three types of analysis, each representing a different approach to risk analysis:

Qualitative analysis is the simplest form of fire risk analysis:

- applicable only in comparative analysis;
- applicable for small deviations from prescriptive requirements;
- always necessary to compare against compliant prescriptive design;
- risk is expressed implicitly ("hidden");
- deviations (noncompliances) are compensated for by additional fire protection measures;
- necessary to assess the impact of all deviations on all FSOs (design features, such as evacuation routes, access facilities, fire resistance…), see Figure 3.

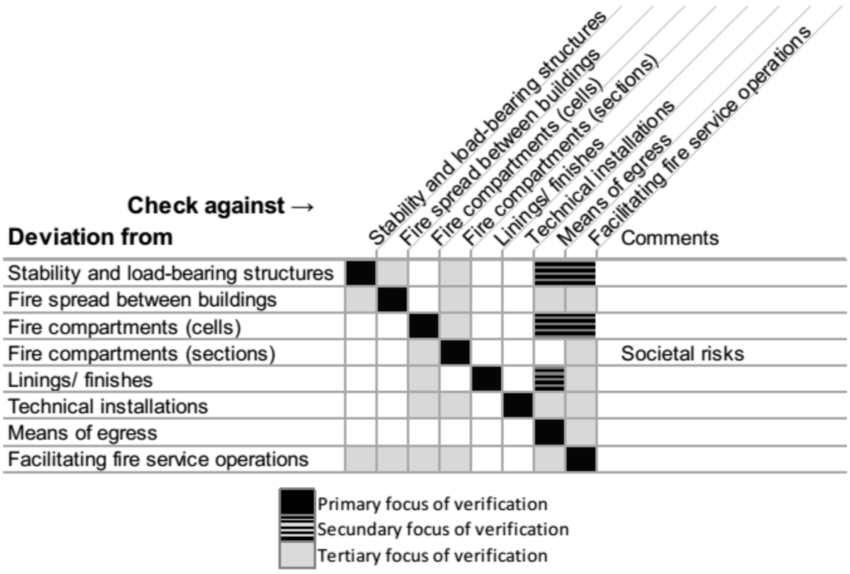


Figure 3 Interaction between deviations from pre-accepted solutions and affected fire safety objectives [2]

Deterministic analysis is a more advanced analysis approach:

- applicable in comparative or absolute analysis;
- risk is expressed implicitly ("hidden");
- characteristic by use of worst credible case scenarios;
- need to identify all relevant scenarios from the perspective of defined fire safety objectives;
- there is no universal worst credible case scenario;
- wide spectrum of analytical tools – from calculations of detector activation times to CFD models.

Probabilistic analysis is the most advanced analysis approach:

- applicable in comparative or absolute analysis;
- risk is expressed explicitly;
- **Semiquantitative probabilistic analysis:**
  - characteristic by broader definition of design scenarios;
  - part of risk can be expressed quantitatively part qualitatively, see Figure 4;
- **Quantitative probabilistic analysis:**
  - characteristic by use of a wide spectrum of design scenarios;
  - probabilistic input distributions, reliability and availability.

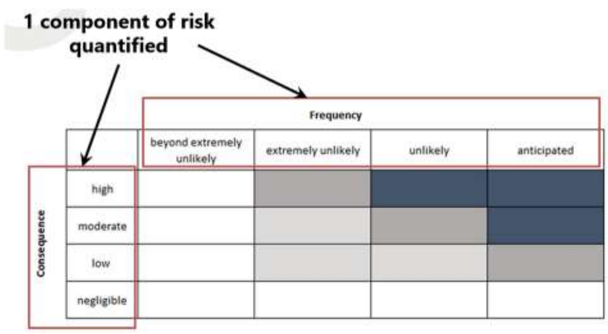


Figure 4 Quantification of fire risk components (based on [3])

3 FIRE SAFETY DESIGN PLAN

The fire safety design plan is the starting point for definition and assessment of design scenarios. The fire safety design plan strongly depends on the building occupancy and its use and should contain information and design elements in at least the following categories:

- fire initiation and effluents production;
- fire and effluents spread;
- constructions and compartmentation;
- detection, activation and suppression;
- occupants characteristics and evacuation;
- fire-fighting action (if relevant).

3.1 Design scenario definition

Design scenarios are of vital importance since they define how the design will be challenged. An analogy may be drawn to the term design load or stress in structural engineering where the structure is expected to withstand the applied load, i.e. exhibit sufficient resistance. Similarly the design should withstand sufficient fire severity in a number of aspects including the following:

- fire and smoke spread limitation within and outside the building;
- structural fire resistance;
- protection of occupants during evacuation or defense in-place;
- limitation of fire-induced damage to equipment, goods etc.

In this regard, design scenarios may be divided into two groups:

- design **fire** scenarios;
- design **behavioural** scenarios.

These two group of scenarios overlap and there is a significant human–fire interaction, including fire-fighting, raising alarm, exposure to toxic products and heat, etc.

3.2 Fire hazard identification

For design scenario specification, the 1st step is fire hazard identification where the following specifics are considered:

- **Internal** – building occupancy type, processes and activities, construction and materials, equipment and furnishings, systems and technologies (fire protection and other)
- **External** – neighbouring buildings, environmental hazards…

Putting it into a context of fire every condition which may worsen the fire severity and its consequences should be called **fire hazard**. This may be seen as follows:

set of conditions	→	manifestation	→	exposure	→	consequence
fire hazard	→	fire event	→	exposed target	→	damage, injury, etc.

Therefore, each identified fire hazard must be incorporated into the design scenario structure along with any prevention and mitigation measures. The process of fire hazard identification is visualised in Figure 6. It is clear that fire hazard is not represented only by fuel and ignition sources being present, but also conditions and events preceding and following the ignition event.

Fire hazard may be categorised as follows, for individual hazard examples, refer to Figure 6:

- **Precipitating hazards** – are conditions which themselves do not cause fires however are precursors for further hazards, mainly fuel and ignition hazards. For example a forklift driver may damage a barrel with flammable liquid which then discharges onto the floor, creating a fuel spill susceptible to ignition- This precipitating hazard materialised (accident occurred) and created fuel hazard (fuel spill), i.e. a set of conditions which may materialise into an ignition event should a sufficient ignition source be present.
- **Ignition hazards –** a set of conditions of sufficient thermal or other energy potential to cause ignition of present fuels.
- **Fuel hazards** – the presence of fuel in form and configuration capable of ignition.
- **Enabling (promoting) hazards** – conditions or circumstances, which are capable of promoting (or not hindering) the development and/or spread of fire and thereby creating greater exposure potential.
- **Vulnerability hazards** – conditions or circumstances which make exposed persons, structures etc. more vulnerable to the exposure from fire.

By combining various fire hazards into a chronological sequence design scenarios are constructed. This again highlights the fact that a single design scenario is rarely sufficient in fire safety engineering. There are usually a number of fire origin locations, different fuel types and configurations within the building.

3.3 Fire scenario definition

Fire scenarios are defined in two steps:

- **Fire scenario selection** – this is a qualitative process. Taking the elements from fire hazard identification a chronological sequence is created which is a fire scenario. The fire hazard elements characterise all aspects which affect fire development and are combined with the effect of active and passive fire safety measures. This process is described in ISO 16733-1:2015. Fire safety engineering – Selection of design fire scenarios and design fires – Part 1: Selection of design fire scenarios.
- **Specification of design fires –** this is a quantitative process. It represents quantification of the identified and selected fire scenarios, most often as a function of heat release rate or temperature in time. The effect of fire promoting, and fire barring elements is expressed through the change of fire heat output or temperature. A general example of design fire is shown in Figure 5. ISO/CD TS 16733-2 Fire safety engineering – Selection of design fire scenarios and design fires – Part 2: Design fires.

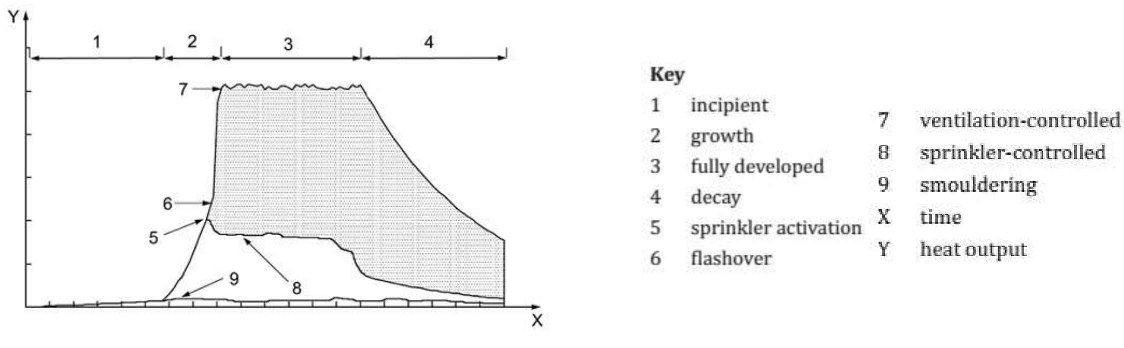


Figure 5 General example of design fire [3]

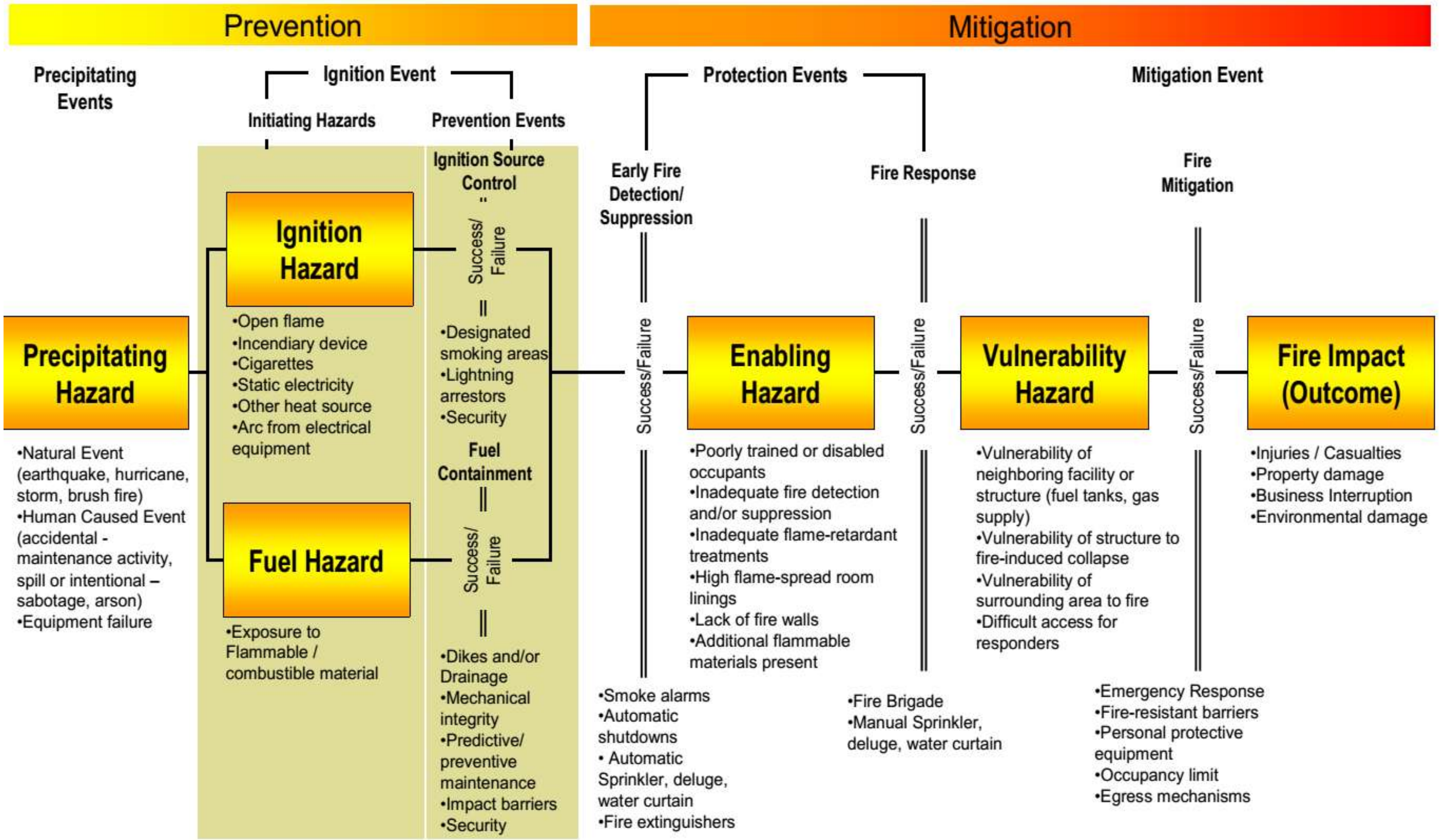


Figure 6 Fire hazard identification process **[4]**

Fire scenarios therefore define the various exposure modes which challenge the fire safety design elements of the building. It must be pointed out that the exposure should be severe enough, however, not unrealistic. Therefore a careful consideration of the factors affecting fire development and heat output (e.g. fuel amount and configuration, ventilation and geometry of the enclosure) is required.

3.4 Behavioural scenarios

Since life safety is usually of primary concern it is necessary to adequately define the occupant composition of the building and their expected behaviour. This is done primarily through an appropriate formulation of behavioural scenarios.

ISO/TR 16738:2009 Fire-safety engineering – Technical information on methods for evaluating behaviour and movement of people recommends to consider the following:

- **persons** – number and distribution, awakes, familiarity, mobility;
- **building and systems** –: detection and alarm system, fire safety management and training, spatial configuration;
- **fire scenarios** – fire and effluent characteristics.

Although the persons are the primary component of the behavioural scenarios, they must consider the interaction / response of persons to building and its systems (walking speeds, reaction to alarm) and fire (heat and toxic effluents).

From the persons perspective a categorisation may be used; an example is shown in Figure 7.

Category	Occupant alertness	Occupant familiarity	Occupant density	Enclosures/ complexity	Examples of occupancy types
A	Awake	Familiar	Low	One or many	Office or workshop areas
B1	Awake	Unfamiliar	High	One or few	Shop, restaurant, circulation space, bar
B2	Awake	Unfamiliar	High	One with focal point	Cinema or theatre auditorium
C	Asleep				Dwelling bedroom
Ci	Individual occupancy	Familiar	Low	Few	Without 24 h on-site management
Cii	Managed occupancy	—	—	—	Bedroom in serviced flats, halls of residence, residence, etc.
Ciii	Asleep	Unfamiliar	Low	Many	Hotel, hostel bedroom
D	Medical care	Unfamiliar	Low	Many	Residential (institutional)
E	Transportation	Unfamiliar	High	Many	Railway station/airport halls

Figure 7 Design behavioural scenarios and occupancy types [5]

3.5 Analytical tools for Fire Safety Engineering

There are a wide variety of analytical tools used in fire safety engineering. These tools include:

- simple "hand" calculation;
- computer models;
- probabilistic studies and calculations;
- experimental methods.

Their selection depends on the nature and the required level of detail of the analysis. The appropriateness, ease of use, necessary simplifications and approximations, compatibility with defined fire safety objectives, availability of input data and other factors must also be taken into account when selectin an appropriate tool.

A detector activation time may be calculated with a simple set of analytical equations, whereas the location of smoke extraction points in an underground garage with jet fan ventilation may require a complex CFD simulation. Therefore there is no universal fire safety engineering tool applicable to all types of problems.

What should be considered very carefully is the appropriateness of input data for the given problem. Compatibility of data and the degree extrapolation are very important aspects to consider. Even simple situation such as taking a heat release rate history for an object burned freely and placing it into an enclosure may result in very inaccurate results. This is because free burning objects are not exposed to thermal feedback present in an enclosure. Similar care should be taken when combining multiple fuel items into a design fire; the sequence of their ignition and total combined heat release rate can usually not be represented by a simple mathematical addition of the partial heat outputs.

3.6 Design and scenario evaluation

Following an engineering analysis, a series of results will be obtained. These should quantify or otherwise describe the expected severity of exposure to persons, structure, etc. On the other hand a series of performance criteria will have been identified to evaluate whether the exposure is within the limits (acceptable) or exceeds them (unacceptable).

There are two possible ways of acceptability evaluation with quantitative (deterministic and probabilistic) analysis:

- point values (thresholds) – where a single threshold value must not be exceeded;
- distributions – where the potential overlap between load and capacity distributions are allowed, providing the probability of such load/capacity combinations (i.e. failure combinations) is sufficiently low.

The example and difference between the two approaches are shown in Figure 8 .

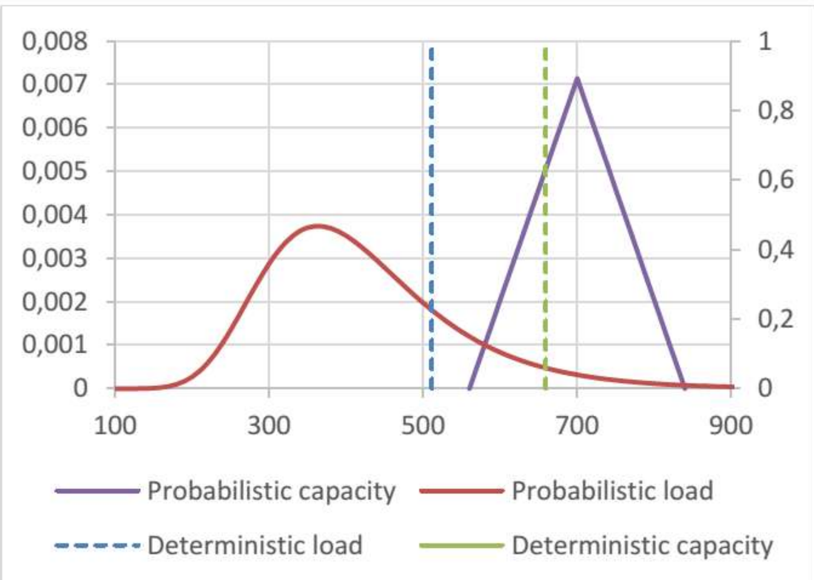


Figure 8 Visualization of deterministic and probabilistic approach to load vs. capacity [2]

It must be pointed out, that it is not possible to design to a zero-failure probability although the deterministic approach may be wrongly interpreted such. It is possible, however, to introduce:

- **safety margin** – additive adjustment applied to calculated values to compensate for uncertainty in methods, calculations, input data and assumptions, or;
- **safety factor** – multiplicative adjustment applied to calculated values to compensate for uncertainty in methods, calculations, input data and assumptions.

The introduction of a safety margin or factor will further decrease the probability of design failure, however, will not completely remove it.

It must also be pointed out that in fire safety engineering the prediction capacity of various analytical and advanced models and calculation methods is not 100% and similarly data may be very difficult to obtain. Hence, a careful use of safety margins or factors is a necessity.

4 DOCUMENTATION FOR FSE

When preparing documentation in all phases of fire safety engineering a detailed approach required. It is not only necessary to capture all the required information but also to provide information in right extent and format, so that the intended affected party may understand and interpret it correctly.

In addition to design description and justification it is necessary to state conditions of use and modifications. This is called protection of assumptions since a number of the input parameters may be very sensitive to direct or indirect modification.

The exact form of documentation (reporting) can vary by jurisdiction and project, and can be regulated or not. Four types of reports that can be issued, which include the required information include [1]:

- **a fire safety design report**, which includes agreed boundaries of analysis, trial fire safety design plan, design scenarios and engineering methods;
- **an FSE assessment report**, which documents the analysis of the design and provides the final design information (may include the fire safety design report);
- **a report for the operational conditions** of use of the built environment as relevant to the design, including critical assumptions, bounding conditions, limitations on use and recommendations for change of conditions;
- **a manual of inspection and maintenance** procedures relative to required fire safety systems for application during the life of the built environment.

It is necessary to keep fire safety documentation “live” and up to date. This is often a problem found in practice, that the original fire safety documentation is not regularly updated it is not possible to evaluate the impact of changes in the facility over the time.

5 IMPLEMENTATION AND FIRE SAFETY MANAGEMENT

After construction and installation it is necessary to check functionality of systems individually and in combination. Therefore proper and thorough testing of all fire safety systems is required before handover. Testing should be conducted on each individual fire safety system as well as in combination with other fire and non-fire systems in the building. This is the only way to ensure the expected functionality of the design as a whole and the appropriateness of the proposed cause&effect logic within the fire strategy.

The use of a fire safety engineered building requires a sound inspection and maintenance programme. Since each of the systems contributes to the overall level of safety, some even critically (e.g. sprinklers), it is necessary to maintain them in a full working order throughout the lifetime of the building.

In addition to normal function the fire safety management routines should define contingency measures should a fire system become inoperative due to an accident or maintenance. With systems of critical importance, e.g. above mentioned sprinklers, it may be necessary to limit or even suspend operations of the facility.

All modifications must be properly consulted with a fire safety engineer and assessed against the original design assumptions made. This is especially true for "small or negligible" changes. Periodicall checks on sum effect of "negligible" changes are vital in order to maintain the original performance of the design. For example, an atrium which is intended to be a fire-sterile, unobstructed escape route, may be increasingly filled with various combustible items. This will not only reduce the effective width of the escape route, but may also contribute to the spread of fire from one side of the atrium to the other through radiative heat from the intermediate fire in the atrium.

REFERENCES

[1] ISO 23932-1:2018. *Fire safety engineering – General principles – Part 1: General*

[2] INSTA/TS 951:2018. *Fire Safety Engineering — Probabilistic Methods for Verifying Fire Safety Design in Buildings*

[3] ISO 16733-1:2015. *Fire safety engineering — Selection of design fire scenarios and design fires — Part 1: Selection of design fire scenarios*

[4] ROSE, S. E., S. FLAMBERG a F. LEVERENZ. *Guidance Document for Incorporating Risk Concepts into NFPA Codes & Standards*. Quincy, MA: Fire Protection Research Foundation. 2007.

[5] ISO/TR 16738:2009. *Fire-safety engineering — Technical information on methods for evaluating behaviour and movement of people*

Quizz for Fire Safety Engineering SMS lecture 17.1.2019, University of Banja Luka

Name:

1. The top level goal of fire safety engineering design is:

a) fire safety objective

b) functional requirement

c) performance criterion

2. Risk expressed qualitatively, semi-quantitatively or quantitatively is:

a) implicit risk expression

b) explicit risk expression

3. In qualitative analysis in fire safety engineering it is:

a) sufficient only to consider the part that deviates from prescriptive requirements

b) possible to justify significant deviations from prescriptive requirements

c) necessary to assess the part thad deviaties from prescriptive requirement agains all potentially impatcted fire safety elements

4. Design fire scenario is:

a) qualitative description of elements affecting fire development

b) quantitative description of fire development

c) both

5. Fire safety engineering is appropriate to be used when:

a) anytime when it is not possible to meet prescriptive requirements

b) the building is complex, has unique features etc. which makes the prescriptive requiriments difficult to apply

c) the investor or architect need to save money